Creative Deployment of Technology in Urban Planning for Sustainable Energy Use and Supply in a South-North Comparison

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Abstract

Energy plays a crucial role regarding Sustainable Development and the achievement of the Millennium Development Goals (MDGs), with renewable energy options located at the nexus between goals 1-6 and goal 7. Increasingly, this tension between human development (including economic growth) and environmental sustainability is being played out in cities: most of the world's population will live in urban settlements by the end of the century, a majority of which will be located in developing countries. Thus, cities and towns become increasingly important, as they are located at the strategic interface of energy planning and project implementation. Before this background, it is the aim of this dissertation to substantiate a threefold Hypothesis.

Firstly, it is hypothesised that **the municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given**. A comparative analysis of two case studies regarding a city in the North (Aachen) and a city in the South (Cape Town) is presented. Results show that renewable energy planning emerged in Aachen driven by environmental concern. On the other hand, Cape Town is preoccupied with energy related challenges tightly linked to socio-economic development issues.

Aachen's planning process is efficient, and the relationship to its private partner is well established and organised. Aachen's energy planning process can be qualified as mature, rigid, and institutionalised, yet still being driven by the vision of a pioneering city.

Cape Town's renewable energy planning process can be qualified as not fully coordinated or dualistic, as on the one hand, it has a well developed strategic approach regarding its public component, but on the other hand, the planning process is flexible and improvised, especially in its collaboration with different private partners.

Secondly, it is hypothesised that **by developing a detailed understanding of energy needs, and coupling these to a set of renewable energy options, a meaningful process of social upliftment and economic development is enabled**. The emerging concept of *energisation* is investigated. Based on insights won, an economic model and a checklist for the drafting of technical energy supply systems are developed, embedding a reframed concept of *sustainable energisation*. Furthermore, a Material Flow Analysis (MFA) of wood fibre based materials is performed for Cape Town. It is found that the city possesses a wealth of renewable energy resources within its boundaries, coupled to important linkages between formal and informal activities.

Thirdly, it is hypothesised that **innovative deployment of Information Technology (IT) supports the identification of energy conversion options, unknown to the energy planner, but necessary for meeting energy demand efficiently**. A model and a software tool for creative option generation were developed, including state-of-the-art search engine technology and the concept of data mining. It is demonstrated that semantically linked keyword chains can be generated based on two distinct starting points, and that this property can potentially be used for the generation of novel renewable energy projects.

Summarily, it can be stated that by carrying out a comparative analysis of two case studies, insights were won regarding the importance allocated to socio-economic development needs in the renewable energy planning process of Southern cities as stipulated in Hypothesis 1. Subsequently, a basket of insights, models and tools were developed by substantiating Hypotheses 2 and 3, helping urban energy planners to understand and link energy needs, renewable resources and technology options, in such a way that it enables a more encompassing approach to and sustainable energy provision of urban dwellers in developing countries.

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Foreword

This dissertation aims to provide a novel approach to one of the most pressing issues of our time, that of renewable energy, in the context of huge development needs of billions of urban dwellers. The approach is a systematic, cross-disciplinary and integrative one, making use of cutting edge information technology. The dissertation has therefore been created using hyperlinks in order to enable the reader to follow the ideas developed within this dissertation in an order different to the overall structure. A hypertext version of the dissertation has been created using the typesetting system LaTeX, and is available as a digital copy on the CD at the back of this dissertation.

Furthermore, a software tool has been developed for the steps undertaken in Chapter 8. A copy of this software tool is available on request. The software tool is not an integral part of this dissertation, and should be considered as a supplement to Chapter 8, allowing the reader to estimate the programming efforts deployed for the realisation of the tool. It should be noted that the software tool is a prototype, has not been optimised regarding user friendliness, requires a number of installation steps, and is reliant on license agreements with 3rd parties. It is available on request for academic purposes only and may not be used for commercial gain.

Contents

List of Figures

List of Tables

List of Acronyms

AF Affordability

AG Aktiengesellschaft

AS Accessibility

AsgiSA Accelerated Shared Growth Initiative of South Africa

ALEP Advanced Local Energy Planning

ANC African National Congress

ANOVA Analysis of Variance

API Application Programming Interface

ASEAG Aachener Straßenbahn und Energieversorgungs-AG

AWA Abfallwirtschaft Kreis und Stadt Aachen GmbH

BEE Black Economic Empowerment

BHKW Blockheizkraftwerk

BImschV Bundesimissionsschutzverordnung

BMU Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

BMZ Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung

BTL Biomass to Liquid

LIST OF ACRONYMS

CCP Cities for Climate Protection

CCT City of Cape Town

CDM Clean Development Mechanism

CDU Christlich Demokratische Union

CEO Chief executive officer

CER Certified Emissions Reduction

CFL Compact Fluorescent Lighting

CHP Combined heat and power

CMA Cape Metropolitan Area

CPS Combinatorial Process Synthesis

CPU Central Processing Unit

DAG Development Action Group

DAO Data Access Object

DB Database

DC Direct Current

DME Department of Minerals and Energy

DSM Demand-Side Management

ED Economic Development

EDI Electricity Distribution Industry

EE Energy Efficiency

EEG Erneuerbare-Energien-Gesetz

EERE Energy Efficiency and Renewable Energy

EIA	Environmental Impact Assessment
EKZ	Environmental Kutznets Curve
EnWG	Energiewirtschaftsgesetz
EP	Environmental Protection
ERC	Energy Research Centre
EROEI	Energy Returned On Energy Invested
ESI	Electricity Supply Industry
ETSAP	Energy Technology Systems Analysis Programme
EU	European Union
FTS	Fischer-Tropsch Synthesis
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HDI	Human Development Index
HDSA	Historically Disadvantaged South African
HFO	Heavy Furnace Oil
ICLEI	International Council for Local Environmental Initiatives
IDP	Integrated Development Plan
IEA	International Energy Agency
IEC	Integrated Energy Centre
IEP	Integrated Energy Plan
IIASA	International Institute of Applied Systems Analysis
IMEP	Integrated Metropolitan Environmental Policy

LIST OF ACRONYMS

IPP	Independant Power Producer
IRES	Integrated Renewable Energy System
IRP	Integrated Resource Planning
ISEP	Integrated Strategic Electricity Plan
ISRDS	Integrated Sustainable Rural Development Strategy
IT	Information Technology
IWMP	Integrated Waste Management Plan
LA21	Local Agenda 21
LCA	Life Cycle Assessment
LCP	Low Cost Planning
LFO	Light Furnace Oil
LPG	Liquid Petroleum Gas
MCDA	Multiple-Criteria Decision Analysis
MCDM	Multiple-Criteria Decision Making
MDG	Millenium Development Goal
MFA	Material Flow Analysis
MGI	Millennium Gelfuel Initiative
MS	Microsoft
MSW	Municipal Solid Waste
MVA	Müllverbrennungsanlage
NER	National Electricity Regulator
NERSA	National Energy Regulator for South Africa

NGO	Non-Governmental Organisation
NIRP	National Integrated Resource Plan
NP	National Party
NREL	National Renewable Energy Laboratory
OBP	Office of the Biomass Programme
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PA	Poverty Alleviation
PC	Personal Computer
PE	Person Equivalent
PHP	People's Housing Process
PLC	Public Limited Company
PPA	Power Purchase Agreement
ppp	Purchasing Power Parity
PPP	Public-Private Partnership
PPPUE	Public-Private Partnership for Urban Environment
PR	Public Relation
PV	Photovoltaics
RAM	Random Access Memory
RDP	Rural Development Program
R&D	Research and Development
RED	Regional Electricity Distributor

RE	Renewable Energy
REEEP	Renewable Energy & Energy Efficiency Partnership
REFSO	Renewable Energy Finance and Subsidy Office
RES	Reference Energy System
RHE	Rural High-Income Electrified Households
RLE	Rural Low-Income Electrified Households
RLN	Rural Low-Income Non-electrified Households
RWE	Rheinisch-Westfälisches Elektrizitätswerk
RWTH	Rheinisch-Westfälische Technische Hochschule
SA	South Africa
SAPIA	South African Petroleum Industry Association
SE	Sustainable Energisation
SEA	Sustainable Energy Africa
SFV	Solarenergie Förderverein Deutschland e.V.
SHS	Solar Home System
SMME	Small Medium and Micro Enterprises
SPD	Soziale Partei Deutschlands
SQL	Sequenced Query Language
SSA	Subsaharan Africa
STAWAG	Stadtwerke Aachen AG
SWH	Solar Water Heater
TASi	Technische Anleitung Siedlungsabfall

UCT University of Cape Town

UHE Urban High-Income Electrified Households

UI User Interface

ULE Urban Low-Income Electrified Households

ULN Urban Low-Income Non-electrified Households

UN United Nations

UNCED United Nations Conference on Environment and Development

UNDP United Nations Development Program

UNFCCC United Nations Framework Convention on Climate Change

URL Uniform Resource Locator

VB Visual Basic

WEA World Energy Assessment

WHO World Health Organization

WSSD World Summit on Sustainable Development

WW World War

WWW World Wide Web

YAP Yet Another Previewer

LIST OF ACRONYMS

Chapter 1

Introduction

1.1 Background

The end of the 20th century witnessed an unprecedented change in the pattern of human settlements. Today, at the start of the new millennium and for the first time in history, more people live in cities and towns than in rural areas. Africa, currently the least urbanised continent, will have almost two-thirds of its population living in urban areas by the year 2025, as it is projected by the UNDP (2004a).[1]

This rapid concentration of hundreds of millions of people has placed an extraordinary strain on the ability of governments - both municipal and national - to meet the needs of city dwellers for basic services. For the urban poor in developing countries, the most threatening environmental problems are those close to home: lack of access to clean water, accumulating garbage, and a lack of access to modern energy services[2]. Deficiencies in the provision of urban services are caused by several factors: the rapidly increasing size of cities, the high concentration of the poor, and the inadequate management and technical skills of municipalities to deal with the accelerating growth in demand for urban services (UNDP, 2004a).

At the same time, the United Nations (UN) committed themselves to the

[1] For more detail, see Section 2.2.3 in Chapter 2.

[2] see Section 2.2.2.4

achievement of eight so-called Millenium Development Goals (MDGs)[1], which range from halving extreme poverty to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 (UN, 2000). Although none of eight goals deals explicitly with energy, access to adequate energy services plays an essential role in the achievement of the first six, whilst renewable energy is fundamental to goal 7: achieving environmental sustainability (UNDP, 2005).

Global efforts are made to meet the goal of environmental sustainability (MDG7) through the restructuring of industrial and urban systems. New policies and legislation regarding the promotion of use of renewable energies are emitted (see e.g. DME (2002b) and BMU (2004)), industrial production standards such as the ISO 14000 series are introduced, concepts of Cleaner Production, Industrial Ecosystems[2] and Waste Minimisation are developed and implemented (see, e.g. Ayres & Ayres, 2002), all of these in order to close material cycles and power these cycles with efficiently used renewable energy[3].

At the interface of these two fields of environment and development, facing the needs of their population and being tied to the achievement of global development goals[4], municipalities realise the key role they are playing. A number of prominent, large cities such as New York, Beijing, Manila and Cape Town have recently committed themselves to ambitious renewable energy targets (see, e.g. SEA, 2003a); some pioneering cities such as Seattle, Aachen and Dubai have already accumulated some experience in the implementation of Renewable Energy (RE) projects (see, e.g. CPI, 2003).

It is the point of departure of this dissertation that, as this RE transition gets in motion in more and more cities, there is insufficient capacity at the core of the urban planning processes[5] to innovatively overcome these emerging and growing challenges discussed above. There is a real danger that aggressively marketed renewable energy solutions can be uncritically purchased by decision-makers in the municipalities; those solutions may not represent the most efficient ones for

[1] see Section 2.2.2.1
[2] see Section 2.3.1.1
[3] see Section 2.2.7
[4] see Section 2.2.2
[5] see Section 2.2.4

the needs to be met, resulting in a misallocation of resources, and undermining the cause of sustainable energy development.

The development of energy supply scenarios is acknowledged to play a key role in energy strategy decision making (and there is a large number of energy planning tools available to support this[1]); the planning of energy use scenarios is unfortunately too often limited to matters of efficiency only, with many planning bodies not realising their key role in economic development beyond a broad infrastructural need. This idea is perhaps best captured in the concept of "energisation", as used in South Africa's Integrated Sustainable Rural Development Strategy (DME (2000); Prasad (2006)), and needs to be explored further.

It should be noted that there is a fundamental difference between the energy planning process in cities and towns in developed (Northern) and developing (Southern) countries. In Northern cities, existing energy infrastructures are modified in order to become more environmentally sustainable, whereas in fast-growing southern cities, new infrastructures need to be put in place. Furthermore, Northern cities can fall back on a strong technical and scientific basis. On the other hand, Southern cities are confronted with huge development needs and political instable systems (see, e.g. Delany & Varga, 2002). Besides this, it has to be mentioned that the relation between energy planning and an energy plan eventually being implemented depends strongly on the political ability of implementation. This phenomenon is known as the administrative or implementation gap (Chapel, 1977).

1.2 Problem Statement

Against the background presented above, it is suggested that the creative generation of possible energy supply and use options plays a critically enabling role within the process of energy planning at the municipal level. It is here that a foundation for a locally most relevant energy plan can be set-up. Uncritical application of models that are unconsciously built on OECD-type energy supply and demand, dating from a time of economically driven decision-making, neglect of

[1]see Sections 2.2.4 and 2.2.5

external costs, and cheap crude oil needs to be avoided. This realisation leads to the formulation of the following problem statement informing this dissertation:

> *As more and more cities the world over are realising the massive implications that their energy infrastructure planning and implementation processes have both on economic and social development of their constituency, and on environmental sustainability, and try to address this by setting renewable energy targets, so will it be recognised that there is insufficient capability to creatively seek out technical solutions to energy use and supply which go beyond choosing from a poor short list of renewable supply options that typically reads: "wind, solar, biomass, hydro" (see, e.g. Geller, 2003).*

1.3 Objectives

Building on this problem statement, it becomes clear that if large numbers of municipalities in developing countries were to set themselves renewable energy targets, there would need to be a significant injection of creative technical capacity into their planning processes. Technology option generation and pre-selection divorced from a detailed understanding of energy needs and available renewable resources leads to a paucity of renewable energy project options that can be fed-back into the decision-making process. It may not be allowed that only then pre-selected technology options are analysed against a broader decision-making framework; rather, project option generation needs to be informed by both the assessment criteria, and by a detailed understanding of needs and renewable resources.

The ultimate goal of this dissertation is to research methods that can enrich the urban energy planning process in developing city contexts. In order to do so, the dissertation aims to develop insights into the key characteristics of energy planning and implementation in such cities, so that eventually, these aspects can formally be integrated as early as possible into the planning process.

1.4 Hypotheses

As emerges from the above discussion, it is hypothesised that the transferability of existing western energy planning methods is very limited because they:

i) Do not implicitly consider typical features of fast-growing cities, nor are they informed by urban development issues,

ii) Have only recently started to systematically include renewables into their ambit, and

iii) Focus heavily on the supply side, covering demand only in terms of efficiency and load management, but not for its socio-economic energisation potential.

However, it is not the objective of the work to set out to prove these points, but rather to contribute to the development of an alternative, richer, more powerful and more appropriate planning process for the cities of the global South. In the context of this objective, it is hypothesised that:

1) The municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given;

2) By focusing strongly on detailed socio-economic development needs and coupling these directly to renewable energy supply options, environmentally sustainable and socially meaningful development can be enabled by the energy planning process;

3) The approach described in 2) will benefit from the use of computer-aided synthesis of options, informed from the emerging fields of Combinatorial Process Synthesis, Data Mining, and the Use of Search Engines.

1.5 Approach and Methodology

To gather and evaluate evidence in support of the Hypotheses set out above, a methodology structured into work phases and working modules was developed so as to generate insights in relation to Hypothesis 1), and to demonstrate the approach suggested by Hypotheses 2) and 3). As can be seen in Figure 1.1, the methodology has been split into three work phases (WPI-III), and seven working modules, each corresponding to a chapter of this dissertation (Chapter 2-8), excluding the introduction (Chapter 1) and the conclusion (Chapter 9). Furthermore, plain arrows in Figure 1.1 represent primary information flows between the different elements - i.e. information based on which a subsequent research task will be carried out -, whereas dashed arrows represent secondary information flows, - i.e. information used for illustrating specific research tasks.

Basically, three different work phases can be identified. The first work phase (WP I) resulted in Chapter 2, which elaborates the background and introduces the theory necessary for understanding and undertaking the further research tasks carried out in this dissertation. The second work phase (WP II) resulted in Chapters 3, 4 and 5, which aim at identifying the differences between renewable energy planning approaches of Southern and Northern cities. The third working phase (WP III) resulted in Chapters 6, 7 and 8, which aim at enriching the Southern energy planning approach based on insights won during the second work phase (WP II).

1.5.1 Work Phase I: Introducing the Scientific Basis

Chapter 2 elaborates the conceptual framework in terms of background information, and introduces theory and methods upon which the following Chapters will be developed. Although it is not the primary aim of Chapter 2 to substantiate any of the three previously defined Hypotheses (Section 1.4), a significant contribution towards Hypothesis 1 will be made by giving the background to urban energy planning in Section 2.2.4, followed by a short discussion.

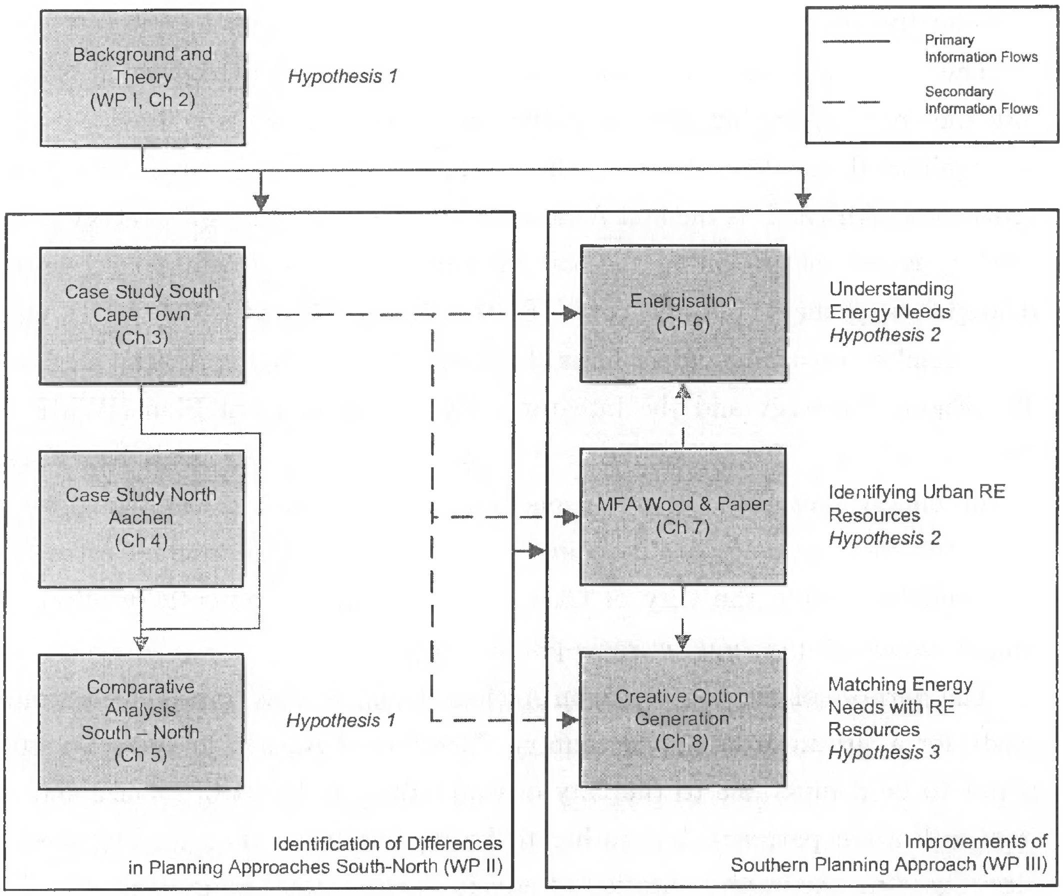


Figure 1.1: Methodological Structure

1.5.2 Work Phase II: The Differences in Northern and Southern Planning Approaches

The aim of the next three Chapters is to understand the differences in the energy planning approaches for cities in the South and the North. The first two Chapters provide case studies[1] for a city of the South and a city of the North, forming the basis for the analysis which will be carried out under Chapter 5.

The aim of the case study on Cape Town (Chapter 3) is to develop insights into the energy planning process at the municipal level in Cape Town. It shall be highlighted that Cape Town is the leading city regarding sustainable energy provision in Africa. It is the first African city to release an Energy Strategy (SEA, 2003a), as well as providing the first attempt to systematically collect energy related data, gathered in Cape Town's State of Energy Report (CCT, 2003). Cape Town displays on a transparent basis all aspects of a developing African megacity. The Energy Strategy and the Integrated Waste Management Plan (IWMP) of the City of Cape Town shall be used as an example for the goals and visions in the energy sector of a growing megacity in a developing country. Certain capacities such as an active City council and an active information infrastructure are available within the City of Cape Town, which can potentially affect the impact of energy planning on socio-political aspects.

The purpose of the case study on Aachen (Chapter 4) is to produce a similar study for a city in a developed country. The role of Aachen in this case study is not to be comparable to the City of Cape Town in terms of its size and energy utilisation patterns, but rather to be representative as a leading western city regarding the implementation of advanced renewable energy concepts. The development of the Aachener Model at the beginning of the 1990s, which lies at the basis of the current German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz (EEG)), forms one cornerstone of Aachen's renewable energy history. Moreover, a currently planned wood gasification plant by the City of Aachen is an unprecedented project in terms of size and technology regarding the provision of urban dwellers with renewable energy.

[1]see Section 2.3.1.2

A comparative analysis of the two case studies (Chapter 5) will lead to the identification and delimitation of typical Southern and Northern features in the energy planning process on the municipal level. Importantly, a mutual Memorandum of Understanding has been ratified by the two city councils, setting out a collaboration in the energy and environmental sectors against the backdrop of the principles of the Local Agenda 21 (LA21).[1] Eventually, this analysis will provide the basis for any further research tasks undertaken under work phase III.

1.5.3 Work Phase III: Enriching the Energy Planning Process for Southern Cities

Based on the results obtained for work phase II, work phase III aims at enriching the renewable energy planning process for cities of the South. Embedded in a Multiple-Criteria Decision Making (MCDM) framework (see Section 2.3.2.1), the urban energy planning process will be revisited at different levels in order to render it more efficient and its outcomes more sustainable.

In Chapter 6, the emerging concept of Energisation is investigated. The goal is to analyse the differences in energy demand for the poor in developing countries, and to understand the frameset necessary for enabling social and economic upliftment. Although the concept has mainly been utilised in rural contexts, its transferability to cities and towns will be tested. Moreover, a checklist shall be developed, enabling energy planners to implement the aspects of energisation into the technical drafting process of the energy supply system. Secondary information regarding the dynamics of the process of energisation will be drawn from the investigation of peri-urban informal settlements in Cape Town under Chapters 3 and 7. Results will help to substantiate Hypothesis 2.

In Chapter 7, an inventory of the material streams wood and paper will be compiled, utilising the case of Cape Town, and applying the emerging method of Material Flow Analysis (MFA) (see Section 2.3.2.3). Data regarding quantities and qualities of these material flows have not yet been captured in detail for the Cape Metropolitan Area (CMA). Wood and paper are of special interest, as they are significant contributours to the problematic of urban waste disposal,

[1] see Sections 2.2.2.1 and 2.2.6

while being potentially suitable for energy recovery. Their investigation promises to yield insights into the availability of urban renewable energy sources, as well as related networks in developing countries, and help to substantiate Hypothesis 2. Information obtained from the investigation of Cape Town's energy planning process in Chapter 3 will be utilised for illustrative purposes.

Based on the method of Combinatorial Process Synthesis (CPS) (see Section 2.3.2.2), a model for the creative generation of options will be presented in Chapter 8. By integrating methods stemming from the sector of Information Technology (IT) - such as Data Mining and the Use of Search Engines (see Section 2.3.2.4) -, a newly created software tool will be described, drawing on the previously developed model. Its purpose is to produce stimuli for Southern energy planners for matching energy demand and renewable energy sources within an urban framework via novel energy conversion routes. Results will help to substantiate Hypothesis 3. A validation of the model and the software tool is included, utilising experiments in two phases, namely the phase of exploratory experimentation and the phase of verification. Experiments were designed using data stemming from the investigation of the case of Cape Town (Chapters 3 and 7).

1.6 Outlook

The dissertation presented here imparts a detailed investigation into a field that will grow in importance on a global level in the next few decades, which is the field of sustainable energy provision.

A unique attempt is presented, aimed at comparing renewable energy planning processes on the municipal level in cities in a developed and a developing country. The links which are being knotted and enforced between the City of Cape Town and the City of Aachen, amongst other things via their LA21-partnership, add a special dimension to this aspect of the dissertation.

The outcome of this dissertation is expected to help enable meaningful market penetration of renewable energy technologies on the municipal level by promoting their position by arguments others than purely economic, especially environmental and developmental. The methods which will be developed in this thesis are the foundation for a set of powerful tools for urban energy planners in developing countries in order to assist them in innovatively seeking out the most suitable and sustainable energy provision means for a defined energy demand.

It is envisaged that the methods developed in this thesis shall be easily transferable to other cities in developing countries, so that the essence of this work will have the most effective impact and contributes in its way to the improvement of the standard of living of the global community.

1. INTRODUCTION

Chapter 2

Background and Theory

2.1 Introduction

In this Chapter, an overview is presented regarding the scientific context, the theoretical basis, and the methods applied for the research undertaken in this thesis. More detailed reviews of specific topics of interest are presented in the appropriate Chapters and Sections of this thesis. In this Chapter, the reader will be pointed to these Sections when appropriate. Although the presentation of the background will follow a logical order, the presentation of the theory and methods will be independent from each other, and will be referred back at a later stage in this dissertation.

2.2 Background

The information presented in this Section represents the context and state of knowledge upon which further development of this dissertation is carried-out.

The topics presented in this Section have been dealt with extensively in the literature. Therefore, an emphasis will be laid on synthesis publications from UN bodies and affiliated institutions, which typically contain hundreds of references regarding academic publications.

Preliminarily, it should be noted that a concise overview regarding energy and related issues is given in the World Energy Assessment (UNDP, 2000b).

An update of the World Energy Assessment (WEA) has been released (UNDP, 2004b), amending findings, figures and developments in the energy field.

In this Section, an emphasis will be laid on African issues, as they are of particular interest for this dissertation.

2.2.1 Global Energy Situation

As can be seen in Figure 2.1[1], annual energy consumption per person ranges from less than 10 GJ to more than 300 GJ. The countries with the highest energy consumption per person lie predominantly in North America, whereas the countries with the lowest energy consumption per person lie predominantly in Subsaharan Africa. Interestingly, Germany has an average per capita energy consumption of 150 to 300 GJ, whereas South Africa has an average per capita energy consumption of 50 to 150 GJ. In 2004, global primary energy consumption amounted to approx. 420 EJ (10 thousand million toe), and is projected to increase to approx. 630 EJ (15 thousand million toe) in 2030. In 2004, the highest share of primary energy was oil with 35%, followed by gas and coal with 25% and 22% respectively. The remaining 18% belong to renewables, nuclear and hydro, where renewables account for approx. 10%. The proportionality is approx. kept for the projections up to 2030.

On the other hand, fossil resources become scarce. The topic as to how long global fossil resources will last has been and still is hotly debated. At this place, a review regarding the different opinions will not be carried out. An example is the theory regarding the prediction of the peak of oil production ("Hubbert's Peak") developed by M. King Hubbert (see Hubbert, 1969). He predicted that the US peak of oil production would be reached between 1966 and 1972 (it effectively did in 1970). It is assumed that the global oil peak will be reached early in the 21st century (see e.g. Heinberg, 2003). The case of renewable resource potentials will be discussed under Section 2.2.7.1.

[1]Energy consumption per capita (2004). (2006). In UNEP/GRID-Arendal Maps and Graphics Library. Retrieved 12:00, January 27, 2007 from http://maps.grida.no/go/graphic/energy_consumption_per_capita_2004

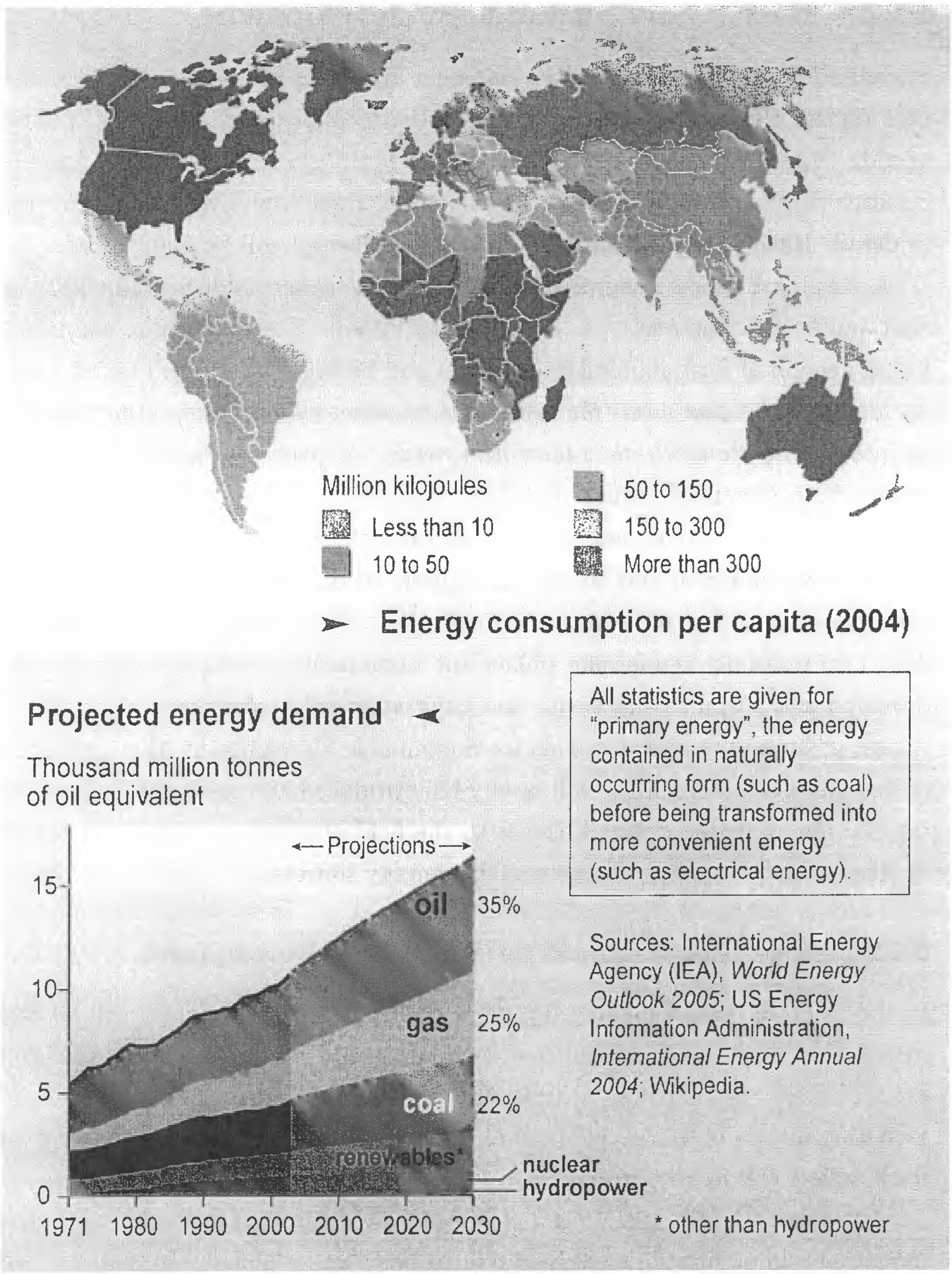


Figure 2.1: World Energy Consumption per Capita

2.2.2 Energy and Sustainable Development

Sustainability and Sustainable Development are topics that grew in public awareness during the last decades, and are at the focal point of the global political agenda. These topics are complex and have established themselves as academic research fields in their own right. At this place, these topics will not be discussed in detail. Rather, their linkages to the topic of energy will be highlighted.

A number of good reviews exist regarding the concepts of Sustainability and Sustainable Development, i.a. by Mebratu (1998). For this thesis, the institutional version of Sustainable Development will be utilised, and will be referred to as *"development that meets the needs of the present without comprising the ability of future generations to meet their own needs"* as given by the UN (1987) in its report "Our Common Future".

Sustainable Development policies address three general policy areas: economic, environmental and social. In support of this, several UN texts, i.a. the "Johannesburg Plan of Implementation" (UN, 2002), refer to the "interdependent and mutually reinforcing pillars" of sustainable development as economic development, social development, and environmental protection.

After giving the global agenda for Sustainable Development, the three pillars of Sustainable Development will briefly be introduced and analysed in the following Sections regarding their linkages to the field of energy, emphasising the role of cities and towns, as well as renewable energy sources.

2.2.2.1 The Global Agenda for Sustainable Development

In this Section, policy making regarding Sustainable Development will be documented by introducing a number of key-events and related outcomes in chronological order. By retracing the history of the development of the concept of Sustainability, a better understanding of its relations to the fields of energy and local action will be acquired.

Agenda 21 (UN, 1992a) is a comprehensive plan of action regarding developmental and environmental objectives to be taken at global, national and local levels by organizations of the UN, Governments, and others. It was adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro (Brazil) in 1992. Energy issues are discussed throughout Agenda 21. It is highlighted that then 'current' levels of energy consumption and production are not sustainable, especially if demand continues to increase, and stresses the importance of using energy resources in a way that is consistent with the aims of protecting human health, the atmosphere, and the natural environment.

The implementation of Agenda 21 was intended to involve action at international, national, regional and local levels. Some national and state governments legislated or advised that local authorities take steps to implement the plan locally, as recommended in Chapter 28 of the document. Such programmes are often known as **Local Agenda 21 (LA21)** initiatives. The following principles are fundamental to LA21 (Urquhart & Atkinson, 2002):

- Integration of social, economic and ecological issues
- A multi-sectoral approach to problem solving, involving all sectors of the community
- Taking a long-term view of society and its problems
- Working within ecological limits to produce sustainable societies
- Local government and civil society partnerships
- Linking local issues to global problems and impacts
- Promoting equity, justice and accountability

The **Millennium Declaration** has been adopted by the UN (2000). It contains the eight **Millenium Development Goals (MDGs)**, which are as follows:

- Eradicate extreme poverty and hunger
- Achieve universal primary education
- Promote gender equality and empower woman
- Reduce child mortality

- Improve maternal health
- Combat HIV/AIDS, malaria, and other diseases
- Ensure environmental sustainability
- Develop a global partnership for development

They form a blueprint agreed to by all the world's countries and all the world's leading development institutions. They have galvanized unprecedented efforts to meet the needs of the world's poorest (see also Section 2.2.2.4). In "The Millennium Development Goals Report 2006" released by the UN (2006a), the progress made in achieving the MDGs is presented. A report by the UNDP (2005) addresses the fundamental role of energy in achieving the MDGs.

The key outcome of the **World Summit on Sustainable Development (WSSD)** in Johannesburg (South Africa) in 2002 is the Plan of Implementation of the World Summit on Sustainable Development (**"Johannesburg Plan of Implementation"**)(UN, 2002). The plan basically reaffirms the commitment of the participating parties to further build on the achievements made since the UNCED, and to take concrete actions for the realization of the remaining goals.

The outcomes of the summit have been analysed and critiqued in numerous academic publications, i.a. by Spalding-Fecher *et al.* (2005), emphasising the links to the energy field in a paper entitled "Energy and the World Summit on Sustainable Development: What Next?". It is stated that although energy issues at the Johannesburg WSSD had a higher priority than before, no institutional home or programme to take the issues forward has emerged. Against the backdrop of 2 billion people living in energy poverty, main challenges regarding energy related development issues remain the access to energy sources, while simultaneously shifting to cleaner and safer energy solutions.

At the International Conference for Renewable Energies held in Bonn (Germany) in 2004 (**"Renewables 2004"**), it was agreed by the ministers and government representatives of 154 countries to build upon the results and agreements reached at the Earth Summit in Rio (1992), the Millennium Declaration and the MDGs (2000), and the WSSD (2002). Furthermore, they reaffirmed to substantially increase the global share of renewable energies of the total energy mix. The

Policy Recommendations for Renewable Energies (UN, 2004) is one of the key outcomes of the conference. The document provides decision makers with a menu of policy options based on available experience and knowledge. With regards to the role of local authorities, it is stated that, although national governments will determine national legal frameworks, the implementation of renewable energies takes place at the local level. Available options and possibilities for local governments are in line with the LA21, and are amongst others:

- Establish local building codes
- Strengthen stakeholder involvement in licensing, and prioritise siting
- Increase awareness and capacities
- Utilise the power of public procurement
- Establish public-private investment funds
- Address energy issues in other areas of local action

2.2.2.2 Energy and Economy

Energy is a required input and thus an engine for economic growth. As can be seen in Figure 2.2, Gross Domestic Product (GDP) and energy use are tightly interlinked, and have continuously increased since the 1970s for countries of the Organisation for Economic Co-operation and Development (OECD). But whereas primary energy use and GDP grew at the same rate until 1978, a decoupling of both growth rates occurred afterwards, not any longer supporting their often postulated one-to-one relationship (UNDP, 2000b).

The linkage between energy consumption and Gross Domestic Product (GDP) has been the focus of extensive research for the past three decades, and will not be presented against the backdrop of this thesis. However, good reviews on related theory are included to the publications by Cleveland *et al.* (2000), Geller *et al.* (2006) and Lee & Chang (2007).

In an international comparison of selected countries as proposed in Table 2.1, a simple relationship can be observed between GDP per capita and energy use

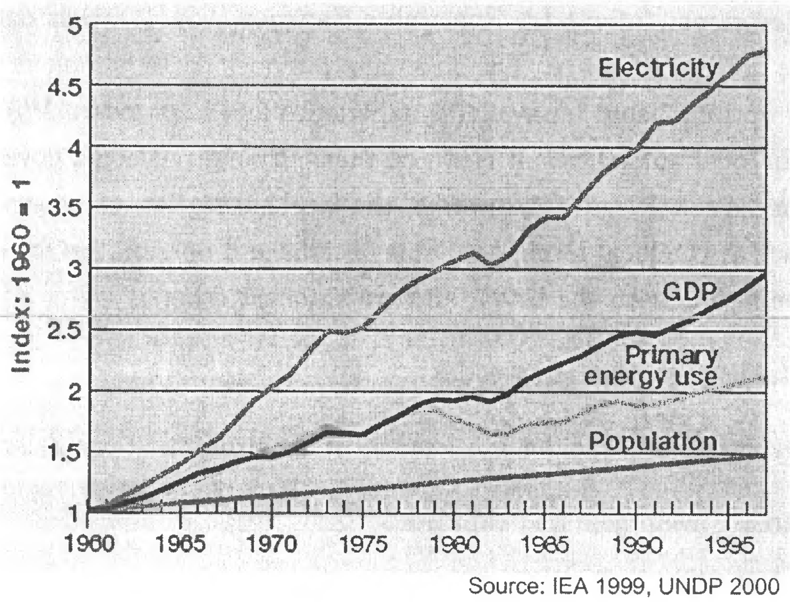


Figure 2.2: Development of GDP and Energy Use in OECD Countries

per capita. The industrialised countries Rep. of Korea, UK, USA and Germany have the highest per capita GDP of >$21,870/a, as well as the highest per capita consumption of energy, ranging from 164GJ/a for the UK, to 329GJ/a for the US. On the other hand, the lowest per capita GDP and energy usage are observed for the developing countries Ghana, India and Egypt, ranging from $2,402/a to $4,455/a, and 17GJ/a and 31GJ/a. These numbers illustrate the strong link between economic performance and energy consumption based on the level of development of a country.

2.2.2.3 Energy and Climate Change

The IPCC (2007) states in its 4th Assessment Report on Climate Change that *"major advances in climate modelling and the collection and analysis of data now give scientists 'very high confidence' in their understanding of how human activities are causing the world to warm"*. Greenhouse Gas (GHG) emissions stemming from the anthropogenic consumption of fossil energy carriers are recognized as being a main cause for global climate change.

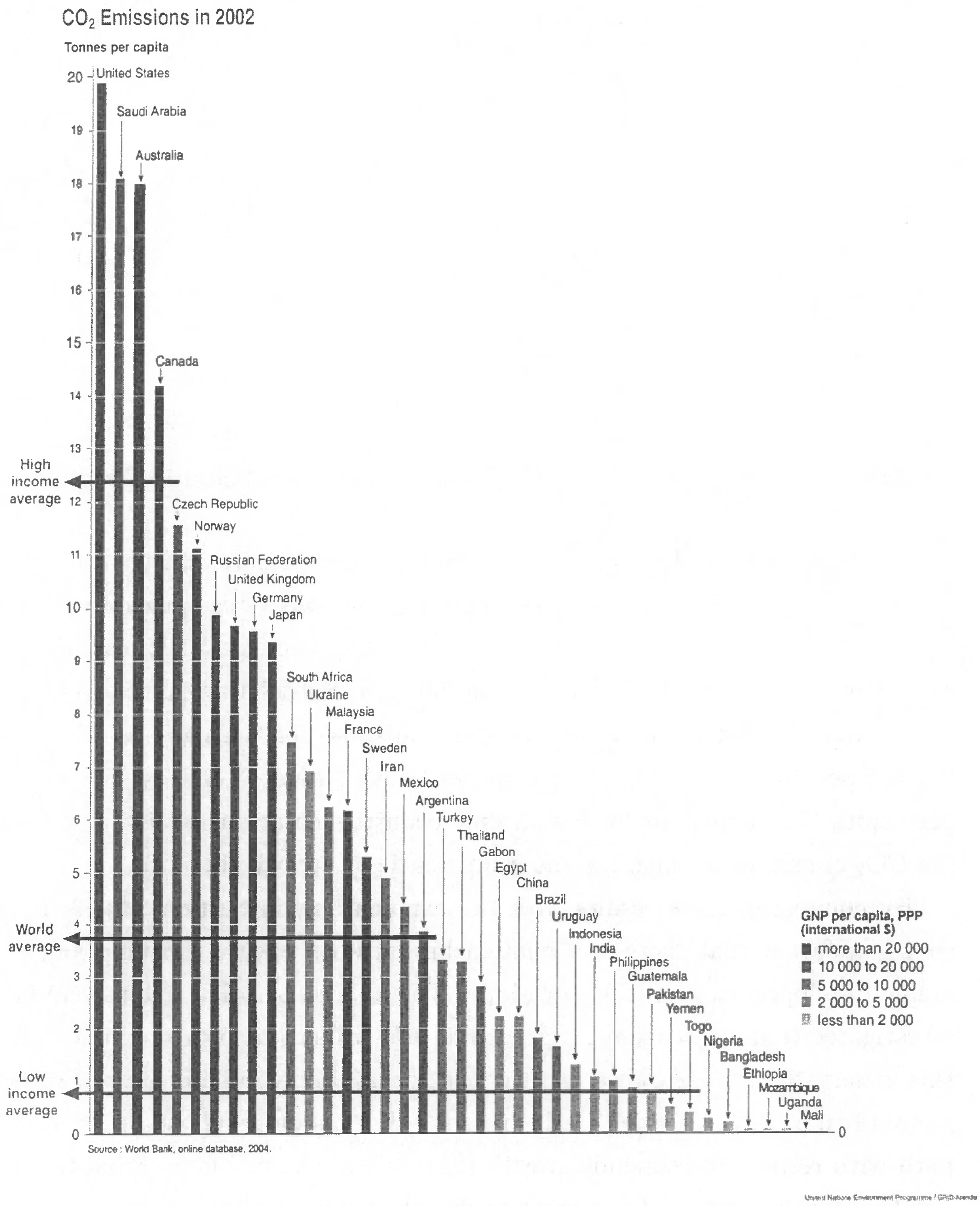


Figure 2.3: Annual CO_2 Emissions per Capita and Country

Country	GDP (2005) [ppp current int. $/c*a]	Energy Use (2003) [GJ/c*a]
India	3,490	22
Ghana	2,400	17
China	6,570	46
Egypt	4,460	31
Brazil	8,730	45
Korea, Rep. Of	21,870	180
United Kingdom	32,010	164
United States	41,850	329
Germany	29,310	177

Source: World Bank

Table 2.1: Annual per Capita GDP and Energy Use - Selected Countries

As can be seen in Figure 2.3[1], CO_2 emissions per capita and country range from <1 t/a to approx. 20 t/a. The highest emissions rates per capita emerge from North America, Saudi Arabia and Australia, whereas the lowest emission rates stem from developing countries situated in Subsaharan Africa, Asia and South America. Interestingly, annual CO_2 emissions for Germany are about 9.5 t/a per person, and 7.5 t/a per person for South Africa. Moreover, the average per capita CO_2 emissions for low income countries lie at almost 1 t/a, whereas the CO_2 emissions for high income countries lie at approx. 12.5 t/a.

By combining these results with the explanations in Section 2.2.2.2, it becomes apparent that there is a relationship between energy consumption, economic development, and CO_2 emissions. This relationship has extensively been investigated from an academic perspective, and will not be presented in detail in this dissertation. It is however worthwhile noting the hypothesis of the Environmental Kutznets Curve (EKZ), which asserts that pollution follows an inverted-U path with respect to economic growth (Suri & Chapman, 1998). From the perspective of the energy sector, economic growth would entail increased energy con-

[1]National carbon dioxide (CO2) emissions per capita. (2005). In UNEP/GRID-Arendal Maps and Graphics Library. Retrieved 12:09, March 1, 2007 from `http://maps.grida.no/go/graphic/national_carbon_dioxide_co2_emissions_per_capita`.

sumption and related CO_2 emissions up to a certain point, beyond which energy consumption and/or related CO_2 emissions would decrease (Richmond & Kaufmann, 2006). A main reason for this decrease is the shift of the economy from industry to services, with a consequent decrease in pollution intensity (UNIDO, 2004).

Against the above backgrounds, it becomes apparent that policy making for sustainable development especially in developing countries is a difficult trade-off process between economic and environmental aspects. An increase of economic output can be achieved via the increased consumption of fossil fuels, which would in turn result in increased CO_2 emissions.

From the perspective of the energy sector, the solution to this catch-22 situation lies in the consideration of energy efficiency measures and renewable energy sources. Robert *et al.* (2002) define these two approaches in a broader sense against the backdrop of a systems model of essential elements for sustainable development as the mechanisms of dematerialization, i.e. the reduction of material flows, and substitution, i.e. the exchange of type/quality of flows and/or activities. Interestingly, Geller (2003) analyses the challenges regarding the implementation of sustainable energy measures. In his book "Energy Revolution - Policies for a Sustainable Future", he introduces a list of barriers to the adoption of energy efficiency and renewable energy technologies, and subsequently proposes a set of policy measures for overcoming these barriers.

With regards to the linkages between energy and climate change, a series of policy documents have been released, and mechanisms have been created, with the aim to reduce energy related GHG emissions and their malign effect on the global climate. These documents and mechanisms are tightly interlinked with the global agenda for Sustainable Development (see Section 2.2.2.1), and will be briefly discussed in the following passage.

Next to the Agenda 21 (see Section 2.2.2.1), a further outcome of the UNCED is the **United Nations Framework Convention on Climate Change (UNFCCC)** (UN, 1992b), and has as objective the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Its objectives have a close relationship to the goals of sustainable development, and have linkages to the framework of Agenda 21, i.a. regarding energy.

The **Kyoto Protocol** is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC) (UN, 1998). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases. The Kyoto Protocol finally entered into force on the 16th February 2005.

Under Article 12 of the Kyoto Protocol, the **Clean Development Mechanism (CDM)** is defined. The UN (1998) states that *"the purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the [UNFCCC] Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3"*.

It shall be noted that both Germany and South Africa have ratified the Kyoto Protocol. But whereas Germany is an Annexure I country, i.e. has to comply with a quantified emission limitation, South Africa is a non-Annexure I country, i.e. does not have to comply with a quantified emission limitation.

Building upon the principles embedded in Agenda 21, the International Council for Local Environmental Initiatives (ICLEI) launched the **Cities for Climate Protection (CCP)** campaign in 1993 (ICLEI, 2007). The CCP approach is described in Section 2.2.4.2.

For further background information, consult Chapter 3 of the WEA (UNDP, 2000b).

2.2.2.4 Energy and the Poor

For the measurement of performance and development of a country, institutions moved away from considering purely economic indices such as GDP, to combined indices such as Human Development Index (HDI), which embrace aspects of sustainability more holistically. The HDI is a quality-of-life index, accounting for life expectancy, literacy, education and standard of living (see e.g. Wikipedia, 2007b).

In Figure 2.4, the HDI for the world's countries have been noted against per capita energy consumption. The graph shows that developed countries such as the US and Finland have a comparatively high HDI and per capita energy consumption, whereas developing countries such as Nigeria and Mozambique have a relatively low HDI and per capita energy consumption. It appears that the higher the per capita energy consumption, the higher the HDI. This relationship is true up to an HDI of approx. 0.9. Then, energy consumption continues to increase while HDI remains relatively unchanged.[1] For countries having an HDI up to 0.9 (mainly developing countries), there a larger HDI-related returns on energy changes than for countries having an HDI higher than 0.9 (mainly developed countries). It is therefore stated in order to substantiate Hypothesis 1 that there should by greater attention to socio-economic development needs in cities in developing countries than in cities of the global North.[2]

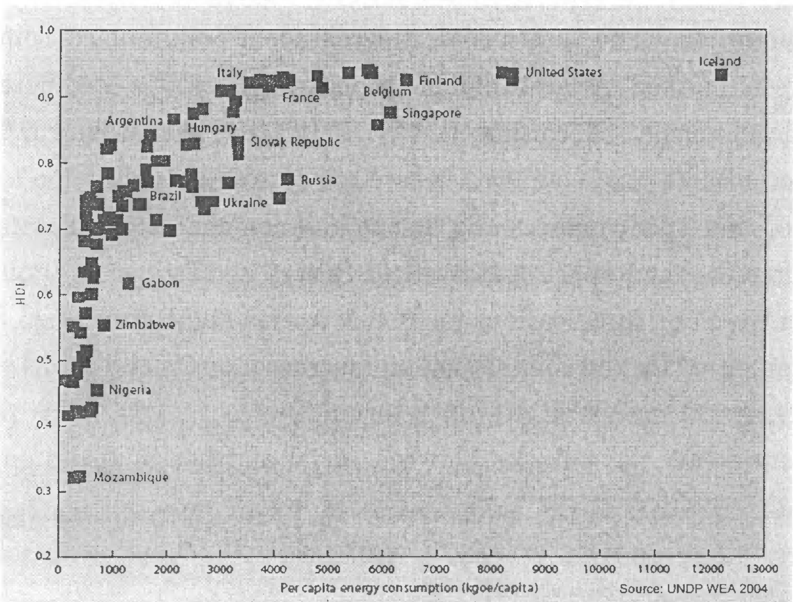


Figure 2.4: Energy Consumption and HDI by Country

[1]Data points roughly fit a reverse exponential curve.

[2]See Jacobson *et al.* (2005) for one analytical approach.

As has been recognised at the WSSD in Johannesburg (see Section 2.2.2.1), 2 billion people worldwide lack access to modern energy carriers, relying on traditional biomass energy carriers such as fuel wood and dung. In Figure 2.5[1], the share of traditional biomass consumption[2] has been represented against the total energy consumption of African countries, including population size. The majority of African countries meet more than 50% of their energy requirements from biomass. North African countries as well as South Africa and Namibia meet less than 25% of their energy needs from biomass. Countries with high population sizes such as Nigeria and Ethiopa cover even more than 75% of their energy needs from biomass. South Africa and Nigeria are the biggest energy consumers in Africa, whereas they differ significantly in population size. These numbers illustrate the importance of traditional biomass resources for African countries.

Exposure to indoor air pollution is a well-documented health risk associated with the use of traditional biomass fuels. As can be seen in Figure 2.6, the global exposure equivalent[3] has been represented for urban and rural areas in countries grouped by HDI. The rural population in developing countries are most affected by this pollution. The rural-urban differential in pollutant concentrations and exposures is marked, as are differences between countries at different stages of human development. According to UNDP (2004a), the urban-rural differential is reversed in high-HDI countries, where exposures are higher due to the greater amount of time spent indoors and due to building characteristics and materials.

"Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of the Poor: Implications for Policy Action and Intervention Measures" is a paper prepared for the commission on macroeconomics and health of the World Health Organization (WHO) (von Schirnding *et al.*, 2002). This paper gives a good overview on the linkages between social and health issues emerging from

[1] Woodfuel and energy consumption. (2006). In UNEP/GRID-Arendal Maps and Graphics Library. Retrieved 12:54, February 8, 2007 from `http://maps.grida.no/go/graphic/woodfuel_and_energy_consumption`.

[2] Although it has not been confirmed explicitly by the sources, the numbers represent the consumption of exclusively traditional biomass fuels.

[3] The global exposure equivalent is defined as the equivalent (particulate) concentration that the entire world's population would have to breathe continuously to equal the population exposure in each micro-environment.

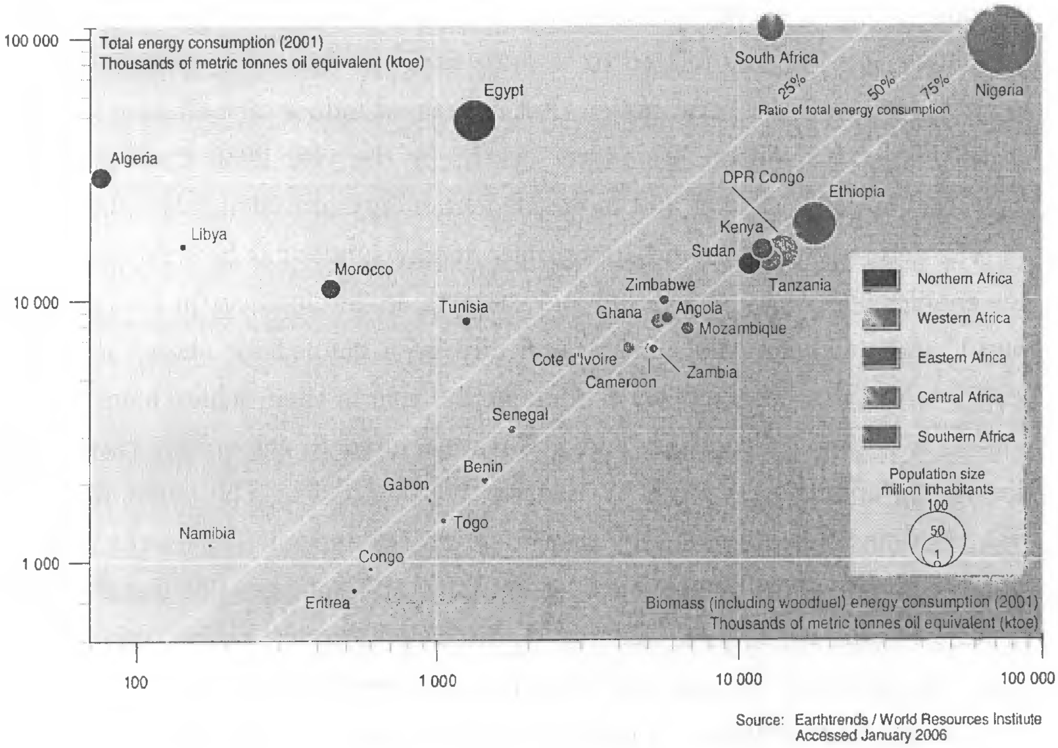


Figure 2.5: Biomass Consumption by Country - Africa

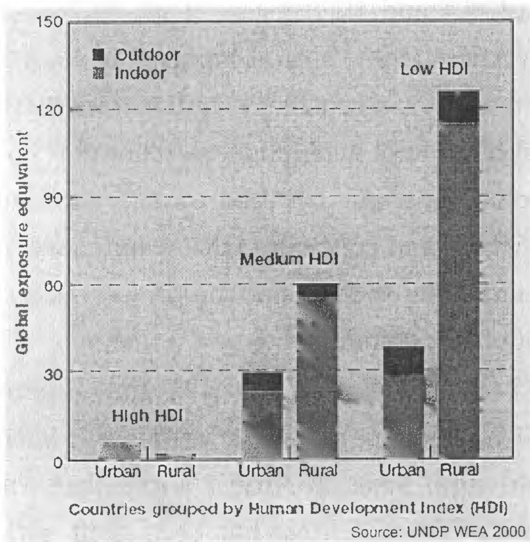


Figure 2.6: Local Air Pollution Impact by HDI

the satisfaction of energy service demand of poor households. The mortality and greenhouse gas impacts related to biomass usage in Africa has been analysed by Bailis *et al.* (2005). It is estimated that household indoor air pollution will cause an estimated 9.8 million premature deaths by the year 2030 if no substantial transition towards cleaner and more efficient energy provision takes place.

The access to modern and appropriate energy supply has been recognised as a key enabler of poverty alleviation and sustainable development in the developing world. Although no MDG has specifically been defined for energy issues, the access to modern energy plays a fundamental role in their achievement (UNDP, 2005). A review on concepts and literature related to the energy transition of developing countries is given by Elias & Victor (2005). The paper deals with two different concepts of energy transition, macro and micro patterns regarding energy and economic development, geographic and demographic factors, as well as implications for human welfare. A detailed literature review regarding the topic 'Energisation' is being carried out in Chapter 6, Section 6.2.1.

The sustainable usage of renewable energy sources is one approach for addressing the issue of energy transition in developing countries. The potentials of renewables in Africa in terms of meeting energy needs of the poor are discussed by e.g. Karekezi (2002) and Habtetsion *et al.* (2004). Modern energy provision to Subsaharan Africa (SSA)'s rural population via a Photovoltaics (PV)-led renewable energy strategy is a considered option. Interestingly, Utria (2004) discusses the potential of ethanol and gelfuel as renewable cooking fuels for poverty alleviation in Africa. His paper is based on the experience of the Millennium Gelfuel Initiative (MGI), and concludes with a summary of a possible implementation framework, including the roles of the private sector, governments and the international development community.

Although it will be shown in Section 2.2.3 that urbanisation will achieve its highest rate in Africa, research regarding sustainable energy supply to the poor mainly focused onto rural areas in Africa, a gap that will be addressed in this dissertation. The issue of urban areas has been dealt with more in depth in e.g. South America or Asia. In the following, the issue of urban energy usage in developing countries will be introduced.

In a study by the World Bank (2004), the relationship between urban growth in developing countries and the decisions of urban households to select and consume different kinds and amounts of residential energy has been investigated. It has been found that in the earliest stages of a city's development, urban dwellers largely consume biomass-based traditional fuels. As cities develop and modernize, the pattern of residential fuel consumption shifts, often to a succession of transition fuels, such as kerosene or coal, and ultimately to the so called modern fuels - Liquid Petroleum Gas (LPG) and electricity.

The choice and consumption of energy carriers varies significantly according to the income class in cities in developing countries. As illustrated by Figure 2.7, the electricity and LPG consumption rise dramatically in the higher-income groups. The relative consumption shares for wood, charcoal, and even kerosene do not change dramatically with income for the 80% of the population with low to moderate incomes. The persistence of traditional fuel consumption beyond the lower income levels is surprisingly common for the cities in the considered developing countries (World Bank, 2004).

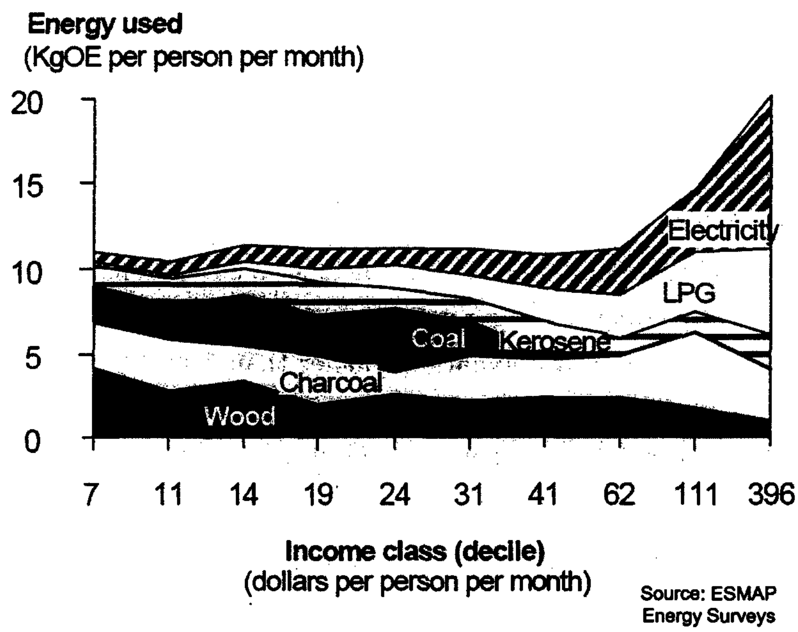


Figure 2.7: Income Class and Fuel Consumption in 45 Cities - Developing Countries

For further background information regarding the topic of energy and the poor, consult Chapters 2 and 10 of the WEA (UNDP, 2000b).

2.2.3 Urbanisation

According to the World Bank (2001), the world population reached 6.1 billion in 2000, and is growing at an annual rate of 1.2 per cent, or 77 million people per year. By 2030, it is expected that 85% of the world's population will live in developing countries. More than half of the world's population will be living in urban areas by 2008, with 1/3 of city dwellers in developing countries living in informal settlements.

As can be seen in Figure 2.8[1], the highest urbanisation rates are observed for Subsaharan Africa (SSA) and Asia and the Pacific. In case of the latter, urbanisation is a parallel phenomenon to a substantial population growth, projected to reach approx. 4 billion by 2020. Africa is predominantly rural, with only 37.3% living in urban areas in 1999. However, with a growth rate of 4.87%, Africa is the continent with the fastest rate of urbanization (World Bank, 2001). Although there is still an urbanisation trend noticeable for high-income countries, the population growth rate decreases over the considered time period.

As can be seen in Figure 2.9, the developing world's urban population is still concentrated in small cities, but the large cities' share is increasing. The proportion of cities in the developing world with a total population of more than five million[2] will rise from 4% to 15% from 1950 to 2015. Whereas the proportion of cities with a size range of 1 to 5 million people will remain relatively stable, the proportion of cities with a population smaller than 1 million will decrease from 78% to 59% over the same period of time.

Against the backdrop of a severe trend of urbanisation and the development of megacities in the developing world, there is an increasing pressure on city gov-

[1] Trends and projections in rural and urban population in developing regions and high-income countries. (2001). In UNEP/GRID-Arendal Maps and Graphics Library. Retrieved 13:13, February 8, 2007 from http://maps.grida.no/go/graphic/trends_and_projections_in_rural_and_urban_population_in_developing_regions_and_high_income_countries.

[2] Commonly referred to as megacities.

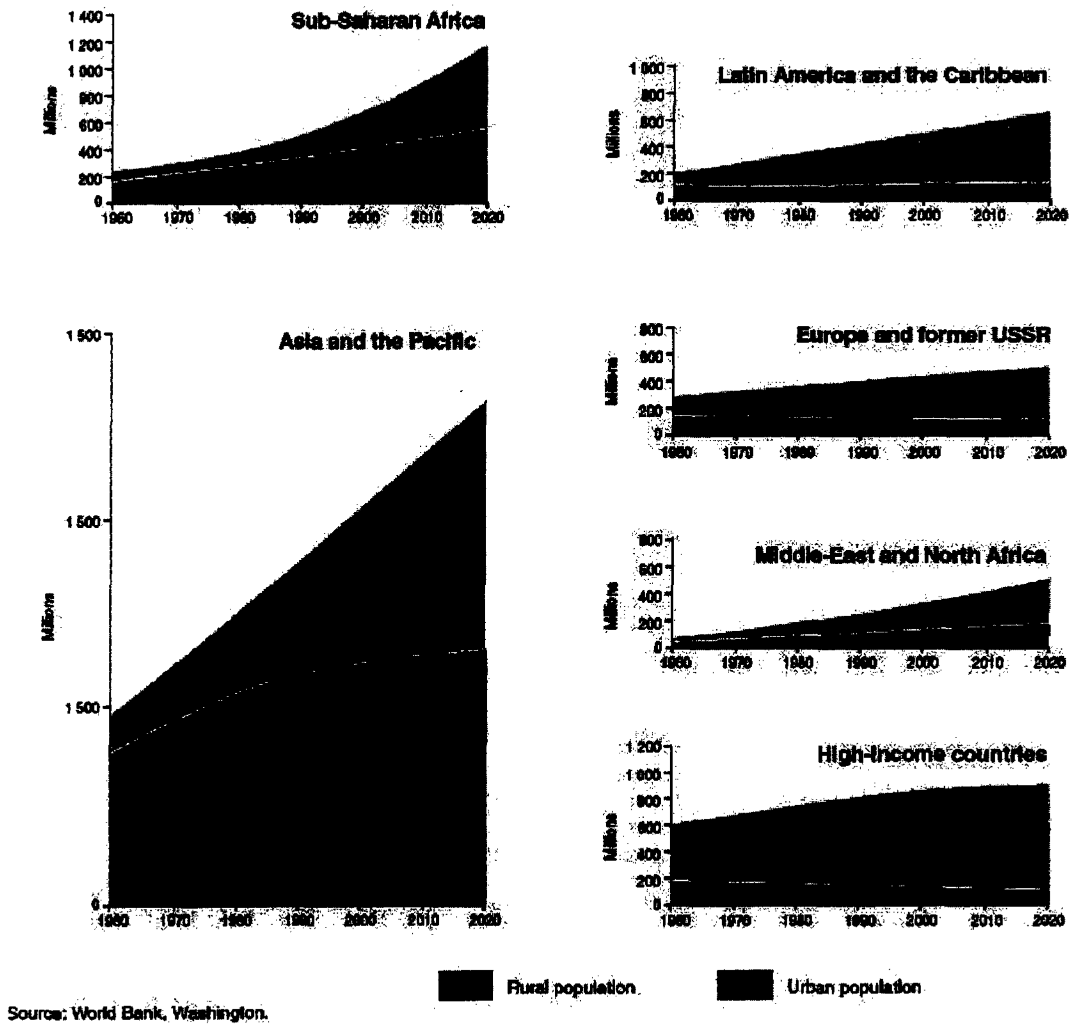


Figure 2.8: Rural and Urban Population by World Region, 1960-2025

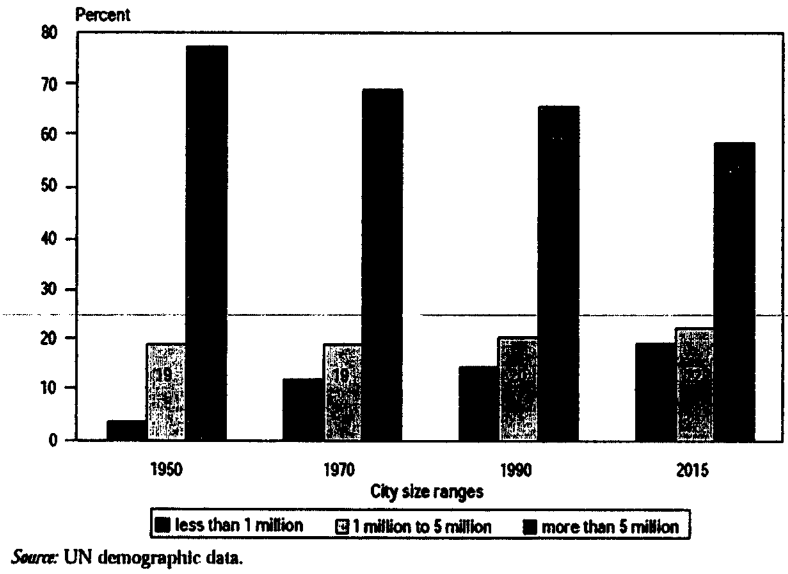


Figure 2.9: Urban Population in Developing World by City Size

ernments to provide adequate basic services and infrastructure to urban dwellers. The Johannesburg Plan of Implementation (UN, 2002) stresses the importance of "initiatives to strengthen national and local institutional capacities in the areas of sustainable urbanization and human settlements, provide support for adequate shelter and basic services and the development of efficient and effective governance systems in cities and other human settlements".

In a document by UNDP (2000a) called "Joint Venture Public-Private Partnerships for Urban Environmental Services", the challenges of urbanisation of the developing world are described with a special emphasis on responsibilities of local governments. Public-Private Partnerships (PPPs) are introduced as part of the solution to the upcoming challenges, and the progress of the United Nations Development Program (UNDP) Public-Private Partnership for Urban Environment (PPPUE) are described.

2.2.4 Urban Energy Planning

2.2.4.1 A Brief History of Energy Planning

According to Gellings & Chamberlin (1993), traditional energy planning was basically constrained to electric utility planning, and largely consisted of matching expected customer load growth with adequate supply-side generating capacity or energy purchases. Strategic planning happened mainly at national level. Local authorities were mainly responsible for electricity distribution.

The oil price crises in the 1970s, and the shift of concerns regarding environmental impact and decreasing fossil resources (see Sections 2.2.1 and 2.2.2.3), gave rise to alternatives to supply-side options, such as Low Cost Planning (LCP) and Demand-Side Management (DSM). Both address options for reducing the need of additional generation sources.

DSM refers to interventions on the customer side of the energy supply chain, and includes activities such as load management (the shifting of load from high cost to lower cost periods - applies mainly to electricity) and strategic conservation (energy efficiency measures) (see e.g. Gellings & Chamberlin, 1993).

The term Low Cost Planning is often used synonymous to the term Integrated Resource Planning (IRP), which refers to the balancing of supply- and demand-side options in order to meet energy demand at the least cost (Gellings & Chamberlin, 1993). Furthermore, Geller (2003) describes the objective of the IRP approach to provide services such as heat, light, refrigeration and motive power - not energy *per se* - as cost-effectively as possible.

At the same time, the importance of renewable energy sources arose, because of their low environmental impact in comparison with other (fossil) sources of energy, their non-finite character, and most importantly because of their flexibility, supporting power system decentralisation and locally applicable solutions more or less independent of the national network (see e.g. OECD, 1995).

Based on the stated backgrounds, the concept of Integrated Energy Planning emerged, implying that energy planning should be integrated with the overall economic planning and policy analysis. An integrated approach to energy planning seeked no longer at a separate planning for energy subsectors, but aimed at understanding the links between energy supply and demand sectors, and between energy and macro-economic factors and socio-economic objectives (Eberhard & Van Hooren, 1995). The principles of Integrated Energy Planning find application on national, regional and local level.

2.2.4.2 Local Energy Planning Concepts

The energy planning process at local level must be coordinated with other planning activities, i.a. regional development and environmental management. Nijkamp & Perrels (1994) gives a list of objectives for the different sectors, and states that these objectives are by no means independent from each other:

1. Objectives in Energy Planning:
   - Low-cost supply
   - Efficiency of use
   - Use of renewables
   - Use of indigenous sources
   - Reduction of imported energy
   - Technology improvement
2. Objectives in Regional Planning
   - Labour market
   - Technological innovation
   - Socio-economic welfare
   - Regional development
   - Amenities
   - Land-use and physical planning
3. Objectives in Environmental Management
   - Effective resource management
   - Reduction of pollution

- Restructuring of industrial processes
- Ecological variability

It is furthermore stated by the OECD (1995) in the "Urban Energy Handbook" that the evaluation of the potential of renewable energy resources in terms of available energy and costs must happen both in the city and the surrounding area, and is an essential part of the urban energy planning process. This process is commonly referred to as "Mining a City".

The list of renewable energy sources considered usually comprise a set of standardised elements. As an example, OECD (1995) presents the following:

- Solar energy (passive solar, solar thermal, photovoltaics)
- Biomass energy (waste incineration, transport biofuels)
- Wind energy

In the following, three approaches for sustainable cities and one technical energy planning concept will be introduced, proposed by internationally recognised organisations, i.e. UNDP, ICLEI, US Department of Energy, and International Energy Agency (IEA). Whereas the three approaches for sustainable cities provide frameworks within which the development of energy strategies can take place, the technical energy planning concept provides a detailed guideline for the implementation of such strategies.

Green City Program A broad initiative is the Green City program led by the UNDP, which looks not only at energy, but the broader issues of sustainability. A Model Green City is defined as *"a city where environmentally lasting solutions have been found for human activity, economic development and environmental management. The aim is to achieve development that is both pro-people and pro-nature, to protect the interests of future generations"* (UNEP, 2002).

5-Milestone Plan Cities participating in the Cities for Climate Protection (CCP) campaign undertake a 5 milestone process. The milestones allow local governments to understand how municipal decisions influence energy use, and how these decisions can be used to mitigate global climate change while enhancing community quality of life. The five milestones are as follows (ICLEI, 2007):

1. Complete an inventory of local GHG emissions,
2. Set a goal for reducing emissions,
3. Develop a plan to achieve the goal,
4. Implement reduction measures,
5. Monitor progress.

Local Action Plan The Sustainable Cities Project, a US Department of Energy initiative, has produced a workbook, "Sustainable Energy: A Local Government Planning Guide for a Sustainable Future", which summarizes the experiences of several cities such as Portland[1] in developing energy plans (DOE, 1992).

The following is an extract from the workbook, and provides suggestions for preparing an action plan:

1. Determine how much you spend on energy.
2. Designate or create a lead office.
3. Link energy programs with community goals.
4. Build grassroots community support.
5. Don't reinvent the wheel.
6. Prioritize actions and develop a draft plan.
7. Implement the plan.

[1]Extensive information on energy related urban programmes are available at the Office of Sustainable Development of the City of Portland, `http://www.portlandonline.com/osd/`

8. Evaluate success and update the plan.

9. Publicise the benefits.

Advanced Local Energy Planning A comprehensive technical approach to local energy planning is Advanced Local Energy Planning (ALEP). It is a concept that has been introduced by the IEA in 2000 with the Energy Conservation in Buildings and Community Systems Programme "Annex 33 - Advanced Local Energy Planning" (Jank, 2000), and has been defined as follows: *"The purpose of ALEP is to find a path towards an economic and ecological sustainable local energy system while also taking into account limited financial and human resources as well as incomplete insight into the future development of economic, technical and social conditions"*. The novelty in the ALEP approach is that long-term strategic planning is being combined with the detailed planning of concrete subsystems; previously, only suboptimal solutions where obtained due to the separate optimisation of the different subsystems.

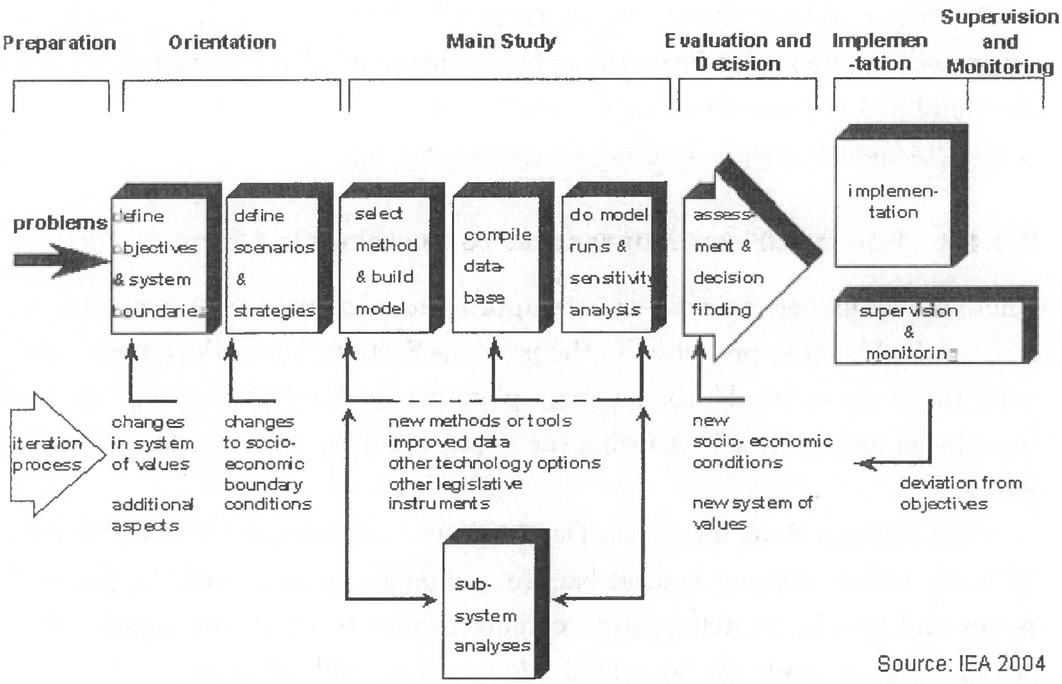


Figure 2.10: The ALEP Process

As can be seen in Figure 2.10, the planning process is an iterative process, which can be divided into 6 phases, namely the phases of preparation, orientation, main study, evaluation & decision, implementation, and supervision & monitoring. The main emphasis in this dissertation will be laid upon the main study phase. According to IEA (2004), the main study deals with the comprehensive analysis of the energy system aimed at medium to long-term strategic planning. The different steps of the main study phase are the following:

1. Definition of the structure of the comprehensive model (e.g. the Reference Energy System (RES))
2. Compilation of the model database
3. Calculation of scenarios and strategies
4. Integration of subsystem analyses
5. Sensitivity analysis

According to IEA (2004), the interaction between comprehensive studies and subsystem analyses must furthermore be accompanied by the use of models, which are simplified mathematical representations of the energy flows and costs of an actual (technical) energy system (see Section 2.2.5).

2.2.4.3 South African Approaches to Sustainable Cities

There are a number of South African approaches similar to the three approaches for sustainable cities presented in the previous Section. Three documents dealing with the issue of local/urban energy planning in South Africa will be briefly introduced and analysed regarding the implementation of Southern development issues.

"The Energy Book for Urban Development in South Africa" is a publication by Ward (2002), giving a concise background on global and South African energy issues and trends, stretching from climate change to CCP campaigns. Next, a strong focus is made on household energy issues and community activism, introducing financing mechanisms, appropriate end-user technology and efficiency measures. Linkages to commercial and industrial urban activities are neglected.

"Energising South African Cities & Towns - A Local Government Guide to Sustainable Energy Planning" by SEA (2003b) consists of an approach for the establishment of a sustainable energy plan for South African cities and towns (see Figure 2.11), and a presentation of related energy case studies and sectoral reviews. It is stressed that although energy sector planning has in the past been driven by supply-side industries, many economic and social benefits can arise from first considering and understanding the demand side picture.

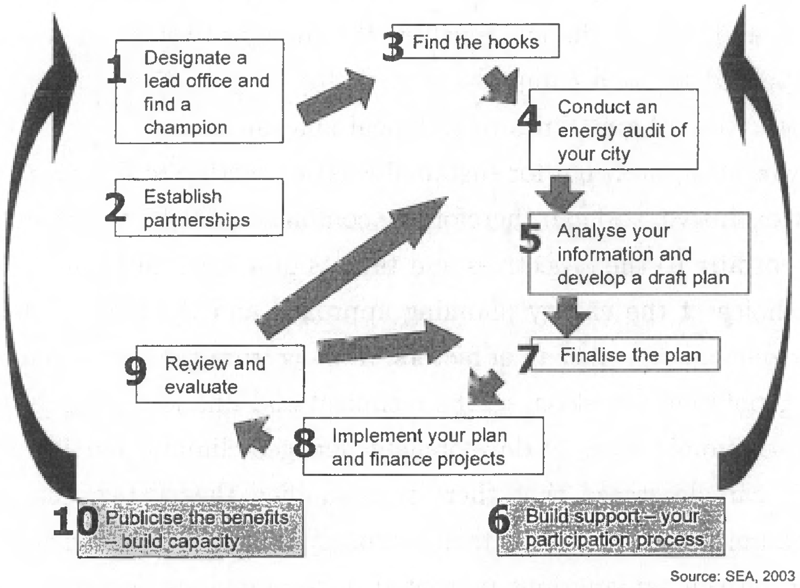


Figure 2.11: A 10-Step Approach for Urban Energy Planning

In a book by Soul City (2002) with the title "Using Energy in the Home", a practical guideline is presented for household energy issues in the context of a community development project. Basic energy related facts regarding costs, end-user appliances, efficiency and safety are concisely compiled for a general audience.

2.2.4.4 Discussion

From the 1970s up to the point of writing, a constant shift regarding energy planning is observed:

- away from a purely centralised/national, supply-side driven approach, heavily focused on fossil-based electricity options,
- towards a more decentralised/local, demand-side driven approach, considering a broader variety of energy sources (including renewables) and products.

Approaches for sustainable cities vary widely in level of detail and focus. Whereas some approaches provide instructions on the setup of energy plans and policy making, others propose part-concepts dealing with issues such as GHG mitigation and climate change, touching the energy sector *en passant*. The ALEP concept proved to be a comprehensive multiple-layer energy planning concept, ranging from broad guidelines to technical analysis.

The various approaches for sustainable cities overlap in several points, are not mutually exclusive, and can therefore be combined in order to achieve an optimal result according to the objectives and targets of a local authority.

The choice of the energy planning approach and the level of detail will furthermore depend on a variety of factors, ranging from the size of the city, over the prevailing political situation, to the technical and financial capacities, as well as the socio-economic state of development and geo-climatic particularities. Summarily, it can be stated that there is no unified theory regarding local/urban energy planning, as requirements are strongly dependent on the single case.

Based on the explanations presented in the previous Sections, the urban energy planning process is characterised as complex because of the following reasons:

- Interaction with cross-sectoral issues such as environmental management and regional planning
- Responsibilities especially regarding supply-side lie with different bodies at different governmental levels, and at the intersection of the private and the public sectors
- Goals must be clearly defined, and be in line with requirements of different stakeholders (see Section 2.3.2.1)
- Integration of issues such as Public Relation (PR) and community participation

- Inclusion of data collection and analysis, as well as project planning, implementation, and monitoring
- Iterative process, as project outcomes need to be assessed against previously defined objectives and goals, possibly requiring the planning process to be revisited at different stages
- Pre-requisite of energy planning infrastructure, and the establishment of partnerships

The presented sustainable city approaches have been developed over the last three decades based on the experience of cities in developed countries. The South African approaches are similar to the other three approaches, sporadically implementing Southern development elements; a systematic and holistic implementation of these elements is however missing.

Furthermore, the ALEP concept has been developed by the IEA based in Paris/France with no particular focus on development issues. Drawing upon a database of good quality, a process with a high level of technical detail is proposed, heavily focused on energy modelling. Applied in a Southern city, it is argued that such an approach would cloud pressing socio-economic development needs through a misplaced emphasis in the planning process, and decrease the efficiency of the planning process as a whole.

In line with Hypothesis 1, it is therefore questioned to which extent the presented approaches and concepts are applicable to cities in developing country settings.

2.2.5 Energy Modelling

The concept of energy modelling has been widely applied and extensively explored from an academic perspective[1], including local and urban planning issues, and will not be presented in detail against the backdrop of this dissertation. However, energy models and related tools need to be understood for the creation of a technical interface to planning issues of particular relevance in this dissertation.

[1] A good review on energy models is given by Jebaraj & Iniyan (2006).

Energy modelling can be used in order to support decision-making during the energy planning process (see Section 2.2.4.2). An energy model is a simplified technical representation of an energy system, and is useful in terms of data preparation, structuring and processing, providing a common base for communication between the different stakeholders in the planning process (see e.g. IEA, 2004). Models may range from complex, computer based forms to simple back-of-the-envelope calculations.

In the field of energy planning, two general types of models have been used (Smekens, 2003):

- Top-down (e.g. general equilibrium or macro-economic frameworks)
- Bottom-up (e.g. energy system models)

Energy system models, in turn, are divided according to their underlying method into two categories, namely simulation and optimisation. According to IEA (2004), these categories are described as follows:

- *Simulation* is better suited for energy demand analyses or explorative analyses. As a general rule, simulation is easier to understand and to apply; moreover, the interpretation of the results is straightforward.
- *Optimisation* is especially suited to calculate least cost strategies under certain boundary conditions. It is more complex to handle, especially as regards results interpretation and error detection where much experience is required. The results can give new insights into the system behaviour.

An extensive list of simulation and optimisation tools for energy purposes is available from the ALEP website[1].

Furthermore, there are models dealing with demand-side or supply-side issues, and are often used in combination. Two of these models will briefly be introduced in the following.

According to Nijkamp & Perrels (1994), a good example of a comprehensive demand-orientated approach is the MEDEE model. Its was developed by the

[1] `http://www.iea-alep.pz.cnr.it/4_Summary.htm`

International Institute of Applied Systems Analysis (IIASA), and can be regarded as both an engineering and an economic model, thus requiring both detailed technical and socioeconomic data.

In a paper by Pietrapertosa *et al.* (2003), comprehensive modelling for approaching the Kyoto targets on a local scale has been investigated. Importantly, the flexibility of the MARKAL models generator is described. According to Pietrapertosa *et al.* (2003), it is the most widespread among the available comprehensive model generators. It adopts a bottom-up approach, and can be applied for large- and small-scale supply-side planning. It was developed under the helm of the IEA in the framework of the Energy Technology Systems Analysis Programme (ETSAP), and has been utilised for energy-environmental planning since the early 1980s. At the base of every model generated with MARKAL lies a Reference Energy System RES, representing energy and material flows between demand and supply sides, crossing demand devices, processes, and conversion technologies. The general structure of the RES will be used as a basis for the development of an extended energy planning approach including the concept of sustainable energisation in Section 6.6, and the development of the creative option generation model in Chapter 8.

An important issue regarding the energy planning process concerns the required level of detail of the modelling process. Although the level of detail is dependent on the scope of the model - i.e. comprehensive energy system or subsystem modelling (see e.g. IEA, 2004) - it is hypothesised that an inadequate level of detail, especially on the local level, can lead to the misallocation of resources and negligence of the implementation phase.

Furthermore, a number of providers of modelling tools have been contacted in order to obtain the permission to use the information contained in their databases regarding energy technologies and energy carriers (see Section 8.3.1).[1]

[1] It would have been of particular interest to obtain the permission to use the RETScreen database for experimentation purposes from the CANMET Energy Technology Centre-Varennes, as the software package recently passed the 100,000 user milestone, and is the world-leader in terms of assisting in the planning of projects that use renewable energy and cogeneration technology (Martin, 2007). The company has been approached, but the permission has been declined.

2.2.6 North-South Cooperation at Different Scales

Against the backdrop of globalisation, cooperation between countries of the North and the South took usually place in only one direction, from the rich industrialised countries to largely poor developing countries, by means of financial aid, development programmes, and private sector investment. It is at the beginning of the 21st century that a phenomenon commonly referred to as reverse globalisation takes place, where companies from a number of developing countries - referred to as BRIC countries (Brazil, Russia, India, and China) - target firms from industrialised nations for acquisition, a largely uncommon phenomenon in the history of the global economy (Dlamini, 2007).

Two policy papers documenting the traditional relationship between developed and developing countries have been released by the German Federal Department for Economic Cooperation and Development (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (BMZ)). The first paper, "The African Challenge - Cornerstones for Strategic Politics Regarding Africa", describes means by which the German Government can support the shift of African low-development countries from poverty to economic, political, and ecologic stability (BMZ, 2001). The second paper, "Promotion of the Use of Renewable Energy Carriers in the Cooperation for Development", specifically focuses on the importance of linking ecological perspectives to the increased energy supply of the poor in Africa, and the role the German government could take (BMZ, 2003).

Developed in the context of the Kyoto Protocol (Section 2.2.2.3), the Clean Development Mechanism (CDM) represents a medium of cooperation between project partners in developed and developing countries. On the one hand, developed countries (Annexure I) have set an average target of 5% below their greenhouse gas emission levels in 1990, which are to be achieved by 2008-2012. On the other hand, developing countries (non-Annexure I) do not have targets, but can develop emission reduction projects. The idea is that because GHGs mix uniformly in the atmosphere, it does not matter where they are reduced. Parties can therefore use emissions trading and credits from projects to help them meet their targets (Flexible Mechanisms) (Tyler, 2005).

From a local perspective, cooperations between cities in the North and the South were established within international initiatives such as LA21. Of special interest against the backdrop of this dissertation is the Memorandum of Understanding signed between the City of Aachen and the City of Tygerberg (now part of City of Cape Town) (Stadt Aachen, 2000), resulting in the Aachen-Cape Town LA21 Partnership. According to CCT (2005), the partnership was established with the goal to promote sustainable development through facilitating collaborations and partnerships regarding the improvement of environmental, social and economic conditions. A steady increase of projects established within the framework of the LA21 partnership rose from 4 to 12 projects in 4 years. Energy related issues are addressed in awareness campaigns and community capacity-building programmes, but no systematic planning and implementation of projects regarding energy efficiency or renewable energy has happened within the LA21 partnership portfolio.[1]

2.2.7 Renewable Resources and Technology

For this thesis, an emphasis will be laid upon biomass, especially cellulosic biomass (wood and paper), and related energy conversion technology. In the following Section, perspectives on biomass will briefly be presented in terms of current usage and future prospects, as well as the state-of-the-art regarding energy conversion options.

2.2.7.1 Usage and Potentials of Renewable Resources

In 2004, renewable energy (excl. hydro) accounted for approx. 10% of global primary energy supply (see Section 2.2.1). As can be seen in Table 2.2, biomass energy accounted for the highest share of renewables with 50 EJ/a, followed by hydropower with only 9 EJ/a. The remaining renewables accounted for a total of less than 1 EJ/a.

The annual natural flows of solar, wind, hydro, and geothermal energy and quantities grown by nature in the form of biomass are referred to as theoretical potentials ('occurrences' in fossil fuel nomenclature). Technical potentials are the

[1]See Section 2.2.2.1. Please check www.capetown.gov.za/soe for updated information.

recoverable quantities of a resource in terms of technology availability and performance ('reserves' in fossil fuel nomenclature). The distinction between theoretical and technical potentials reflects the degree of use determined by thermodynamic or technological limitations without consideration of practical feasibility or costs (UNDP, 2004a).

Regarding the technical potentials, geothermal energy and solar energy account for the highest shares, some $> 5,000$ EJ/a and $> 1,600$ EJ/a respectively. The technical potential for hydropower and biomass have already been deploited to approx. 20%. From a theoretical perspective, the biggest potential lies by far with geothermal energy with 140,000,000 EJ/a, followed by solar energy with 3,900,000 EJ/a.

Resource	Current use [EJ/a]	Technical potential [EJ/a]	Theoretical potential [EJ/a]
Hydropower	9	50	147
Biomass energy	50	>276	2,900
Solar energy	0.1	>1,575	3,900,000
Wind energy	0.12	640	6,000
Geothermal energy	0.6	5,000	140,000,000
Ocean energy	n.e.	n.e.	7,400
Total	60	>7,600	>144,000,000

Source:UNDP 2004

Table 2.2: Renewable Resources - Current Use and Projected Potentials

Although biomass is currently the most important renewable energy carrier and is of paramount importance to the poor in developing countries, its utilisation is seldom sustainable, as it is mainly utilised as traditional fuel in combination with inefficient conversion technologies, causing i.a. important health problems (see Section 2.2.2.4). In this dissertation, a special emphasis will be laid upon the biomass sector, as it bears the largest potential in terms of restructuring and shift towards more sustainable conversion routes.

2.2.7.2 Conversion Technologies for Biomass

Energy conversion technologies for biomass long played a secondary role behind renewable technologies such as wind, solar and hydro, because of a negative public perception, relating them to dirty energy solutions, and energy technologies for the poor. However, succesful bioenergy projects around the world have recently shifted biomass back into the arena of public interest (Sims, 2002).

An extensive list of literature related to biomass conversion options covers research undertaken during the last three decades (see e.g. Anderson & Tillman (1977), Bridgwater & Kuester (1988), Klass (1998), Sims (2002)), which will not be presented in detail in this dissertation.[1] However, the fundamental conversion options, and the current situation regarding the biomass sector will be briefly presented in this Section.

Biomass sources are diverse, including organic waste streams and agricultural and forestry residues, as well as plants grown for energetic purposes (e.g. energy crops and short rotation trees). In the past, biomass utilisation was misleadingly linked in the public opinion to issues such the cutting down and burning of native forests (Sims, 2002). Although this practice rarly occurs, biomass cultivation would lead to an enormous demand for land in competition with other kinds of land use, if it were to play a significant role in the future (Steger *et al.*, 2005). These prospects have lead to much controversy in the developing world, especially in connection with food security (Wakeford, 2007). Against these backgrounds, existing biomass waste streams are attractive resource alternatives.

Conversion technologies for biomass can be divided according to three main groups as can be seen in Figure 2.12, namely thermochemical, biochemical, and

[1] A comprehensive list of technical reports and other publications on biomass conversion covering the period from the 1970s up to 2007 is available from the website of the Office of the Biomass Programme (OBP) of the US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) (`http://www1.eere.energy.gov/biomass/document_database.html`), and the website of the National Renewable Energy Laboratory (NREL) (`http://www.nrel.gov/biomass/publications.html`). For further background information regarding global perspectives on renewable energy resources and related conversion technologies, consult Chapters 5,6 and 7 of the WEA (UNDP, 2000b).

physical conversion processes.[1] In a second phase, obtained energy products can be converted in a combination of steps in order to obtain the final energy carriers heat, electricity and liquid fuels.

Whereas lignocellulosic, dry biomass (e.g. wood) is suited for thermochemical conversion options, wet biomass (e.g. sewage sludge) is suited for the anaerobic digestion route. Sugar- and starch-rich biomass is suited for the fermentation option, and oil-rich biomass is suited for the extraction route.

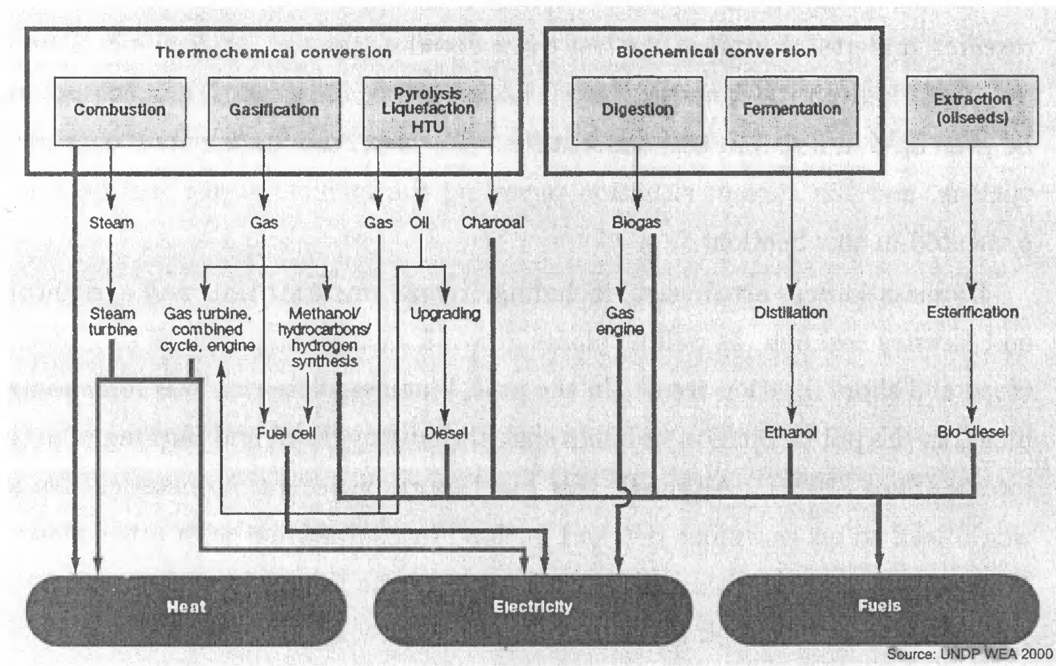


Figure 2.12: Main Biomass Conversion Pathways

Today, the conversion of biomass via direct combustion is the most commonly used technology. It ranges from small stoves in developing countries[2], to large-scale applications in industrialised countries (Steger *et al.*, 2005). Large-scale combustion is currently seen as the most efficient and cleanest way of converting biomass; the technology is commercially available and presents minimum risks

[1]This representation includes main conversion routes, and does by no means claim to be complete.

[2]The energetic utilisation of biomass in developing countries is related to serious health problems, see Section 2.2.2.4.

to investors (Bridgwater, 2003). In 2003, applications were economically viable only when waste materials were used as input feedstock (Bridgwater, 2003). The most interesting way is the co-firing of biomass in existing coal-fired power plants (Steger *et al.*, 2005).

A much discussed technology in terms of future potentials is the gasification process, especially because of its diversity of possible energy products. The obtained syngas can be further converted into electricity, heat, and secondary fuels, such as hydrogen, methanol, and Fischer-Tropsch diesel (Steger *et al.*, 2005).[1] In 2003, there was very little information on costs, emissions, efficencies, and operational experience regarding the gasification technology (Bridgwater, 2003).

From the thermal conversion perspective, fast pyrolysis gains currently in interest with regards to the production of liquid fuels (Bridgwater, 2003).

Anaerobic digestion is the most commonly used technology for converting high-moisture wet biomass to energy, and its utilisation for the production of methane has been technically succesful at a variety of scales in developed and developing countries. Especially in the developing world, low costs and the simplicity of small-scale digestion made it an attractive energy conversion option (Sims, 2002).

The production of ethanol from the fermentation of sugar-rich biomass has been widely used in Brazil and the USA, either neat or blended with gasoline, for over two decades (Sims, 2002). The conversion route is however considered a less attractive option for European conditions in terms of chain efficiency and costs (Steger *et al.*, 2005).

The production of biodiesel obtained from the esterification of vegetable oils and waste cooking oils has been extensively studied (Amigun *et al.*, 2006). Biodiesel is currently commercially available in several countries (Sims, 2002).

The production of alcohol from wood via enzymatic hydrolysis is a promising technolgy, and is currently under development (Steger *et al.*, 2005).

Interestingly, Hamelinck (2004) assesses the technical and economic potentials of biofuels other than 1st generation ethanol and biodiesel. After a preliminary investigation of feedstock costs, potentials of hydrogen, methanol, Fischer-Tropsch

[1] Note that for the case of Aachen (Section 4.5), technical knowledge regarding the gasification process is helpful.

Synthesis (FTS)-liquid fuels, and ethanol produced from biomass are analysed and compared.

Against the backdrop of increasing volumes of waste especially in urban areas, Murphy & McKeogh (2006) propose an integrated waste treatment system for the production of energy. A combination of three subsystems for the respective treatment of agricultural slurry, Municipal Solid Waste (MSW), and sewage sludge is proposed. It is concluded that a system designed for treating the waste from 1,000,000 Person Equivalent (PE) could power 12,400 cars, provide electricity for 30,900 houses and heat 15,100 houses. Put differently, this means that the energy recovered from waste generated by a certain population[1] suffices to supply approx. 10% of the same population with electricity, and 5% with heat.

2.3 Theory and Methods

In this Section, theory will be introduced upon which specific components of this thesis are based. This will be followed by an introduction to methods that are applied in specific research tasks. None of these Sections stay in direct relation to each other, and do not follow a defined order. It will be drawn upon this information at later stages in this thesis.

2.3.1 Theory

2.3.1.1 The Theory of Urban Ecosystems

Since this dissertation engages with flows of energy in urban contexts, it is appropriate to introduce here the concepts of urban ecology and industrial metabolism.

According to Hughes (1974), the term 'Ecosystem' refers the totality of living and non-living things on an area of the earth's surface, interacting to produce a characteristic flow of energy and cycling of materials.

Even though the city is commonly described in terms of economic activity or intensified social interaction, Hughes (1974) proposed that it should be considered as an ecosystem, as the city is closely linked to the physical and biological world

[1] Assuming an average household size of 3

both within its own boundaries and without. The main difference of an urban ecosystem to other land ecosystems is its massive energy flow.

Husar (1994) states that in an ecosystem, the cycling of materials is maintained by three groups: producers, consumers, and decomposers. In a natural ecosystem, most of the material is transferred from the producers (plants) to the recyclers (bacteria); only a small fraction is passed through the consumers to the recyclers. For urban ecosystems, the flow from the producers (firms) to the recyclers is relatively small, as it is senseless to produce goods without being consumed first.

Furthermore, natural ecosystems are characterised by the physical proximity and functional matching of producers, consumers and recyclers. This proximity allows the reduction of energy losses based on short transportation distances, which enables the sustainable development of the considered ecosystem. On the other hand, anthropogenic ecosystems are characterised by a physical displacement between producers, consumers and recyclers, which requires a significant amount of energy for transportation purposes (Husar, 1994). Note however that cities are centres of collective human activity, which renders transportation distances typically shorter than in rural areas (Institute of Ecology, 1974).

Furthermore, Ayres (1994) states that the term 'Metabolism' in its original biological context refers to the internal processes of a living organism. By analogy between biological and industrial systems, based on the fact that both are i.a. material processing systems driven by a flow of free energy, Ayres (1994) gives the following definition:

> *An industrial metabolism is the whole integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes in a (more or less) steady state condition.*

Whereas the metabolism of the earth is made of natural cycles that are closed, flows of the industrial metabolism are typically open. In other terms, the industrial system does not generally recycle its nutrients, which renders it inherently unstable and unsustainable. The only two measures for addressing this unsustainable state regarding waste materials are recycling and reuse (Ayres, 1994).

2.3.1.2 Case Study Theory

Case studies are used extensively in humanities, natural sciences, social sciences, pseudoscience and business (see e.g. Wikipedia, 2007a), and are especially useful when it is the researcher's intention to abstract theoretical insights from observations of complex systems that are not suitable for experimentation.

The utilisation of case studies became popular only in recent decades, and can be understood as a research strategy, sometimes likened to an experiment, a history, or a simulation, though not linked to any particular type of evidence or method of data collection (Yin, 2002).

A case study describes events in a framework within an environment. The problems are not always highlighted or made clear; they emerge as the case material is subjected to analysis (Rogers, 1978).

There is a number of different types of case studies, which are as follows (Wikipedia, 2007a):

- Illustrative case studies
- Exploratory case studies
- Critical instance case studies
- Program effects case studies
- Prospective case studies
- Cumulative case studies
- Narrative case studies
- Embedded case studies

Of special interest in this dissertation is the illustrative case study. It primarily describes one or a limited number of instances, and allows to start from a general perspective and then highlight specific elements. Based on an analysis of available data and interviews, its goal is to collect facts, opinions, points of view, suggestions, and/or reactions to hypotheses and conclusions (EU, 2007).

Moreover, a careful case selection is of paramount importance for generalizing and inducting theory from case studies. The process of inducting theory stretches from the specification of research questions to the closure of the case study. The process is described as being highly iterative and tightly linked to data. The approach is especially appropriate in new topic areas, as it is the case for specific topics investigated in the context of this thesis (Einsenhardt, 1989).

A researcher might have to opt for single-case or multiple case research. By evaluating the pros and cons of the two approaches, Eisenhardt (1991) concludes that the similarities between both are more important than the differences. For both, good storytelling is an essential first step, but good theory is fundamentally the result of rigorous methodology and comparative, multiple-case logic.

In the context of this thesis, case studies are utilised for the comparison of the renewable energy planning process in the South and the North (see Chapter 3 and 4), and the MFA of urban wood-fibre based material streams (see Chapter 7).

2.3.2 Methods

2.3.2.1 Multiple Criteria Decision Making

A method utilised to seek out the most suitable energy strategy option to meet a specific energy demand is Multiple-Criteria Decision Making (MCDM). MCDM methods deal with the process of making decisions in the presence of multiple objectives (see Figure 2.13). A decision-maker is required to use multiple quantifiable or non-quantifiable criteria to choose between several mutually exclusive options. The criteria are usually conflicting and therefore, the solution is highly dependent on the preferences of the decision-maker and must be a compromise. In most of the cases, different groups of decision-makers are involved in the process. Each group brings along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise (Pohekar & Ramachandran, 2003).

The use of MCDM in energy planning is widespread and well documented. The use of MCDM methods has proved to be particularly useful in addressing the environmental dimensions of the energy planning problems (see, e.g. Hobbs & Meier, 2000).

As can be seen in Figure 2.13, MCDM methods typically contain ten steps, which can be split into three phases: i) Problem Definition (steps 1-3), ii) Tradeoff Analysis (steps 5&6), and iii) Evaluation (steps 4, 7-10) (Hobbs & Meier, 2000).

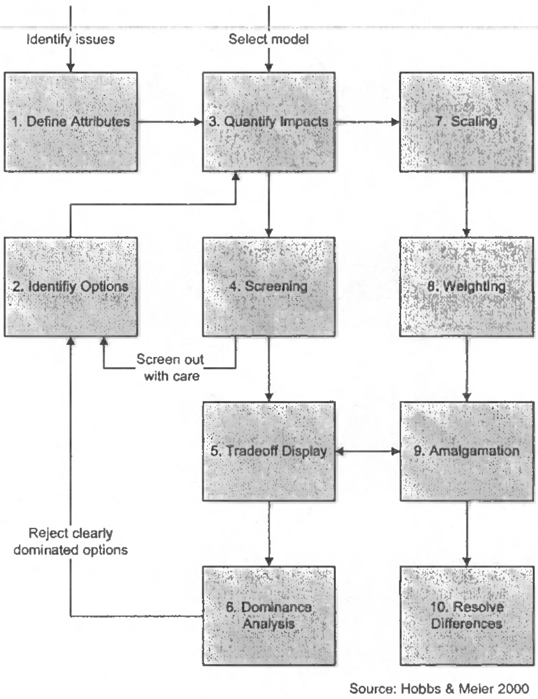


Figure 2.13: Process of Multiple Criteria Decision Making

Academic research has intensively focused on the tradeoff analysis and the evaluation steps (see e.g. Pohekar & Ramachandran, 2003). However, the main purpose of using the MCDM methodology in the context of this dissertation is to frame the decision-making problem at the level of the City Council based on attribute definition, data gathering and options generation (see Chapters 6, 7 and 8). An emphasis will be laid on the problem definition steps, especially step 1 'Attribute Selection and Definition', and step 2 'Options Identification'. The following two Sections have been synthesised from (Hobbs & Meier, 2000).

Attribute Selection and Definition Attributes, or measures of goodness, express the planning objectives to be considered in a given problem. The selection of attributes to be included to the decision-making process is one of the most critical tasks, as they need to reflect the perceptions of the participants, whilst remaining quantifiable. Further issues regarding the selection of attributes include the setting of boundaries, double counting, conceptual independence, specificity in the attribute definition, and attribute proliferation. The presence of uncertainty in the planning process can be expressed as a risk attribute.

Options Identification It is critical that decision-makers draw upon a meaningful set of options in order to assure the best outcome of the MCDM process. As too many options would render the process too complex, and too few options would not address all the facets of the problem, a set of options needs to be selected which is representative for the different types of options and their impacts.

As all options might not be known at the beginning of the MCDM process, option selection needs to be iterative, so that new options can be fed into the process at a later stage.

Moreover, the attribute selection and definition step has been placed before the options identification step, because it potentially leads to a more objective-focused selection of options. Further means for stimulating the generation of options is the definition of different scenarios regarding future development, the use of mathematical programming models (e.g. the generation of a range of resource mixes), and the application of methods borrowed from other disciplines, such as the method of Combinatorial Process Synthesis (CPS) (see Section 2.3.2.2).

In order to assure a broad spectrum of options, it is important that the selection process is not left to technical analysts alone: an early involvement of the public and a broad-based participation within the concerned organisations is of paramount importance.

A typical outcome of the options identification step is a decision tree.

2.3.2.2 Combinatorial Process Synthesis

Combinatorial Process Synthesis (CPS) is a relatively novel paradigm for flow sheet synthesis within the discipline of chemical engineering. Its two-staged synthesis algorithm generates all feasible operational alternatives followed by rigorous optimisation of structurally superior flow sheets (Chakraborty & Linninger, 2002). Figure 2.14 represents the superstructure generation process for deriving products from a portfolio of secondary resources (Chakraborty *et al.*, 2004). The flow sheet generation step combined with multiobjective optimisation delivers operating policies with optimal trade-off among the conflicting objectives 'cost' and 'environmental impact' (Chakraborty & Linninger, 2002).

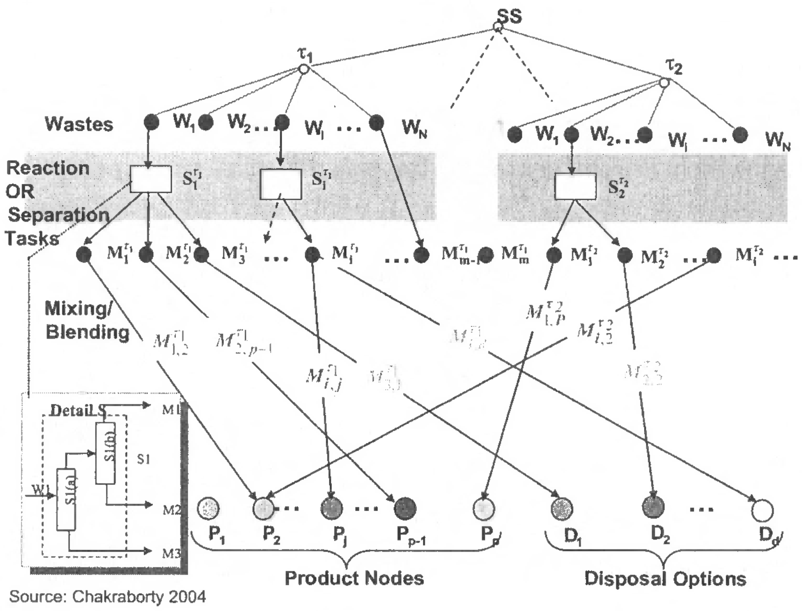


Figure 2.14: Combinatorial Process Synthesis - Superstructure Generation

It is believed that the method of CPS can assist in the generation of options in the field of energy planning. Against the background of a MCDM process (see Section 2.3.2.1), technology-based options are generated and optimised in a bottom-up approach. The first stage of the proposed methodology aims at automatically constructing a flow sheet of all feasible energy conversion options by matching available energy resources with energy demands. The second stage aims at classifying on a detailed technological level the different previously generated conversion options by their suitability to serve a defined purpose, in line with the objectives of the energy planning process. In this thesis, it will be focused on the first stage of the CPS.

2.3.2.3 Material Flow Analysis

A Material Flow Analysis (MFA) is defined as the *"quantitative accounting of material inputs and outputs of processes in a chain perspective"* (Bringezu & Moriguchi, 2002). MFA can be understood as a material balance focusing on a specific material or a group of materials, passing through a specific geographical area or an industrial sector (Clift, 2006). The results of a MFA are typically used for estimating resource consumption or waste arisings, and optimise recovery and recycling rates. The levels at which MFAs are applied vary widely, from national macro-levels to detailed factory levels. A good overview on the fields of application of the method of MFA is included to a publication by Clift (2006).

In this thesis, the identification of potential renewable resources is of special interest. The method of MFA is particularly suited for the identification of biomass resources, as they typically lie at the intersection of material and waste streams.

In the literature, the method of MFA has been applied in several instances to the wood & paper sector, as well as the waste management sector. In the following, three approaches will be briefly discussed in order to illustrate the usage and flexibility of the method of MFA within a particular framework. Chapter 7 represents a detailed investigation of wood-fibre based material streams in Cape Town.

In order to promote material cycling, Hashimoto & Moriguchi (2003) developed a set of indicators for measuring the effectiveness of policy and actions on society's metabolism. From a perspective of Material Flow Analysis (MFA), material cycles in society's metabolism can be classified according to three types: reuse of used products, recovery of by-products (as material and heat), and recovery of used products (as material and heat). Against this background, six indicators were developed: direct material input (DMI), use rate of recovered used products (URRUP), material use efficiency (MUE), material use time (MUT), recovery rate of used product (RRUP), and domestic processed output (DPO). In a second step, Hashimoto *et al.* (2004) carried out a MFA of wood resources in Japan during the period 1960 1999, and tested the validity of the developed indicators. It was concluded that the indicators are useful for analyzing the state of material cycles, and discussing the future goals of material cycling.

The method of MFA can also be applied for the representation of a particular industrial sector. Beck *et al.* (2004) apply the method for the representation of the wood products industry in the Greater Sydney Area. Based on the represented industry network, multiobjective optimisation (MOO) is used to investigate preferred configurations in terms of resource efficiency and sustainability. The industry network contains two types of elements: nodes and links. A mathematical model was applied for mass balance closure over the nodes, and linear equations were utilised for describing the activities and constraints of the nodal activities. It was concluded that a holistic view of material networks offers opportunities for greater resource efficiency, as more options for material recycling can be identified.

Furthermore, the method of MFA has been applied to the waste management sector. For instance, Rotter & Loeschau (2005) developed a mathematical approach based on a waste transfer matrix for the calculation of the cumulative material distribution. A case study on the waste management situation in Berlin is presented, showing the distribution of residual wastes according to sinks (i.a. atmosphere, landfill sites) and energy products.

2.3.2.4 Data Mining and the Use of Search Engines

It is the 3rd Hypothesis of this dissertation that the innovative deployment of Information Technology (IT) supports the identification energy conversion pathways unknown to the energy planner. In order to investigate this, it is necessary to draw on the concepts of search engines, data retrieval, knowledge discovery, and data mining. In the following, these concepts will be presented, giving key literature references regarding the scientific fundamentals corresponding to the described points.

The World Wide Web (WWW) may be viewed as a collection of interconnected documents and other resources, linked by hyperlinks and Uniform Resource Locators (URLs) (Wikipedia, 2006g). Search engines such as Google, Yahoo!, and Ask Jeeves, assist the user in finding specific information in the WWW. According to Wikipedia (2006c), *"a search engine is an informational retrieval system designed to help find information stored on a computer system, such as the WWW, inside a corporate or proprietary network, or in a personal computer. The search engine allows one to ask for content meeting specific criteria and retrieves a list of items that match those criteria. This list is often sorted with respect to some measure of relevance of the results".*[1]

In order to retrieve required information fast and efficiently, each search engine has its own crawler, which is constantly indexing millions of webpages a day. The crawler grabs a part of each website, and stores it along with its index in a localized database. When a user submits a query to a search engine, only a concise and indexed copy of the web is searched. Only then, the user is directed to the appropriate URL.

Words from the title and the meta tags[2] - meta description and meta keywords -, as well as the links that appear on the webpage, are usually scrutinized in order to index a webpage.

In a book by Berry & Browne (2005), the theoretical fundamentals of search engines regarding mathematical modeling and text retrieval are discussed. By starting with the document file preparation, the author presents the theory on vector space models and matrix decomposition. Thereupon, search query management and feedback regarding ranking and relevance of results are discussed. Importantly, the search by link structure is analysed, discussing the underlying theory of the PageRank approach. Finally, some considerations regarding the user interface are discussed.

In the work reported in this dissertation, the Google search engine has been investigated regarding its implementation potentials for a web based option generation application. In the following, two books are presented, respectively dealing

[1]The term search engine commonly refers to a web search engine.

[2]Meta tags are not part of the content of a webpage, but are used for describing the content

with general issues and detailed programming related aspects regarding the use of the Google search engine and its features.

"Google - The Missing Manual" is a compendium manual on the use of the google search engine and its features (Milstein *et al.*, 2006). The book is structured into four Sections, where Section 1 "Searching with Google" and Section 2 "Google Tools" are of special interest for this thesis.

In a book by Calishain & Dornfest (2003), the technology behind the Google search engine is presented (to some extent), as well as solutions to programming problems in order to perform searches that can not be performed using the regular Google interface. Of special interest for this thesis are Chapters 8 and 9, where the Google Web API is introduced, and a number of Google Web API applications are presented.

For the development of the application in Chapter 8, the concepts of data mining and knowledge discovery need to be understood. The concept of data mining is often used as included or synonymous to the concept of knowledge discovery, and is defined as follows (Wikipedia, 2006a):

> *Data mining is a technique for searching large-scale databases for patterns; used mainly to find previously unknown correlations between variables that may be commercially useful.*

In their book on the principles of data mining, Hand *et al.* (2001) give the following definition:

> *Data mining is the analysis of (often large) observational datasets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data owner.*

Furthermore, the data mining exercise plays no role in the data collection strategy, and is therefore often referred to as secondary data analysis.

A book by Klosgen & Zytkow (2002) gives detailed information on the fields of data mining and knowledge discovery. The book is split into eight sections, and gives extensive literature references after each section. Of particular interest are the sections on the application fields of data mining and knowledge discovery, its interdisciplinary links especially to statistics, automated scientific discovery, neural networks, and visualisation - all of which are touched to some degree in this dissertation -, as well as the presentation of practical case studies.

2.4 Summary

The aim of this Chapter was to provide a basis regarding the background of this thesis, as well as to present the theory applied for the research tasks of this thesis.

In the first Section of this Chapter, relevant background information was given against which the remainder of this thesis is being carried out. After briefly introducing the global energy situation, the connections of the three pillars of sustainability with the energy sector were investigated. The dynamic links between GDP, CO_2 emissions and human welfare were highlighted. The global agenda for sustainable development was presented, and an emphasis was laid upon local development issues and energy. Within this framework, policies and mechanisms for climate protection were introduced.

Regarding poverty related issues, the importance of traditional biomass as an energy source in the developing world was stressed. Health impacts related to local air pollution and the usage of combustibles was presented. The relation between income and fuel choice was discussed for urban areas in developing countries: energy transition towards modern energy services is a fundamental element for socio-economic development in the developing world.

Moreover, urbanisation trends were presented, highlighting the rising importance of cities and towns in the developing world. Thereupon, a brief history of energy planning concepts was retraced. Approaches for sustainable cities were presented, as well as South African approaches to urban energy planning. The ALEP concept was presented, emphasising its heavy focus on the modelling process. A preliminary discussion was carried out, and, in line with Hypothesis 1, it was questioned whether Northern planning concepts can be applied in the cities of the global South.

Next, three cooperation models were presented for different levels in the developed and the developing world, mentioning the phenomenon of reverse globalisation, and emphasising activities in connection with climate protection and economic development.

Of particular interest in this dissertation is the usage of renewable energy resources, especially biomass. Therefore, the current usage and future projections regarding renewable resources was given. An emphasis was laid upon biomass conversion pathways and technologies.

In the second Section of the Chapter, the theory and methods applied for the research tasks in this dissertation were presented.

The theory of urban ecosystems was introduced, along with the concept of industrial metabolism. The application of case study theory was discussed: case studies are used throughout this thesis for the induction of theoretical findings.

Moreover, MCDM was presented as a tool for framing an energy planning process. CPS was introduced as an emerging method in the field of chemical engineering for the automatic generation of options and trade-off between the conflicting objectives cost and environmental impact. It is stipulated that CPS can assist in the MCDM process. Furthermore, MFA was introduced as a tool for data collection, synthesis and presentation.

Finally, the concept of search engines and data mining were explained. An emphasis was laid on the non-conventional application of the Google search engine, as well as the applicability of methods for secondary data analysis such as data mining.

Chapter 3

Urban Renewable Energy Planning in the South: the Case of Cape Town

3.1 Introduction

In the previous Chapter, the scientific background, the theoretical basis, and the methods applied for the research undertaken in this dissetartion have been given. In the next phase, the renewable energy planning approaches of a city of the South and a city of the North will be investigated and compared in order to develop insights into their similarities and differences.

This Chapter aims to describe and evaluate the approach to renewable energy planning of a city of the global South, drawing upon the case of Cape Town.

Cape Town's current and possible future energy pictures will be introduced. A short history of energy policy in South Africa will be given in order to locate the City of Cape Town in its socio-political context, investigating the roots of Cape Town's current challenges in the field of renewable energy planning.

Subsequently, an emphasis will be laid upon the renewable energy planning process of the City, starting by giving the legislative context guiding and affecting the City's renewable energy decisions. Insights will be given on the functions of national energy planning and regulation bodies, the role of municipalities in the energy planning process, and the impacts of the reform of South Africa's Electricity Distribution Industry (EDI).

Cape Town's energy planning process will be presented and critiqued based on original information gathering and by means of interviews. By investigating the City's energy planning approach, a basis will be created for the comparison with a city in a developed country (see Chapters 4 and 5), with the aim to substantiate the first Hypothesis stated under Section 1.4: *"The municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given"*.

3.2 Energy Picture of the City of Cape Town

Importantly, the City of Cape Town released the Cape Town Energy Strategy (SEA, 2003a), in which the City's goals and visions regarding the development of its energy sector were given. Furthermore, the City set itself a challenging renewable energy target - 10% of energy demand covered by renewable energies by the year 2020 - which is more ambitious than the national target set in the White Paper on the Promotion of Renewable Energy and Clean Energy Development (DME, 2002b). The following Sections will give a brief overlook on the current status of Cape Town's energy sector, as well as possible future development scenarios in order to describe the starting point for further research.

3.2.1 Status Quo

The metabolism[1] of the City of Cape Town is powered by an overall final energy utilisation of ca. 120 PJ/a (Winkler *et al.*, 2005). As can be seen in Figure 3.1, more than half of it is used to sustain the city's transport sector, followed by industry, households, government and commerce. As depicted by Figure 3.2 Cape Town's energy sector heavily relies on fossil energy carriers, the liquid fuels petrol and diesel jointly forming the lion share of energy carriers being consumed; their main purpose is to provide the necessary energy for urban transport needs.

[1]See literature review in Section 2.3.1.1 for the definition of the term

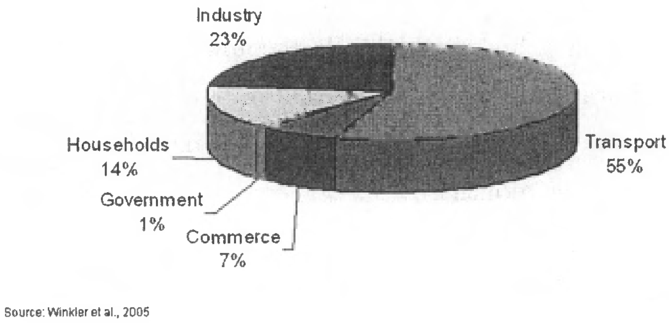


Figure 3.1: Energy Demand by Sector - Cape Town

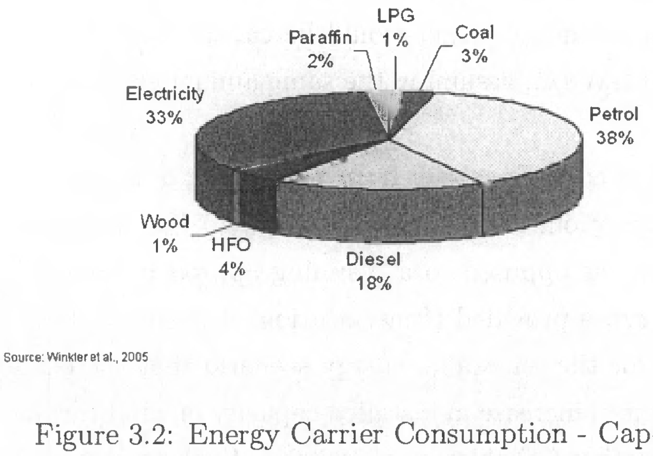


Figure 3.2: Energy Carrier Consumption - Cape Town

Electricity forms the second biggest share with 33%, Cape Town's electricity needs jointly being met by the Koeberg nuclear power station and by overland high-voltage transmission lines from the coalfields region east of Johannesburg. The energy carriers coal and Heavy Furnace Oil (HFO) form a total share of 7%, mainly being utilised in industry, whereas the energy carriers paraffin and LPG are mainly used on a household level, accounting for a total of 3%. The utilisation of the renewable energy source wood only contributes 1% to the total energy usage of the City of Cape Town, where peaks of wood utilisation are observed during the winter months.

3.2.2 Outlook

In a so called business-as-usual scenario as depicted in Figure 3.3 (Winkler *et al.*, 2006a), it is assumed that the city's energy metabolism will remain entirely based on fossil fuels, reaching a total energy utilisation of ca. 150 PJ by the year 2020. Main drivers for such a scenario are economic growth and demographic development. In a so-called renewable energy scenario, it is assumed that Cape Town's target of 10% renewable energy consumption by the year 2020 is met.

It is noteworthy that the renewable energy target has been calculated based on the target-year electricity consumption and not total energy consumption. An overall 10% renewable energy target would be ca. 15 PJ/a (ca. 4,200 GWh/a) instead of ca. 1,500 GWh/a, assuming the same annual growth rate of 2% across all energy carriers.

A second point of critique arising from the setting of an energy target based on electricity consumption, is that energy planning often happens from an electricity point of view, as opposed to a planning approach aiming at diversifying the energy carrier types provided ("energization"[1]) (Laing & Rosselli, 1998). It has been assumed for the renewable energy scenario that the energy target will be met by a substantial increase in installed capacity of wind turbines (>10 MW) for electricity generation (Winkler *et al.*, 2006a). Such an approach excludes alternative means of meeting energy needs, e.g. renewable liquid fuels, Solar Water

[1] see Chapter 6

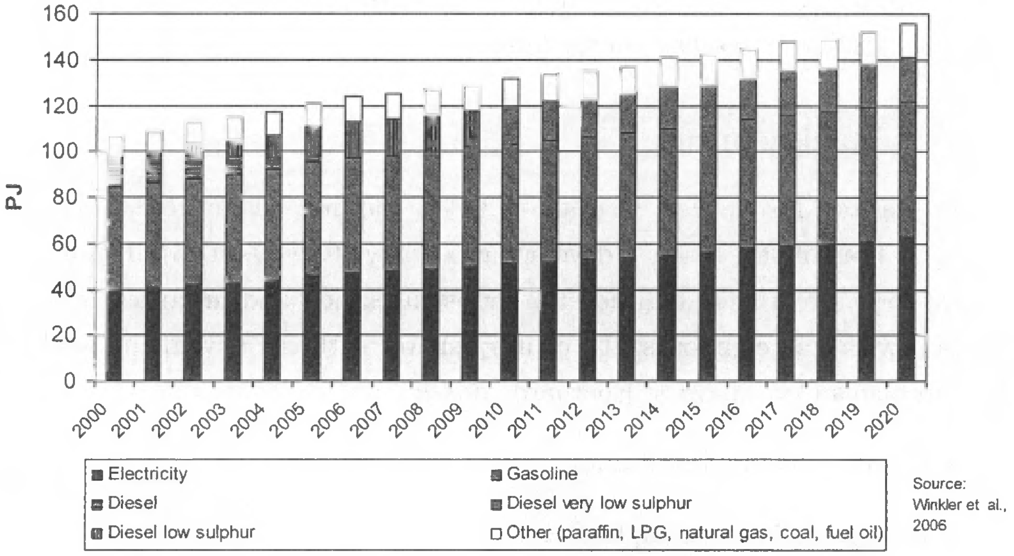


Figure 3.3: Energy Consumption Development: Business-as-Usual Scenario - Cape Town

Heaters (SWHs), ecological sanitation, and many others, and inhibits creative energy planning processes at the earliest stage.

3.3 Cape Town in Context: A Short History of Energy Policy in South Africa

The history of energy policy of the City of Cape Town is tightly linked to the history of energy policy of South Africa. In this Section, it is aimed to concisely bring up the key issues in South Africa's energy history in order to identify the roots of the current context of energy policy within the City of Cape Town.

This Section starts by giving a general background to energy policy in South Africa, which is followed by the consideration of three different periods of energy policy making in the country's history.

Throughout this Section, it will be attempted to answer the following question:

"How has it happened that Cape Town, a city of the South, with

significant governance, development, and infrastructure problems, has set itself a renewable energy target?"

3.3.1 Background

According to Marquard & Eberhard (2000), the first challenge South Africa is facing is that of still being a developing country (OECD, 2003). Despite South Africa (SA)'s relatively high level of industrialisation and urbanisation by comparison with its neighbours, the country shares with the developing world some key problems (Marquard & Eberhard, 2000):

- Uneven income distribution
- Extremely high unemployment
- Large percentage of population living in extreme poverty
- Lack of capacity and resources on governmental level

The second challenge is that of globalisation, having a high impact on SA's macro-economic policies, while also bringing forward global environmental issues such as climate change. According to Imola (2006), Africa's cities are the ones to be the most vulnerable to current and future climatic changes.

The third, and by far the most important challenge, is the transition from an apartheid to a post-apartheid state (Marquard & Eberhard, 2000).

All the above challenges have their roots in the past history of the country. These roots need to be investigated in order to develop an understanding as to what drives current policy making, and where the main challenges lie for national and especially local government.

According to Davidson & Winkler (2006), it is best to consider three different periods when it comes to the country's energy policy history, namely the period of the apartheid regime from 1948 to 1994, the period following the 1994 democratic elections up to 2000, and from 2000 onwards, when the euphoria of the newly won democracy had started to recede.

Davidson & Winkler (2006) say furthermore that energy policies of all three periods contributed differently to the growth of the energy sector. As can be

Period	Main Policy Goal
Apartheid period	Energy security
Advent of democracy	Energy provision to previously disadvantaged population groups
From 2000	Achievement of targets set in 1994

Source: Davidson & Winkler, 2006

Table 3.1: Periods of Energy Policy in South Africa

seen in table 3.1, it can be stated that summarily, each period had a main energy policy goal.

In the following, these three periods will be briefly described, emphasising issues regarding interfaces to energy planning on local governmental level, as well as the integration of renewable energy technology. In order to achieve this goal, mainly two papers by Marquard & Eberhard (2000) and Davidson & Winkler (2006) will be compared and discussed in order to illustrate the above mentioned points of interest.

3.3.2 Energy Policy during the Apartheid Era

The apartheid energy era began in the late 40s and 50s driven by the motors of national development, and energy security, the latter becoming increasingly significant during the 70s and 80s. A synthetic fuel programme, a nuclear programme, and the construction of huge coal-fired power plants focused on the supply side of energy provision (Marquard & Eberhard, 2000).

Davidson & Winkler (2006) states that before 1994, energy policies were designed to provide energy services based on 'separate development', the apartheid government's euphemism for racial discrimination.

According to Marquard & Eberhard (2000), the demand side was characterised by very low domestic consumption (relative to OECD countries) and a physical infrastructure that provided energy services to a small minority of mainly white South Africans. Davidson & Winkler (2006) state accordingly that for the domestic sector, modern energy services were provided to a the 'white' population group only, and limited or no services at all to the rest of the population.

South Africa, as a result of cheap coal and cheap electricity, had one of the most energy-intensive economies in the world (Marquard & Eberhard, 2000). Hughes *et al.* (2002) state that SA's economy is still energy intensive, meaning that the country uses a large amount of energy for every Rand of economic output.

Marquard & Eberhard (2000) say that the policy process during this period was characterised by extreme secrecy, and that the introduction of democracy was a prerequisite for the development of a more rational energy system. Davidson & Winkler (2006) confirms that security, secrecy and control characterised most of the policies that prevailed.

From no point of view - social, environmental, or economic - could the commonly accepted goals of sustainable development be met under the apartheid regime (Marquard & Eberhard, 2000).

3.3.3 Energy Policy in a New Democratic South Africa

The new energy paradigm in the era after the 1994 elections focuses on the energy needs of the low-income households. Davidson & Winkler (2006) say that the new government was determined to provide basic services to the poor and disadvantaged majority of South Africans.

From an intellectual perspective, research interests developed regarding low-income households from the end of the 80s, which led to tensions with the then acting National Party (NP) (see Marquard & Eberhard (2000)). Accordingly, Davidson & Winkler (2006) state that before the African National Congress (ANC) won the first democratic elections in 1994, a number of groups had been working with the ANC to formulate an energy programme to address the needs of the poor and disadvantaged.

The formation of this pool of intellectuals around social aspects of energy provision in South Africa is at the base of a productive relationship between researchers and ANC activists in the policy processes preceding the 1994 elections (Marquard & Eberhard, 2000).

From this collaboration emanated later contributions for the energy aspects of the ANC's Rural Development Program (RDP) as well as the 1998 White Paper

(DME, 1998).

According to Marquard & Eberhard (2000), only one significant shift in the allocation of resources occurred in the energy sector of the post-Apartheid regime, namely the electrification programme[1], in which the target of 2.5 million domestic connections was exceeded by the end of the century. Davidson & Winkler (2006) say furthermore that the programme expected that newly electrified households would switch from using fuel wood, candles and batteries to using electricity for their household needs. The electrification target became part of the ANC's RDP Marquard & Eberhard (2000).

In 2000, consumption per connection is way below Eskom's break-even point, which renders the programme financially unsustainable (Marquard & Eberhard, 2000).[2] However, Davidson & Winkler (2006) say that the government funded the programme together with Eskom, which had the advantage of tax-free status. This means that the financial burden of the programme had been decreased for Eskom already. Note that for the poorest customers, electricity prices were still too high (Marquard & Eberhard, 2000).

The link between electrification and providing effective energy services to the poor, has proved more problematic, as has the link between electrification and local development (Marquard & Eberhard, 2000).

By contrast to the electricity sector, the new government has had far less impact on the liquid fuels sector by 2000; the same phenomenon can be observed on the local governmental level (see Section 3.4.5.1). Despite the importance of the liquid fuels sector in the economy, as well as the importance of products such as paraffin to low-income households, the structure of the sector remained relatively unchanged during this period of democracy (Marquard & Eberhard, 2000).

Integrated sustainable energy planning is less efficient from a governmental planning perspective on the national as well as the local level, bearing in mind

[1]see Section 6.3.1

[2]Eskom may choose to hand over its low-income residential market to the newly formed Regional Electricity Distributors (REDs) as it traditionally operates at a loss (see Section 3.4.5.1)

that liquid fuels account for a large share of 33% of SA's final energy consumption (DME, 2002a).

Also: several pieces of energy legislation were passed in the 1987-2000 era, of direct relevance to the future of the energy sector in the country, i.a. the White Paper on Energy Policy (see Section 3.4.1).

3.3.4 Energy Policy after the Democratic Euphoria

Since 2000, three concerns emerged to be the main challenges in the country's energy sector: restructuring[1], social justice, and environmental protection.

Although the restructuring of the Electricity Distribution Industry (EDI) into the maximum number of financially viable and independent Regional Electricity Distributors (REDs) was already approved in principle by the Cabinet in May 1997, it is only at the beginning of the new millennium that the planning and implementation process started to take shape (Eberhard, 2004).[2] Furthermore, some of the most significant arenas for implementation are shifting out of national departments of government, to bodies such as the National Electricity Regulator (NER) and various regional energy bodies (see e.g. Marquard & Eberhard, 2000)[3].

On the other hand, the concept of Black Economic Empowerment (BEE) is more and more integrated into the energy sector as a means for addressing social injustices. BEE is an integrated strategy aimed at substantially increase black participation at all levels of the population (BEECom, 2001).

In May 2001, the Cabinet approved proposals for the reform of the Electricity Supply Industry (ESI) through a managed liberalization process. Elements of this are i.a. i) a restructured generation industry, of which ESKOM will retain a share of 70%, with privatisation of the remainder in form of Independant Power Producers (IPPs), transferring 10% to black economic ownership, and ii) a regulatory framework that ensures the participation of IPPs and the diversification of primary energy sources (Eberhard, 2004).

With regards to the liquid fuels sector, SAPIA (2000) developed a charter on empowering Historically Disadvantaged South Africans (HDSAs) in the

[1]see Section 3.4.3

[2]Note that by 2007, no RED was operational.

[3]see Section 3.4.2

petroleum and liquid fuels industry. Its aim is to substantiate the policy objective stated in the Energy Policy White Paper (DME, 1998) to achieve sustainable presence, and ownership or control by HDSAs of a quarter of all facets of the liquid fuels industry.

In 2003, the government released the first Integrated Energy Plan (IEP)[1] (DME, 2003a), addressing the issues of restructuring, social injustice and sustainable energy by providing a framework for decision making on energy policy and for the development of different energy sources and energy technologies in the country.

A rising issue in the era after 2000 is that of environmental concern. Davidson & Winkler (2006) say that regarding the promotion of renewable energy, mostly rural areas have been affected, where poor households are electrified with Solar Home System (SHS) in places where grid electrification is not economically viable; the broader approach known as energisation is also being considered (see Chapter 6).

The government released the White Paper on Renewable Energy (DME, 2002a), stating its commitment to the contribution to the global effort to mitigate GHG-emissions by setting a target of 10 000 GWh of renewable energy by 2013, and presenting a framework within which the renewable energy industry can operate and grow. Moreover, it stated that renewable energy projects that receive Government assistance will be required to incorporate BEE and contribute to job creation.[2]

Furthermore, the government released a draft of the South African Biofuels Industrial Strategy (DME, 2006a). By supporting the integration of biofuels into the South African market, its purpose is to contribute to the country's development goals, renewable energy target, generate employment, and reduce the negative impact of energy consumption on the environment. The policy options presented in the strategy are in line with BEE. Furthermore, biofuels are an element of the Governments Accelerated Shared Growth Initiative of South Africa (AsgiSA) (see Mlambo-Ngcuka, 2006).

[1]see Section 3.4
[2]see Section 3.4

However, issues of environmental protection and social upliftment tend to be concurrent at times. In low-income households, the most effective path to remedying risks related to the usage of unsafe energy sources such as paraffin in low-income households at least partially is electrification; however, electricity is currently affordable by very poor households only because it is produced from very low-grade cheap coal with high environmental impact (Marquard & Eberhard, 2000). This situation is rendered even more difficult by the introduction of a 'poverty tariff', which provides 50 kWh/month of free electricity to poorer households (Davidson & Winkler, 2006).

Davidson & Winkler (2006) conclude that in order to achieve its objective of sustainable development, South Africa needs to substantially increase the supply of modern affordable energy services to all its citizens, while at the same time maintaining environmental integrity and social cohesion.

3.4 Energy Planning in Cape Town

The purpose of this Section is to develop insights into the energy planning process of the City of Cape Town, emphasising renewable energy aspects. In order to do so, it is important to define the legislative policy framework for energy planning in Cape Town. Importantly, the national energy planning and regulation bodies will be presented, as well as the reform of South Africa's EDI. The role of South African local governments will be discussed regarding the energy sector, so that subsequently, the energy planning process of the City of Cape Town can be investigated.

3.4.1 Legislation, White Papers and Frameworks

Currently, several national and local government policy papers and reports define the framework and guidelines according to which Cape Town's energy planning takes place. In the following, the key policies and reports will briefly be introduced in order to locate Cape Town's energy sector in its policy context.

White Paper on the Energy Policy of the Republic of South Africa (DME, 1998). This White Paper clarifies government policy regarding the supply and consumption of energy for the next decade.

Amongst other things, an Integrated Energy Planning process is described. It is stated that a key policy challenge is to link electricity into the municipalities infrastructure plan. Therefore, at local government level, the IEP forms a component of the Integrated Development Plan (IDP). The government will provide the necessary resources to establish IEP structures and systems to develop energy policy.

Furthermore, the need for improved communication between the national, provincial and local government is clearly recognised. Mechanisms for improving communication are i.a. the establishment of provincial energy committees, and the establishment of energy advisory functions within the Department of Minerals and Energy (DME)'s regional offices in order to assist in provincial and local energy planning.

White Paper on the Promotion of Renewable Energy and Clean Energy Development (DME, 2002b). This policy document envisages a range of measures to integrate renewable energies into the mainstream energy economy. To achieve this aim, Government is setting as its target an additional 10,000 GWh (0.8 Mtoe) renewable energy contribution to final energy consumption by 2012, to be produced mainly from biomass, wind, solar and small-scale hydro.

From an urban perspective, it is highlighted in the foreword to the White Paper by Deputy Minister S. Shabangu that *"the easier entry points for renewable energy are generally not in the remote rural areas, but in the urban household and industrial sectors. It is here that the possibilities for solar water heating, and the use of waste for power generation lie".*

It is furthermore stressed that a significant barrier to the further implementation of renewable energy is that many renewable energy technologies remain expensive compared to conventional energy supplies for bulk energy supply to urban areas or major industries.

Integrated Energy Plan for the Republic of South Africa (DME, 2003a). The purpose of the integrated energy plan is to balance energy demand with supply resources in concert with safety, health and environmental considerations. The integrated energy plan is a framework within which specific energy development decisions can be made by national Government.

The role of local government is addressed in connection with the programme for universal access to affordable, clean and appropriate energy. The most important concern is the transition from traditional energy carriers to commercial energy carriers, especially in the rural areas. Energy demand rises with increased energisation[1] (especially electrification) in households. Such energisation programmes should be linked to the integrated development programmes both at provincial and local level. The synergy between regional/local development and energy supply would enable sustainable growth.

National Electricity Regulator - Regulatory Framework for the Electricity Distribution Industry of South Africa (NER, 2004) The regulatory framework has been prepared by the NER as part of the EDI restructuring process in South Africa. This process would combine Eskom's and municipalities' electricity utilities - thus separating electricity generation and distribution operations, and hence opening the sector to competition (see Section 3.4.3). The purpose of this high level framework is to provide a view of the instruments required to regulate the future Regional Electricity Distributors (REDs).

With regard to the relationship with municipalities, the future regulation of the EDI will be founded on a complementary set of rights, obligations and controls, applied through a combination of local and national government arrangements. This will be designed to balance both the constitutional role of local government in local electricity supply, and the requirement for overall consistent regulation of the sector by NER at a national level.

Cape Town Energy Strategy (SEA, 2003a). The overall goal of the energy strategy is to promote sustainable development. Its aspirations are to help integrate sustainable approaches into the core functions of the City, within a

[1]see Chapter 6 for a detailed review of the concept of energisation

framework that provides a clear vision and direction for the City as a whole, and specifically the energy sector. Its aspirations are to facilitate the integration of energy objectives into all the City of Cape Town functions and programmes. Its aspirations are also to improve delivery and financial sustainability in local authority operations; improve air quality; reduce greenhouse gas emissions; and promote economic and social development for the City.

The energy strategy supports the City Vision, Integrated Metropolitan Environmental Policy (IMEP) objectives and the City's IDP, as well as other national and international imperatives and commitments. In the Cape Town State of Energy Report (CCT, 2003), more than 50 energy-related activities have been identified across the City of Cape Town's different departments and within other organisations, with little co-ordination between them. This energy strategy will co-ordinate such initiatives within the City, in order to promote a common energy goal.

Importantly, the City of Cape Town set itself a renewable energy target of 10% of energy generated from renewable sources by 2020.

Draft Energy and Climate Change Strategy (CCT, 2006a) Besides reaffirming its commitment to the renewable energy goal stated in the Energy Strategy (see above), the City of Cape Town proposes with the Draft Energy and Climate Change Strategy a list of quantified targets based on strategic goals related to local aspects of sustainable energy and climate change. The City of Cape Town affirmed its commitment to the achievement of these goals at the WSSD in Johannesburg in 2002.

The energy efficiency and renewable energy targets are summarised as follows, grouped by sector (CCT, 2006a):

- Transport
  - 10% increase of rail transport share by 2010
  - 10% decrease of private vehicles in city centre by 2010
  - Non-motorized transport strategy by 2010
- Commercial & Industrial

  - All facilities to use Compact Fluorescent Lightings (CFLs) by 2010

- Residential
  - 10% of all households and City-owned houses to have SWHs by 2010
  - All City-owned houses to use CFLs by 2010
  - 30% of households to use CFLs by 2010
  - All new houses to have insulated ceilings from 2005
  - All existing houses to be retrofitted with insulated ceilings by 2020

- Government
  - All City buildings to use CFLs by 2010
  - 5% reduction in City-internal electricity consumption by 2010

- Energy Supply
  - 100% of formal houses connected to electricity from 2005
  - 90% of informal houses connected to electricity by 2010
  - 10% renewable energy supply by 2010
  - Reduction of CO_2 emissions by 10% by 2010 (from 2005 levels)

3.4.2 National Energy Planning and Regulation Bodies

The DME is the State organ responsible for ensuring exploration, development, processing and management of minerals and energy resources in South Africa (DME, 2005a).

The NER is the regulatory authority of the electricity supply in South Africa. The primary function of the NER is to license electricity generation, transmission and distributions; to approve electricity tariffs and; to set minimum standards for quality supply and services. The NER recently celebrated its 10^{th} Anniversary, coinciding with the launch of the new National Energy Regulator for South Africa (NERSA). NERSA has a newly expanded mandate, including the functions of NER (NER, 2005).

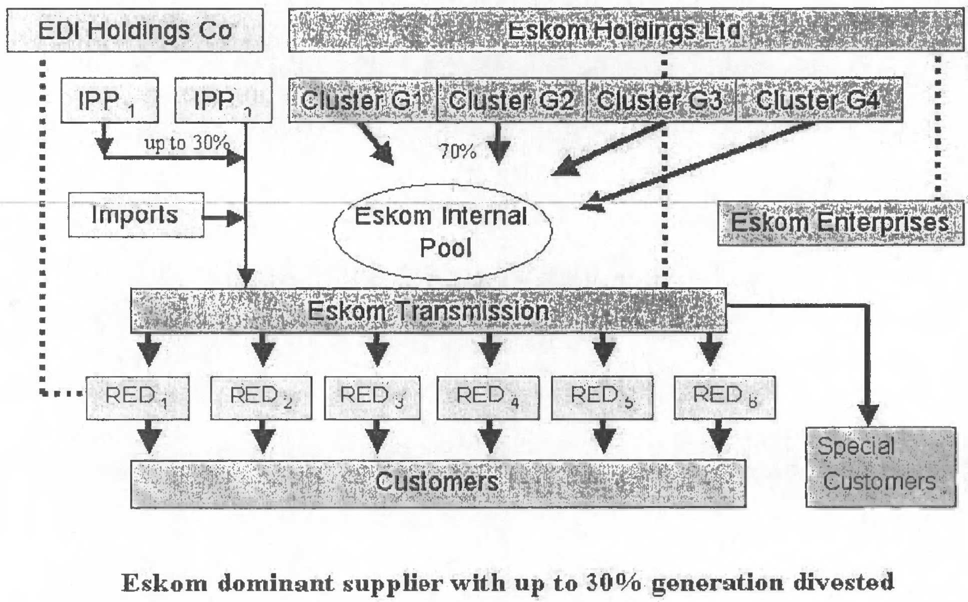
Electricity demand forecasting and supply planning is currently undertaken in a two-tier system, consisting of NERSA's National Integrated Resource Plan (NIRP) and ESKOM's Integrated Strategic Electricity Plan (ISEP). In a report released by DPE (2006) dealing with security of electricity supply in South Africa, it is stated that the current two-tier system is lacking transparency, and calls for an integrated planning solution under the direction of NERSA and not ESKOM, South Africa's state-owned electricity utility.

Regarding the liquid fuels sector, demand forecasting and planning for refining capacity is undertaken by the different member companies of the South African Petroleum Industry Association (SAPIA), both in their individual corporate capacities and through the association.

3.4.3 The Reform of South Africa's Electricity Distribution Industry

The EDI has for some time been characterised by inefficiencies, unreliable and intermittent power supply due to equipment age, and unjust treatment of customers (DME, 2006b). Therefore, the Cabinet approved in 1997 the EDI Interim Committee Report that recommended the restructuring of the EDI into six REDs (DME, 2006b). This process would combine Eskom's and municipalities' electricity utilities - thus separating electricity generation and distribution operations, and hence opening the sector to competition as illustrated in Figure 3.4 (Eberhard, 2001).[1] The proposed six REDs will buy and sell electricity, controlling the distribution network in their respective areas. They will replace the existing distribution networks which have historically been the responsibility of the hundreds of local municipalities and Eskom, who have controlled 41% and 59% of this market respectively (Pickering, 2005). The first RED was signed into operation in July 2005; however the process of establishing the structure is expected to be completed by January 2007 (BUA, 2005). RED 1 is formed by the amalgamation of the City of Cape Town and Eskom Western Region.

[1]See also Regulatory Framework for the Electricity Distribution Industry of South Africa, Section 3.4.1



Source: Eberhard 2001

Figure 3.4: Model of the Restructured Electricity Supply and Distribution Industries

3.4.4 The Role of Local Government in Energy Planning

Local government has in the past played a part in the production and distribution of electricity. Up to 1.3% of the national electricity supply is generated from these sources (Eberhard, 2005). However there has not been any growth in this sector, and no licenses have been issued since 1954.

The restructuring of the electrical distribution sector with the establishment of REDs will require local government to play a secondary role in this sector (see Section 3.4.3). There are, however, a number of roles that municipalities will have to play. Two of these roles are the facilitation of renewable energy projects, and the adoption of energy efficient practices and the implementation of energy efficient policies and bylaws (Austin *et al.*, 2006).

Barriers for local government for maximising their support of RE and Energy

Efficiency (EE) initiatives and practices are as follows (Austin *et al.*, 2006):

- Financial constraints, as they are obliged to spend money on basic service delivery first
- Lack of technical skills particularly in the smaller municipalities around mini-grid electrification, micro-hydro, solar PV, wind, and biogas production.

The following anecdotal evidence, presented by Austin *et al.* (2006), illustrates this second point in a poignant manner:

> *"The lack of focus and understanding into the opportunities available for the production of renewable energy from existing resources combined with the low priority given to energy production over the provision of basic services can lead to situations such, in the present practices by the City of Cape Town's, where a lack of proper maintenance at the Athlone anaerobic sewage digesters has resulted in the venting of over 4 million m^3/a of methane rich biogas to atmosphere. The potential earnings in LPG equivalent from the sale of this waste gas would be approx. ZAR 12 million/a, not to mention the climate impacts of these emissions."*

3.4.5 The Energy Planning Process of the City of Cape Town

In the past, the competencies for energy planning for the City of Cape Town laid with the Development Services and the Electricity Services of the City. With the establishment of REDs, competencies are partly shifted from the City to the RED, in this case RED 1 (see Section 3.4.3). As the restructuring of the power sector into REDs is an ongoing process, it creates gaps, grey zones and interim regulations which render energy planning a fuzzy enterprise, especially regarding the responsibilities of the different planning bodies.

3.4.5.1 Infrastructure for Energy Planning in Cape Town

In the following Section, the energy planning infrastructure for the City of Cape Town will be introduced as given by Figure 3.5 (Haskins & Massey, 2006). A critique of the infrastructure is based on interviews with Gordon Munro, Deputy Director of Electricity Services of the City of Cape Town, and Osman Asmal, Director of Environmental Planning, Development Services of the City of Cape Town.[1]

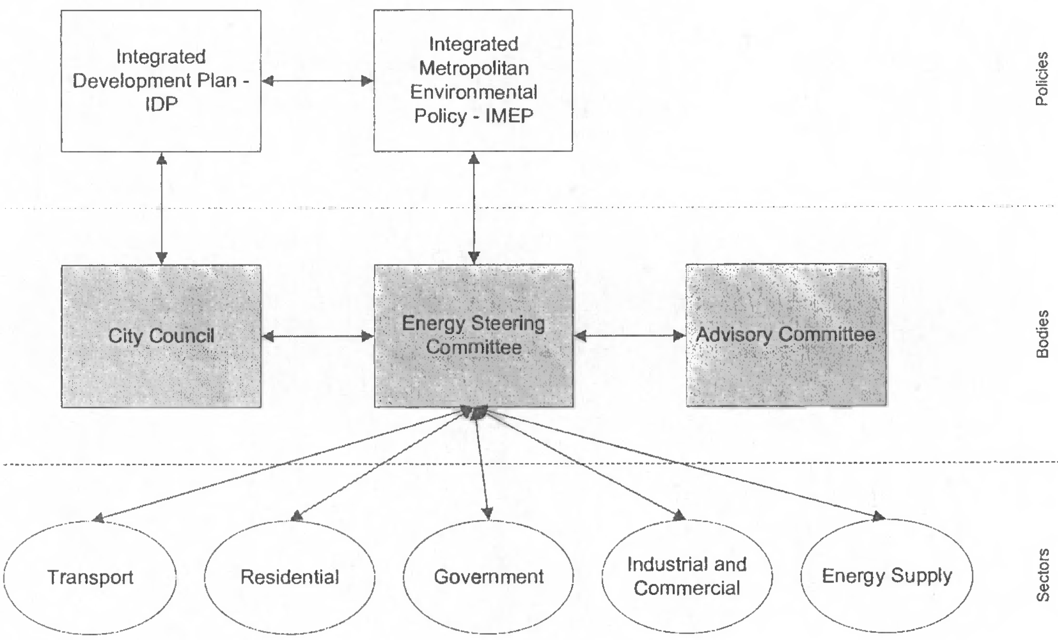


Figure 3.5: Energy Planning Infrastructure - Cape Town

For the City of Cape Town, energy planning is broadly outlined in the communal Integrated Development Plan (IDP), which is updated on a 5 year basis. The plan focuses on social and economic development issues, and guides and informs the budgeting, management and decision making in a municipality (CCT, 2006d).

More focused on energy and environmental issues, a draft Energy Strategy has been compiled for interaction with stakeholders (see Section 3.4.1), as part

[1]See Appendix A for transcripts of qestionnaires utilised for interviews.

of the City's Integrated Metropolitan Environmental Policy (IMEP). The IMEP addresses issues related to the fields of biodiversity, air quality, environmental education and training, coastal and waste management, as well as noise pollution.

An energy steering committee, which is assisted by an advisory committee constituted out of experts from the public and private sectors, as well as academia, undertakes planning and implementation enterprises related to the sectors of transport, government, industry & commerce, residential, as well as energy supply. The energy steering committee reports back to the city council.

Munro (2004) states that *"the City as a whole, and therefore its energy planning bodies as well, are suffering of a shortage of personnel and funds"*. Furthermore, as energy planning responsibilities are not being carried by one single service within the City, but shared amongst mainly two services, namely the Development Services and the Electricity Services, decision making is rendered a complex and time-consuming process. According to Munro (2004), *"strong guidance from federal government is lacking. Broad policies have been formulated, e.g. the White Paper on Energy, but implementation plans, funds and financing models are missing"*.

Munro (2004) says that, *"in order to tackle the field of energy planning holistically, it would be necessary to involve the transport sector as well, not only the responsible City department, but also key industry players such as the oil companies Shell, Chevron and Engen. This is of crucial importance before the background of the fact that 55% of Cape Town's energy demand stems from the transport sector"*. Munro (2004) says furthermore that *"there is a demand for green energy because of industry demand for green products to be sold overseas, putting pressure on our energy supply infrastructure to become more sustainable"*. Note that an aim of the City is also to become less dependant from Eskom (Munro, 2004).

According to Asmal (2004), *"more than 50 energy related projects have been identified in Cape Town, which form the backbone of Cape Town's State of Energy Report"* (see Section 3.4.1). Asmal (2004) says furthermore that *"the formulation of Cape Town's Energy Strategy has been lead by a team of people stemming from different City departments and independent consultants, e.g. from UCT Energy Research Centre and Sustainable Energy Africa. This team had to report to the city council consisting of 220 councilors"*.

3.4.5.2 Renewable Energy Planning in Cape Town

Regarding renewable energy planning, the City of Cape Town set itself a challenging renewable energy goal, namely 10% of its energy needs met by renewables by 2020 (see Section 3.4.1). According to CCT (2003), Cape Town has a wealth of untapped renewable energy resource potential available for achieveing this goal - primarily in wind, small-scale solar, and possibly wave applications.

In the following, four projects out of a number of sustainable energy projects happening within the CMA will be introduced and discussed, illustrating the diversity of issues informing the planning process. They all involve the City of Cape Town, and are at different stages of the planning and implementation process.

The Darling Wind Farm Project In pursuit of its renewable energy goal, the City of Cape Town is the first South African city having agreed on a contractual basis to buy green electricity from an IPP over a period of 20 years, namely the Darling Wind Farm project, situated at about 70km north of Cape Town (WWINDEA, 2006).

The implementation of the project with a final total installed capacity of 13 MW is structured into two phases (DME, 2005a):

- Phase 1 comprises four 1.3 MW wind turbines
- Phase 2 comprises a further six 1.3 MW wind turbines

The first four wind turbines, which are expected to arrive in September 2007 from Germany, will generate approx. 13.2 GWh/a of electricity. The total investment in the project is >ZAR 70 million, of which at least 30% will enter the local economy (Pollack, 2007).

By reaching a favourable Power Purchase Agreement (PPA) with the Oelsner Group, the main shareholder of the Darling Independent Power Producer (Darling IPP), the City agreed to buy generated electricity upon commissioning of the project (DME, 2005a). Customers of the residential, commercial and industrial sector in Cape Town will be able to purchase the generated renewable electricity at a premium of ZAR 0.25/kWh.[1] It is guaranteed that units purchased will be matched by the input of the same number of units from the Darling Wind Farm into the national grid (Pollack, 2007).

The planning of the Wind Farm was mainly undertaken by the Oelsner Group with support from AN Windenergie GmbH, Germany, and Bonus Energy, Denmark. Support in terms of assisting in the development of an on-grid wind energy programme in South Africa was provided by Danida (former DANCED), the UNDP, and the Global Environmental Fund (GEF) (DME, 2005a).

The project was first proposed in 1997, and an Environmental Impact Assessment (EIA) was undertaken between August 2001 and January 2002. No critical issues were identified preventing the construction of the first phase. It was recommended that the second phase should only be approved after a positive monitoring of the first four wind turbines (DME, 2005a).

However, there have been meaningful delays in the planning process, caused amongst other things due to (DME, 2005a):

- The IEA (A further update had to be carried out in 2004)
- Identification and negotiation of a PPA
- Negotiations and agreements for access to an use of the grid

The proposal for the wind farm was subject to legal wrangles with the authorities over a period of six years, which were eventually settled out of court at the beginning of 2005 (Gosling, 2005).

The project was finally accepted when Environment Minister Marthinus van Schalkwyk turned down the only appeal to this decision in July 2005. Against the background that the Darling Wind Farm has been declared a demonstration project at the WSSD in Johannesburg in 2002, the minister stated furthermore in connection with South Africa's commitment to actively target implementation of renewable energy measures that *"demonstrating the feasibility of small, decentralised, clean power generation facilities was important in order to create*

[1] The premium will have to be paid in addition to the basic tariff for private end-consumers of ZAR 0.45/kWh; the total price per kWh of wind generated electricity will thus amount to ZAR 0.70.

jobs and eradicate poverty through the creation of SMME opportunities" (Gosling, 2005).

It is estimated that the reduction of GHG-emissions will amount to approx. 254,000 t over the lifespan of the project (Pollack, 2007). Further benefits of the project are job creation. It is estimated that 15-19 jobs will be created for each MW of electricity produced. Furthermore, 30 jobs will be created in connection with activities related to the wind farm (DME, 2005a). Against the backdrop of a Sustainable Environment and Employment Scheme (SEES), the wind farm shall attract tourists especially to its educational and research centre (DME, 2005a).

The Solar Water Heater By-Law The City of Cape Town has drafted several implementation plans regarding the usage of renewable energy technology or energy efficiency measures, amongst other things the Solar Water Heater (SWH) by-law, which it is expected to pass in July 2007. The objective of this by-law is to regulate the incorporation of SWH for the production of sanitary hot water in buildings in Cape Town Metropolitan Area in order to (Nielsen & Bengtsson, 2006):

- Reduce the use of electricity and fossil fuels and their related environmental impacts, such as carbon dioxide, sulphur dioxide and nitrous oxide emissions (CO_2, SO_2, NO_3)
- Create local jobs in the solar water heating industry
- Reduce energy supply risks
- Alleviate poverty by improving the quality of life through the provision of hot water to those who can not access or afford electricity

Against the backdrop of a national electricity utility (ESKOM) struggling to meet energy demand with fossil-fuel based electricity, Cape Town aims to substantially reduce its electrcicty consumption in the residential sector, improve its energy security, and lower GHG-emissions by implementing this by-law (CCT, 2007).

The City set itself the target to install SWHs in 10% of the households by 2010, and 50% by 2020, bearing in mind that the residential sector accounts for 17% of electricity consumption on the national level, and that electric water geysers are accountable for the highest electricity consumption on a household level (CCT, 2007). Osman Asmal, the city's director of environmental planning, said in an interview with a local newspaper that *"the City has 10% targets for both the number of city households to be fitted with solar geysers and for renewable energy as a percentage of the overall energy consumption, both by 2010. [...] Recently, one of our partners reminded me of what that target meant, and it threw me back a little - it means putting in 1000 solar water heaters a month. That's ambitious, and it's going to be an interesting task for us to try and pull that off"* (Yeld, 2006).

The installation of SWHs will be compulsory from the date of the enactment of the bylaw for all new buildings and all existing buildings where additions are made which require the use of hot water (CCT, 2007).

The City will not itself finance the fitting of solar geysers. Asmal conceded that *"from a straight financial viability point of view, calculated in terms of traditional economics, fitting solar geysers is probably financially unsound"*. Sources of financing could be provided by ESKOM, Absa Bank, the government's central energy fund, or the CDM fund (Yeld, 2006). In an interview with another local newspaper, Liz McDaid of sustainable development company Green Connections stated that *"a big block to the move to solar water heaters was that the city had not offered incentives. It might appear to the City that this would be a financial loss, but given the implications to the economy of three-hour [electricity] blackouts, it certainly would make good financial sense in th elong term"* (Gosling, 2006). The ESKOM power-blackouts have cost the Western Cape economy hundreds of millions of rand.

However, a press release by the CCT (2007) came up with the following figures regarding the financing of the installation of SWHs. Based on a life expectancy of 15 years, the payback time for the investment in a solar water heater is expected to be 3 to 7 years without any additional subsidisation, and up to 3 years considering a subsidisation from a planned ESKOM financing scheme.

Regarding the planning process of the by-law, Asmal states that *"the City has been working since 1998 with a non-governmental organisation, Sustainable Energy Africa, in looking at sustainable energy. Through the organisation, the*

City has obtained funding to bring out the Danish experts to help draft the bylaw" (Yeld, 2006).

Energy Upgrade Project for Kuyasa Low-Income Housing At the basis of the Energy Upgrade Project stands a housing project of ZAR 95 million, consisting of the construction of 2,300 brick houses in Kuyasa, Khayelitsha, built by means of the South African People's Housing Process (PHP) (CCT, 2006e).

Thereupon, the City of Cape Town developed the Kuyasa Low-Income Housing Energy Upgrade Project in partnership with the non-profit development organisation SouthSouthNorth over a period of three years. It consists in retrofitting these 2,300 low-income households with energy efficient lighting, insulated ceilings, and SWHs (REEEP, 2005a). The objectives of the project include the following (REEEP (2005a) and CCT (2004)):

- Reduction of GHG emissions through energy efficiency measures and the utilisation of alternative energy sources on a household level.
- Provision of sustainable development benefits such as access to energy services, and employment creation.
- Reduction of of local air pollution, with subsequent decrease in carbon monoxide poisoning and respiratory illnesses.
- Reduction of household energy costs through reduced energy demand and consumption, making more disposable income available for the residing poor families.
- Reduction in number of accidents, damage to property and loss of human life as a result of fires.

The Kuyasa Housing project has first been designed as a CDM project under the Kyoto Protocol (see Section 2.2.2.3), qualifying for carbon finance through the international carbon market (REEEP, 2005a). The project is expected to generate emission reduction credits over a period of 21 years, and to produce emissions reductions of 2.7 tonnes of CO_2 per household and year (CCT, 2004).

Interestingly, the traditional development route of these households would be altered by leap-frogging to energy efficiency and renewable energy measures, instead of going through a development path coupled to an increased consumption of fossil-based energy carriers: Environmental protection is linked to poverty alleviation. This argumentation created a case of precedent, according to which other poverty alleviation projects would fall under the CDM, enabling these projects to access an important source of finance (REEEP, 2005a).

A pilot project was launched in 2003 comprising 10 households, aiming at identifying patterns of energy usage and related emissions. Furthermore, an assessment of available technologies has been undertaken, in order to identify the best suited options for the project. The local company AGAMA was contracted for retrofitting the households with the help of local labour. Importantly, the concerned community was involved at all times in the planning process, and contributed to the financing of the project. The latter posed an important problem, as the additional funding from the CDM carbon income was not sufficient. Additional funding came eventually from the Provincial Government and the Poverty Alleviation Fund (REEEP, 2005a).

It was furthermore aimed to create a project which is replicable in other South African settlements, which is of particular importance against a background of 1.5 million low-income households in South Africa. It is however stated by Dr. Marianne Osterkorn, Renewable Energy & Energy Efficiency Partnership (REEEP) international director, that *"considerable barriers exist to such an expansion, particularly in financing"* (REEEP, 2005b).

In connection with an awarded joint third place in the international Point's Carbon Best CDM Project 2004 Competition, Shirene Rosenberg, SouthSouthNorth project manager, states that *"[...] SouthSouthNorth is proud that our learning-by-doing approach and commitment to the benefits of sustainable development is being recognised on the world stage"* (CCT, 2004).

The Cape Flats Wastewater Works The Cape Flats Wastewater Works is Cape Town's largest sewage treatment station, designed for a throughput of 200Ml/d, running at approx. 80% capacity (Water Wheel, 2003).

The wastewater works have been fitted with equipment worth ZAR 60 million for the dewatering, drying and pelleting of the produced sewage sludge. The objectives of this investment are to reduce the quantities of sewage sludge that need to be disposed, to incorporate innovative recycling loops for a reduced fuel consumption at the treatment station, and to produce an energy by-product suitable for fuel substitution in a number of industrial applications (Water Wheel, 2003).

The starting point of the project was the fact that the disposal of sewage sludge in the direct surroundings of the wastewater works was no longer feasible in terms of land constraints and environmental threat. The sludge had to be transported to landfill sites, which resulted in additional costs. By reducing the volume of the produced sludge from 2000m^3 to 50m^3 by dewatering and drying it, considerable costs related to transport and disposal are saved. The costs for disposal of $10m^3$ of sludge are estimated at around ZAR 1,800. From an environmental perspective, emissions related to transport are reduced, and landfill airspace is saved. Furthermore, an estimated ZAR 10-15 million are saved on fuel due to a novel recycling system (Water Wheel, 2003).

Based on a personal communication with Michael Toll (Toll, 2005), chief engineer of the Cape Flats Wastewater Works, a flowchart representing the energy recovery infrastructure of the works has been designed. As can be seen in Figure 3.6, an amount of 65m^3/h of raw sewage is fed into the anaerobic digesters, which in turn produce a sewage sludge with a water content of 96%, and 1,200m^3 of methane. The methane is stocked in a 2,000m^3 gas holder. The sludge from the anaerobic digesters is dewatered in a centrifuge, resulting in a 40t/d of sludge with a water content of 80%. 8t/d of this sludge are disposed of as cake, whereas 32t/d are fed into the drying plant, which is partly fuelled by the methane stocked in the gas holder. A total amount of approx. 10m^3/d of dry sludge with a water content of 5% are obtained. This sludge is used in the pelleting unit for producing approx. 7t/d of pellets. The condensate obtained from the drying process is passed through a heat exchanger, which allows to recuperate heat in form of water at 70°C, used for maintaining the temperature of the digesters. Furthermore, methane is utilised for feeding the boilers which heat the digesters. As the obtained end product, i.e. bagged pellets, has a high calorific value, and can

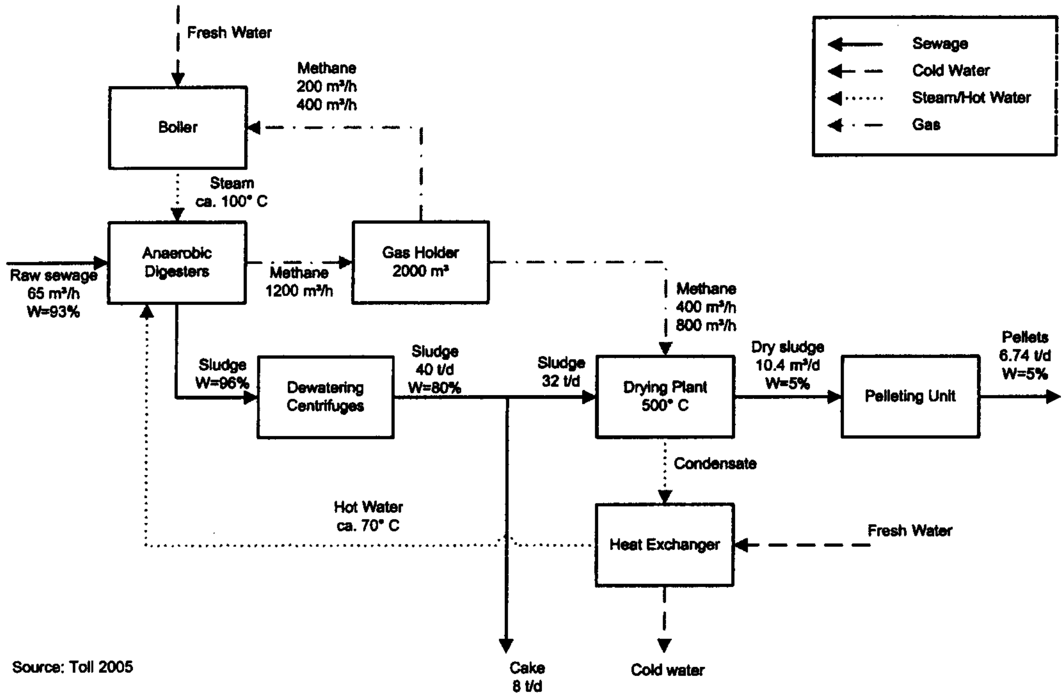


Figure 3.6: Cape Flats Wastewater Works - Flowchart Energy Recovery

therefore be potentially utilised as fuel substitute in e.g. the brick and cement manufacturing industry. At the point of writing, it is known that PPC cement partly substitutes its fuel needs with the pellet product, which can be obtained for free at the wastewater works.

In terms of the planning approach, a team of municipal engineers embarked on a field trip to Europe in order to collect information regarding the state-of-the-art in sludge management practices. Criteria for the choice of a technology were technical suitability and cost-effectiveness. Finally, it was opted for the Swiss Combi system of direct thermal sludge drying after centrifugal thickening and dewatering. The technology could be coupled with the infrastructure in place at the wastewater works, resulting in a number of interesting synergies regarding the cycling of material and energy flows. The local consortium Biwater-Murray and Roberts JV was awarded the tender to build the plant, and will operate it for the first five years (Water Wheel, 2003).

3.4.5.3 Discussion on Cape Town's Energy Planning Approach

In the following, the four presented projects will be briefly discussed in order to highlight the City's involvement in their respective planning and implementation processes.

With regards to the Darling Wind Farm Project, which was basically planned and rolled out by the private sector, the City intervened during the implementation phase as partner in the Power Purchase Agreement (PPA), assuring the project's economic viability. The project has been motivated by a classic environmental driver - i.e. the supply of renewable electricity -, typical for Northern countries, as it is illustrated by the fact that the countries involved are Germany and Denmark.

The SWH by-law has been developed by the City of Cape Town in partnership with Danish experts within the frameset of LA21 in order to contribute to the City's renewable energy target. Although the by-law focuses specifically on a technical intervention, i.e. the installation of SWHs, it remains broad regarding the means of implementation, especially in terms of financing. Furthermore, it becomes apparent that theoretical goals and practical implementation have not been matched, when the city's director of environmental planning states that it "threw him back" to hear that the set targets will imply an installation of 1000 SWHs a month.

Although each of the four projects presented here include issues of environmental protection and economic development, the Energy Upgrade Project for Kuyasa Low-Income Housing is a typical South-North project, in the sense that it addresses Southern development issues by linking environmental protection to poverty alleviation, whilst being financed by Northern sources via the Clean Development Mechanism (CDM). The City is actively involved in the planning process with the assistance of SouthSouthNorth and the concerned population. A case of precedent and a template for replication is created by adopting a learning-by-doing approach.

Initially, the Cape Flats Wastewater Works project was not a renewable energy and energy efficiency project. The main driver was of technical, environmental and financial nature, based on the fact that sludge could no longer be disposed at the surroundings of the station. The planning for the implementation of a dewatering and drying plant to the station was undertaken by the wastewater department, and not by one of the services responsible for energy planning within the City. A renewable energy carrier was obtained as end-product, and innovative material and energy cycling lead to energy efficiency measures and financial savings (win-win situation). Interestingly, the dewatering and drying plant is run by a private consortium, successfully demonstrating the establishment of a Public-Private Partnership (PPP).

3.5 Conclusion

The aim of this Chapter was to describe an approach for urban renewable energy planning in the South based on the case of the City of Cape Town.

By presenting Cape Town's energy picture, it was shown that the City heavily relies on fossil fuels. The City addresses these issues by releasing an Energy Strategy and formulating a renewable energy target, although displaying a lack of understanding regarding the richness of possibilities for their implementation.

On the other hand, a presentation of the national history of energy policy revealed that a main challenge for South Africa is to adjust social imbalances rooted in the country's past. Regarding the energy sector, this issue is addressed by means of the South African electrification programme, and the implementation of Black Economic Empowerment (BEE) into energy policy. Furthermore, inefficiencies in the energy sector are tackled by the restructuring of the Electricity Distribution Industry (EDI) and the involvement of Independant Power Producers (IPPs). A concern of rising importance is that of environmental protection, dealt with by means of policy and legislation aiming at the introduction of renewable energy and energy efficiency measures. It becomes apparent though that environmental protection and social upliftment are sometimes conflictive.

Against these backgrounds, it was asked why a South African city like Cape Town, faced with huge governance, development and infrastructure problems, sets itself a challenging renewable energy target?

It was shown that the City's planning process is embedded within a framework of national and local government policy papers and reports, providing a set of broad strategic guidelines. Whereas the responsibilities for national planning and regulation of the energy sector lie with the Department of Minerals and Energy (DME) and the National Energy Regulator for South Africa (NERSA), demand forecast and supply planning for electricity and liquid fuels is collectively undertaken by bodies from the public and the private sectors. Through the restructuring of the EDI, competencies regarding electricity distribution are moved away from municipalities towards regional bodies (REDs). It is observed that the role of South African municipalities shifts towards the facilitation of renewable energy and energy efficiency projects.

By analysing the energy planning process of the City of Cape Town, it has been shown that on the one hand, the City is hampered in its approach by a shortage of personnel and funds, a lack of guidance and technical skills, complexities in its planning infrastructure, as well as fuzziness in responsibilities emerging from the restructuring of the EDI. The City undertakes broad strategic planning and formulates bold renewable energy and energy efficiency targets, but an implementation gap becomes apparent, especially in terms of incentives and financing schemes, as has been demonstrated for the case of the SWH by-law.

On the other hand, renewable energy and energy efficiency projects are currently carried-out within the Cape Metropolitan Area (CMA), and the City displays a talent for improvisation and flexibility regarding its involvement in the planning and implementation process, with or without the assistance of external partners. It assures economic viability of the Darling Wind Farm project by acting as partner in the Power Purchase Agreement (PPA); it couples environmental and social issues - a typical Southern challenge - in the Energy Upgrade Project for Kuyasa Low-Income Housing, assuring Northern financing through the Clean Development Mechanism (CDM); it drafts a by-law for the installation of SWHs, coupled to a challenging implementation target; and it demonstrates in the case of the Cape Flats Wastewater Works that renewable energy and energy efficiency measures can be planned and implemented by a City service not as such responsible for sustainable energy matters, furthermore creating an interesting Public-Private Partnership (PPP).

The renewable energy planning process will be described in detail for the case of Aachen in the following Chapter, which gives the opportunity to compare and discuss both planning approaches in Chapter 5.

3. URBAN RENEWABLE ENERGY PLANNING IN THE SOUTH: THE CASE OF CAPE TOWN

Chapter 4

Renewable Energy Planning in the North: the Case of Aachen

4.1 Introduction

It is the aim of this Chapter to investigate the framework and the dynamics of the energy planning process of the City of Aachen, a pioneering city of the North in the context of urban renewable energy use. Throughout this Chapter, it will be aimed at answering the following question:

"What can be learned from the renewable energy planning process of a city of the North, which can be useful for a city of the South?"

The outcomes of this Chapter will allow to draw conclusions on the transferability of elements of the renewable energy planning approach of the City of Aachen to cities in developing countries. Furthermore, a basis will be formed upon which the fundamental differences between renewable energy planning approaches for cities of the North and the South can be highlighted. A comparative analysis of a city of the North and a city of the South will be carried-out in Chapter 5.

The case study on Aachen considers four key elements. In a first step, Aachen shall be situated in its historical context of renewable energy planning. Here, it shall be shown how the City of Aachen dealt with the different challenges in the field of renewable energy usage during the last decades. The second element is a status quo analysis and a brief projection regarding the energy sector of the City of Aachen. It will be investigated which energy resources are used, and what the potentials of renewable resources are. The third element emphasises the investigation and description of the decision making process that lead to the planning of a wood gasification plant in Aachen. This will give insights into planning processes regarding renewable energies in the City of Aachen based on a practical example. Eventually, further potentials of energetic usage of wood based materials within the city boundaries will be identified and discussed. This last element is of special importance regarding the level of detail regarding data collection in comparison to a city of the South (see Chapter 5), and the comparison of results for the MFA carried-out for wood-fibre based material streams in Cape Town under Chapter 7.

4.2 Method of Data Gathering

For this Chapter, the method of data gathering is mainly based on i) completed studies commissioned or initiated by the City of Aachen or the Public Services Company of the City of Aachen - Stadtwerke Aachen AG (STAWAG), and ii) interviews with key players in the field of renewable energy planning in Aachen. These interview partners are cited as follows in alphabetical order with their respective position:

- Dipl.-Ing. Wolf von Fabeck, Honorary Director and Founding Member of the Development Association for Solar Energy, Germany (Solarenergie Förderverein Deutschland e.V. (SFV))
- Dipl.-Ing. Dirk Heckmann, Project Manager, Technical Marketing of Non-Conventional Energy Solutions, STAWAG
- Dipl.-Ing. Klaus Meiners, Head of the Division for Immission Control, Department for Environment of the City of Aachen
- Dipl.-Ing. Leonhard Unterberg, Project Leader, STAWAG Energie GmbH

- Dr.-Ing. Christian Wirtgen, Chief Engineer of the Coking, Briketting and Thermal Waste Treatment Group (KoBrA) of the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University, and Leader of the Coordination Office for Biomass

4.3 History of Energy Planning in the City of Aachen

The history of energy planning of the City of Aachen is strongly interlinked with the history of energy planning of Germany and Europe. Thus, the following Section will start with the enactment of the first law on energy economy in the year 1935 in order to concisely describe the economical, political and legislative development of the framework for energy planning of the City of Aachen. Eventually, a special emphasis will be laid upon the dynamics between the sectors of waste management and energy in order to find out to which degree this interface has already been considered in Aachen's energy policies.

4.3.1 The Beginnings of a Regulated Energy Economy

The following passage has been summarized and translated from Hufmann & Meiners (1991).

"Energy in its variety of forms is necessary and essential for the economic development of Germany and the wellbeing of its citizens." (Engelmann, 1990). Therefore, the energy sector is considered as a key industry (motor of the economy), delivering an important basic product to the whole economy.

Energy politics of the Federal Republic of Germany orientates itself at the Energy Industry Act (Energiewirtschaftsgesetz (EnWG)), 13.12.1935, a law that was issued under the Third Reich period. Energy policy was in line with the maxim of most secure and cost-effective energy supply. Step by step, these goals shifted in priority, and new energy policies gained in importance (e.g. protection of environment and resources).

In the 1950s and 1960s, especially the aspects of security of supply and international competitiveness of the German industry were predominant (Hohmeyer, 1989). The goals of energy policy were to acquire new energy resources in order to broaden the variety of energy carrier supply, as well as to inhibit energy price augmentations (Jochimsen, 1984).

4.3.2 The Birth of a Sustainability Mindset

The oil price crises occured in 1973 and 1979. At that time, the USA and the current Organization of the Petroleum Exporting Countries (OPEC)-states were the essential oil producers. After the USA had surpassed their production maximum, the OPEC-states, only accounting for 38% of total oil production, were able to trigger an offer restriction and a substantial increase of the oil price due to a reduction in oil production (Schindler & Zittel, 2000).

At the beginning of the 1980s, after both the oil price crises and the acknowledgment that the stock of fossil resources is limited (Euler, 1984), the environmental consequences of an unlimited growing energy consumption shifted to the focal point of the discussion on energy politics. A readjustment of the energy-political course became necessary. This is also stated by the fact that the most important environmental issues are still closely related to energy politics and energy economy (von Weizsäcker, 1988). The restructuring of the energy economy developed itself to a task of high political and economic weight (Euler, 1984).

Meiners (2005) states that *"the discussion around finite reserves of fossil resources and the protection of environment and climate had led to the consideration of alternatives to the conventional energy production based on fossil energy carriers. Possible alternatives were by then renewable and nuclear energy. Eventually, the usage of nuclear energy revealed to be coupled to comparatively high environmental risks, which led Germany to phase out its nuclear energy program, i.a. due to high pressure from environmental activists".*

4.3.3 Development of the "Aachener Modell"

Up to the end of the 1980s, environmentally concerned political parties, most notoriously the left-wing party "Die Grünen", kept the discussion alive around the topics of environmental protection, finite fossil resources and the phasing out of the nuclear program, although taking a rather passive and destructive position.

(Meiners, 2005) states that *"at the beginning of the 1990s, a change of paradigm within the party Die Grünen led to its active participation in the shaping of a sustainable energy supply landscape in Germany, which could be felt in the City of Aachen as well"*.

In the period 1991-1994, the much cited "Aachener Modell" was developed. A question which had to be answered - acknowledging that the development of renewable energy technology could not be stopped anymore - was based on the prevailing ambiguity as to when renewable energy technology should be introduced. From a microeconomic point of view, free market dynamics would allow renewable energy technologies to penetrate the market place only once these technologies would be economically viable alternatives to their fossil counterparts. From a macroeconomic perspective, external costs would have to be considered, which would create an advantageous climate for the introduction of renewable energy technologies due to the pressure of minimizing costs; a side-effect would be the increase of job creation due to economic stimuli triggered by the development of new technology. The City of Aachen decided to adopt the macroeconomic perspective, and developed a subsidization model for renewable technologies ("Aachener Modell") in order to accelerate their market penetration.

In 1994, the introduction of the Aachener Modell was adopted by the city council of Aachen (Meiners, 2001). In the period from 1995 to 1999, the public service companies of the City of Aachen, STAWAG and Aachener Straßenbahn und Energieversorgungs-AG (ASEAG), mainly supported the erection of photovoltaic installations by buying the generated electricity fed into the public grid. The buy-back price for generated electricity was set to DM 1.76/kWh (ca. ZAR 7/kWh). The amount was contractually guaranteed for the technical lifespan of the installation. The Aachener Modell was at first restricted to the financing of photovoltaic and wind powered installations.

The City of Aachen made a budget of ca. €1.5 million (ca. ZAR 12 million) available for the realization of the Aachener Modell. This subsidization model was financed by redistributing the costs to the totality of standard electricity customers. This resulted in an increase of the price for electricity of 1%. As the Aachener Modell was introduced before the liberalization of Germany's electricity market, and Aachen's citizens being obliged to buy electricity from the communal authorities, the price increase was quite easily introduced.[1]

A countrywide impulse was noticeable at this point in time, as several cities beside the City of Aachen started simultaneously with the implementation of renewable energy concepts. When big industrial companies such as Siemens Aktiengesellschaft (AG) and Bayer AG decided to invest in renewable energy technology, the market development was definitely started.

Eventually, a total of 240 photovoltaic projects were or still are being financed via the Aachener Modell with a total capacity of ca. 1,000 kW (Stadt Aachen, 2001). Besides the environmentally sound effects achieved via the focused support of renewable energy technologies, the manufacturing of photovoltaic cells started in Aachen, consolidating the city as a business location.

Due to an innovative energy planning approach, and the implementation of a renewable energy financing model, the efforts of the City of Aachen were finally accredited when the Aachener Modell was adopted as the basis for the development of the German Renewable Energy Sources Act (EEG) introduced on the 1.4.2000.

The introduction of the EEG triggered a nationwide boom in the entire field of renewable energies. As for the Aachener Modell, the subsidization via the EEG is financed through the redistribution of overhead costs to the standard electricity customers. The introduction of the EEG notably caused a decrease of investments in PV-projects in Aachen, as the subsidization is lower than the subsidization via the Aachener Modell (von Fabeck, 2005).

BMU (2007) sates that the generation costs for fossil based electricity amounts to approx. €0.02-0.05/kWh in 2006, whereas the EEG-subsidisation for electricity generated from renewable sources is on average €0.10/kWh for the same year. Especially regarding the different renewable energy sources, meaningful differences can be observed. Whereas the subsidisation for wind-generated electricity is approx. €0.15/kWh, electricity generated via PV-solar systems amounts to approx. €0.52/kWh, a factor 10 bigger than the generation price for fossil based

[1] It has to be noted that socio-political activists were against the redistribution of the costs to the totality of the population, as economically weaker population groups would be disadvantaged.

electricity. Biomass-based electricity is subsidised with approx. €0.15/kWh. These numbers show that electricity generated from renewable energy sources is not yet competitive with its fossil fuel based alternatives. Meiners (2005) states that the renewable energy market developed itself slower as initially expected.

4.3.4 Current Policy Framework

Currently, the policy framework for renewable energy planning for municipalities in Germany is mainly regulated by three key documents, which will briefly be introduced in the following Section. There is no additional legislation emitted on the municipal level to foster the growth of the renewable energy market.

4.3.4.1 EU Directive on Renewable Energy Sources

The European Union (EU) Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Energy Market (EU, 2001) was adopted on the 27.10.2001. The purpose of this directive is to create the basis in the electricity sector for doubling the share of renewable energies to 12% of the total EU energy consumption until 2010. The share of renewable energy sources in the electricity production of the entire EU shall then increase from 14% in 1997 to ca. 22% in 2010.

In order to achieve this goal, indicative goals are set for the member states regarding the share of renewable energy sources in their electricity production. For Germany, this goal is set to be 12.5% by 2010. This corresponds to a doubling of the 6.25% in 2000. The member states are responsible for the means they utilize for achieving these goals. The role of municipalities has not explicitely been adressed.

4.3.4.2 German Energy Industry Act

In Germany, energy regulation is mainly subject to the German Energy Industry Act - Energiewirtschaftsgesetz (EnWG) - which is federal law. A new EnWG (BMU, 1998) dealing with the general structure of electricity and gas markets came into effect on 29 April 1998, and is directed towards the liberalization and deregulation of the German electricity and gas markets with the intention to lower prices for electricity and gas to a competitive level within the European common market. The amending law serves to implement the EU directive concerning common rules for the internal market for electricity into national law, in particular by changing the EnWG of 1935 (see Section 4.3).

According to the Federal Department of Environmental Affairs (BMU, 2005a), a further step towards the liberalization of the German energy market has been achieved by the new amendment of the German Energy Industry Act (BMU, 2005b) on the 1st of July 2005. Due to a growing competition in the energy sector, energy supply will become more user-friendly, and energy prices will decrease in the long-term. The support of renewable energies as promoted by the German Renewable Energy Sources Act has fully been integrated to the Energy Industry Act, and is furthermore supported by additional guidelines.

The responsibility of energy provision lies no longer with the municipalities as governmental bodies as such, but with the energy provider with the majority of connections in a specific area of the grid (e.g. public/private sector companies). The responsibility of energy provision does not apply if the connection and provision of a potential customer is not commercially viable.

4.3.4.3 German Renewable Energy Sources Act

The German Renewable Energy Sources Act (EEG) was issued on the 29^{th} of March 2000. Its latest amendment was on the 21^{st} of July 2004 (BMU, 2004), and it is binding in its current form since the 1^{st} of August 2004.

It is the aim of this law to protect nature and environment, to contribute to the avoidance of conflicts around fossil energy resources, and to support the further development of technologies for the generation of electricity based on renewable energy. Furthermore, it is the aim of this law to contribute to the achievement of the renewable energy goals of the Federal Republic of Germany, namely 12.5% of electricity supply based on renewable energy by 2010, and 20% by 2020 (see EU Directive on Renewable Energy Sources).

This law regulates the prioritized connection of plants for the generation of electricity based on renewable energy to the general electricity supply grid, the prioritized take-over, transmission and remuneration of this electricity by the grid operators, and the countrywide balancing of the provided and remunerated electricity.

The Renewable Energy Sources Act defines a financing mechanism in order to attract investment from private and public sectors in the field of renewable energies in the recently privatized energy sector (see 4.3.4.1).

4.3.5 Energy Planning in the City of Aachen

The Office of Environmental Affairs (Umweltamt) and the Energy Advisory Board (Energiebeirat) are the two institutions of the City of Aachen dealing with energy matters. The Public Services Company of the City of Aachen (STAWAG), initially being a private company owned by the City of Aachen, became a Public Limited Company (PLC) in 1967, the majority of its shares belonging to the City of Aachen.[1] See Appendix ?? for the STAWAG holding organigram.

The STAWAG supplies as a multi-utility company the domestic, commercial and industrial sector with electricity, gas and heat via its grids.[2] The lion share of energy fed into the grids is supplied by third party energy providers such as Rheinisch-Westfälisches Elektrizitätswerk (RWE) AG[3] and E.ON AG[4]. In 2003, the STAWAG contributed 0.25% to the electricity supply from own plants (Combined heat and power (CHP) plants and natural gas expansion plant); regarding the supply of district heat, the STAWAG contributed ca. 17.1% (STAWAG, 2003).

According to Meiners (2005), *"integral energy planning is not anymore undertaken by the City of Aachen. In 1994, the City of Aachen released a framework energy concept (ENERKO, 1994), which turned out to be too rigid. As the key challenges in the field of renewable energies are generally known, the City shifted to the publication of implementation-oriented part-concepts such as the 'Action*

[1]The STAWAG has got 2 Chief executive officers (CEOs) (Dr. Dieter Attig and Dieter H.H. Stolte), as well as an executive board being constituted of 15 political members (chief mayor, city director, worker's representatives, chamber members, as well as expert citizens) (Stadt Aachen, 2004).

[2]The STAWAG also supplies water, which is not of relevance in this context.

[3]www.rwe.de

[4]www.eon.com

Plan for Climate Protection 2010' ('Handlungskonzept Klimaschutz 2010') (ENERKO, 1998)[1] *and the development and implementation of projects".*

Meiners (2005) says furthermore that *"there are no fixed renewable energy targets for the City of Aachen either"*. Since the deregulation of the German energy market by the new German Energy Industry Act of 1998 (see Section 4.3.4.3), local government has less authority over the energy sector as before, where citizens were obliged to buy their energy products from the local authorities. Germany relies on existing energy market dynamics for the achievement of its renewable energy goal set by the EU (see Section 4.3.4.1). It actively promoted a price advantage for renewable energies via the EEG (see Section ??). Local government, i.a. the City of Aachen, supports the created market platform. In case the renewable energy goals set by the EU are not met, investments in this sector must be rendered even more attractive, mainly by increasing subsidisation as regulated by the EEG.

A series of studies and academic theses have been undertaken dealing with the potentials of renewable energy usage in Aachen:

- Wind
  - Integral investigation of wind potentials Aachen-Nord-West (Kluttig, 1993)
  - Potentials of usage of wind energy (Kluttig, 1994)
- Solar
  - Potential contribution of photovoltaics to the electricity supply of a city (Bischof, 1993), diploma thesis written in collaboration with STAWAG[2]
- Biomass

[1] In autumn 2005, an update of the "Action Plan for Climate Protection 2010" was expected.

[2] According to von Fabeck (2005), *"the outcomes of the thesis were quite remarkable, as it was suggested that the entirety of all south-oriented roof areas are sufficient for supplying up to 50-65% of Aachen's energy needs via photovoltaics. This turned out to be too optimistic. Using a more conservative approach, the specific roof areas would be sufficient to meet ca. 25% of Aachen's energy needs in 100 years".*

- Study on biomass potentials for the City of Aachen (Kluttig *et al.*, 1998)
- Study on potentials of fuel wood for the area Aachen/Eifel (VIKA, 2000)

• Municipal solid waste

- Waste management concept for municipality and City of Aachen, 1993, as amended in 2001 (AWA, 2001)

4.3.6 Interactions Between Waste Management Sector and Energy Sector

Up to the point of writing, there was no systematic approach regarding the potentials of energetic usage of municipal solid waste in Aachen. In the following Section, two projects of the City of Aachen will be introduced which lie at the intersection between the sectors of waste management and energy.

4.3.6.1 Existing Waste Incineration Plant MVA Aachen-Weisweiler

In Figure 4.1, the existing waste incineration plant in Aachen-Weisweiler (Müllverbrennungsanlage (MVA) Weisweiler[1]) is represented. According to Meiners (2005), *"the waste incineration plant was planned and commissioned before the introduction of the Aachener Modell. In its planning phase, the plant has been optimized in order to reduce emissions and costs. By-products are electricity and heat, whereas earnings from heat sales are negligible. The plant has not primarily been conceptualized for energy recovery. Its specific costs per ton of waste processed are comparatively high"*.[2]

It is only recently that the plant started to operate at its full capacity due to the amendment of the Technical Instruction on Municipal Waste - Technische Anleitung Siedlungsabfall (TASi) - (BMU, 1993) in June 2005, introducing a

[1] www.mva-weisweiler.de

[2] The costs of waste processing at the Weisweiler incineration plant are ca. €190/t (ca. ZAR 1,520/t), whereas standard waste disposal would have cost €60 - 120/t (ca. ZAR 480 - 960/t) before the amendment of the Technical Instruction on Municipal Waste in June 2005.

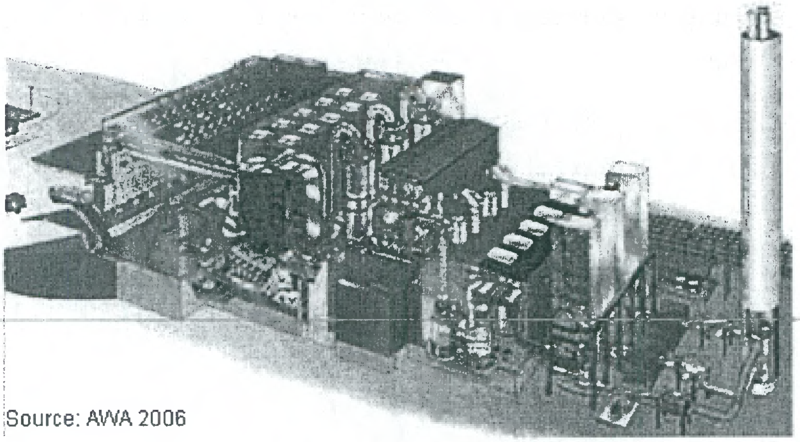


Figure 4.1: Waste Incineration Plant MVA Weisweiler

countrywide landfill ban for untreated biologically degradable organic waste, resulting in the diverting of municipal waste streams from landfills to, i. a., waste incineration plants.

According to AWA (2006), the facility is owned by two private companies: RWE Umwelt West GmbH (Grevenbroich), and the AWA Waste Management GmbH (Eschweiler). The primary investment costs were €312 million (ca. ZAR 2.5 billion), plus an additional €46 million (ca. ZAR 380 million) for the connection to the RWE coal power plant in Weisweiler. The technology used consists of three independent combustion lines with direct current roll grate firing. The types of waste processed are domestic residual waste (content of the "Graue Tonne" - literally Grey Bin) and commercial waste. The plant[1] is supplied with waste from the municipality and the City of Aachen, the municipality of Düren (municipal wastes), Euregio (Belgium and Netherlands), and cross-regional commercial wastes.

The plant generates 51.5 t/h of steam per line at its rated capacity, which is used to operate a steam turbine in the coal power plant Weisweiler. The electric capacity is 35 MW, which is sufficient to supply ca. 60,000 households with electricity. Its emissions are significantly below the maxima set by the 17^{th} German

[1] 11 workers per shift are necessary to operate the plant in a 3-shift-system. Furthermore, 2-3 workers, and at peak times up to 5 workers, are needed to ensure reception control and operation of the weighbridge.

Federal Imission Protection Ordinance (17. Bundesimissionsschutzverordnung (BImschV)) released by BMU (2003).

4.3.6.2 Planned Biogas Plant Aachen-Vetschau

According to Unterberg (2005), *"a biogas plant was planned in order to generate biogas from animal manure, maize and barley in the City of Aachen. Shortly before its realization phase, the project was stopped due to a political veto"*. In the following, a concise version of the events related to the planning of the biogas plant will be given based on a report released by the Stadt Aachen (1999), as it promises to give and understanding of the planning process and the importance of its different aspects and key players.

At the point of writing, green waste is being composted, and its quantity would not be sufficient to secure supply for the planned biogas plant (AWA, 2001). Therefore, a study on biomass cultivation potentials has been undertaken in the regions of Cologne and Lower-Rhine. The dimensioning of renewable energy plants in general, and this plant in particular, is based on the German Renewable Energy Sources Act (EEG), aiming at achieving the highest remuneration for produced energy whilst assuring its technical feasibility. In this case, the plant has been designed to produce an average of 1,500 m^3/h of biogas with an electric capacity <500 kW. A subsequent gas cleansing would have allowed the gas to be fed into the natural gas grid.

According to the Legislation on Waste Management (BMU, 1996), the City of Aachen, as a public waste management institution, is obliged to recycle wastes if this is technically feasible, the resulting overhead costs are not unreasonable compared to other processing techniques, and there is an existing or potential marked for recovered materials or energy. Biodegradable wastes collected in the City of Aachen via the "Biotonne" (compostable domestic waste), compost containers, recycling yards, and wastes privately brought to compost places (garden and green wastes) are concerned by this recycling duty of the City.

Against the initially calculated quantity of 24,000 t/a by external auditors in Aachen's waste management concept, the City estimated the quantity and quality of waste suitable for biological processing based on collected and existing

Biodegradable waste source	[t/a]
Households	15,000
Parks & Gardens	5,000
Total	20,000

Source: Stadt Aachen 1999

Table 4.1: Biodegradable Waste Quantities and Qualities Aachen

figures as given by Table 4.1. In 1995, the City of Aachen emitted an invitation to tender for the construction and operation of a biogas plant for a throughput of ca. 20,000 t/a.

At this stage, the Municipality of Aachen (representing the governmental entity of the greater region of Aachen excluding the City of Aachen) expressed its need for an additional composting capacity of 10,000 t/a. Thereupon, the administration invited in a limited tender process to submit reworked quotes considering the additional 10,000 t/a, amounting to a total of 30,000 t/a of plant capacity.

Thereafter, the Abfallwirtschaft Kreis und Stadt Aachen GmbH (AWA) (waste management company of the Municipality of Aachen) communicated on a short notice that it found itself not in the position to secure the provision of the guaranteed 10,000 t/a, but only 6,000 t/a. The insecurity about the quantity structure led to the City of Aachen wanting to get out of the project. However, the bidder community threatened to take legal action. The administration led parallel negotiations with the bidder community in order to present a plan allowing the plant to be operated with an annual throughput of only 26,000 t/a. The bidder community agreed to work with the administration in order to find a solution, and to achieve a price of ca. €80.-/t (ca.ZAR 640.-/t) of waste processed.

Of these total costs, possible earnings from energy sales as well as financial support funds had to be deducted. The price after deduction of earnings resulted in ca. €70.-/t (ca. ZAR 560.-/t). This price was lower than the price for composting by an external company of ca. €76/t (ca. ZAR 610/t), which was acceptable for the tax payer.

Finally, (Unterberg, 2005) states that *"after meaningful expenses of time and money for planning and negotiations, it was political will after the 1999 municipal elections, where the Christian democratic party - Christlich Demokratische Union (CDU) - won against the then acting social party - Soziale Partei Deutschlands (SPD) -, to freeze the whole project, claiming it was not yet financially viable"*. Up to the point of writing, the plant has not been realized.

4.4 Energy Picture of the City of Aachen

4.4.1 Status Quo Consumption of Energy

As can be seen in Table 4.2, the metabolism of the City of Aachen is powered by approx. 9,000 GWh/a of energy. The energy carrier gas accounts for the largest share (approx. 34%) in the total energy mix. Light Furnace Oil (LFO) accounts for the second largest share with 23%, followed by electricity, accounting for 16%. Noteworthly, a district heat system exists in the City of Aachen, delivering 3% of energy to its customers. The renewable energy technologies wind and PV deliver electricity to the electricty grid, approx. 23 GWh/a and 1 GWh/a respectively, accounting for no more than 1% to the total energy mix each.

Meiners (2005) states that *"the overall energy mix of the City of Aachen is different to the energy mix of average German cities, due to the important role that gas plays relatively to other energy carriers"*.

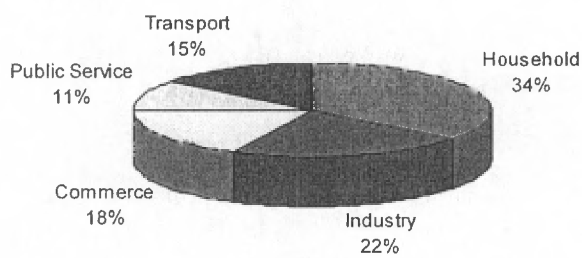
When it comes to allocating energy consumption to the different sectors as shown in Figure 4.2, it can be seen that households are the biggest energy consumers with 34%, followed by industry and commerce, accounting for 22% and 18% respectively. The smallest share belongs to goverment, accounting for only 11%.

Energy consumption within the City of Aachen translates to approx. 2 million t/a of CO_2-emissions. As can be seen in Figure 4.3, households account for the largest CO_2-emissions with 34%, followed by industry and commerce, accounting for 23% and 21% respectively. The smallest CO_2-emitter is the public service sector with only 10%.

Energy carrier	[GWh/a]	[%]
Electricity	1,484	16
Wind	23	<1
Photovoltaics	1	<1
Gas	2,994	34
District Heat	289	3
Petrol (motor fuel)	888	10
Diesel	1,076	12
LFO	2,020	23
HFO	218	2
Total	8,969	100

Sources: STAWAG 2003, MWV 2005, ENERKO 1998

Table 4.2: Energy Consumption by Energy Carrier - Aachen



Sources:
STAWAG 2003, MWV 2005, ENERKO 1998

Figure 4.2: Energy Consumption by Sector - Aachen

By comparing CO_2-emissions by sector to energy carrier consumption by sector, one can observe a similar trend regarding shares by sector. It should be noted though that the share of energy carrier consumption for the transport sector is 2% higher than its share in CO_2-emissions, and that the share of energy carrier consumption for the commercial sector is 3% lower than its share in CO_2-emissions, which might give an indication on technology system efficiency or quality and cleanness of fuels utilised.

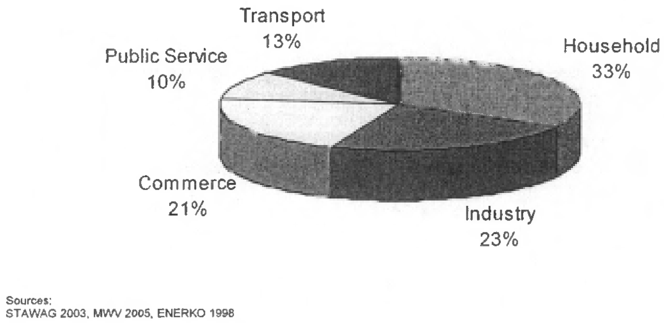


Figure 4.3: CO_2 Emissions by Sector - Aachen

According to Meiners (2005), *"the utilisation of wood as renewable energy carrier currently plays a minor role. It is estimated that there is approx. 1 MW capacity of single wood plants using wood chips mainly in Aachen's suburbs. Furthermore, an increasing trend is noticeable regarding impulse projects in the household and commercial sector regarding fireplaces, stoves and wood stoves"*.

4.4.2 Outlook Consumption of Energy

According to STAWAG (2003), Aachen is affected by the generally subdued national and international state of the economy. This factor negatively affected sales of STAWAG's energy products in 2003. On the other hand, favorable climatic conditions in 2003 - a cold winter and a hot summer - opposed the ailing economic situation. In 2003, demand for gas and district heat increased, whereas electricity consumption decreased slightly. It is assumed that the trend observed will be similar for the coming years, where economic situation and climatic conditions will continue to play key roles.

Regarding the role renewable energy carriers will play in the future, Meiners (2005) says that *"with the realisation of STAWAG's wood gasification project in 2010, renewable electricity will achieve a share of at least 20% in the household and small-scale company sector"* (see Section 4.5.2.12). As can be seen in the back-of-envelope calculation in Table 4.3, the wood gas plant will generate a total amount of approx. 75 GWh/a of electricity. By adding the 30 GWh/a of

Wood gas plant	10 MW * 7,500 h/a	75 GWh/a
Wind + solar		30 GWh/a
Total		105 GWh/a
Total households and small-scale companies		430-450 GWh/a
Share of renewable electricity: households and small-scale companies		20-25%

Source: Meiners 2005

Table 4.3: Back-of-Envelope Calculation: Share of Renewable Electricity - Aachen

electricity generated by wind and solar, this will amount to a total of approx. 105 GWh/a. By taking into account that total electricity demand of households and small-scale companies lies at about 430-450 GWh/a, the share of electricity from renewable energies in the households and small-scale companies sector will settle at about 20-25%.

4.5 Renewable Energy Planning

The energy planning process on the municipal level in Aachen shall be explained based on an example. The project chosen is a wood gasification plant, being in its final planning stage at the point of writing. In a first step, the wood gasification project of the STAWAG shall be introduced. In a second step, the decision making process shall be investigated.

4.5.1 Description of the Wood Gasification Project

Charl (2004) states that from the end of 2006, the wood gasification plant of the STAWAG shall generate as the first large scale technical plant of its kind in Germany, a total of 70,000 MWh/a of electricity from wood in order to supply 20,000 of Aachen's households. With a total of CO_2 savings amounting to 45,000 t/a, it sets new standards in the field of energetic biomass utilization. Via a coordination office at the Institute for Coking, Briquetting and Thermal Waste Treatment (KoBrA) of the RWTH Aachen University, a number of different university institutes work together with the STAWAG and the company Choren Industries based in Freiberg, Saxony. The company CHOREN Industries developed the patented Carbo-V®-process for the production of wood gas, with which Aachen shall be supplied with electricity and heat.

According to Charl (2005b), the project with a total investment volume of €44 million is in its authorization process at the point of writing. The plant feed consists of untreated wood wastes from forests and landscaping. The wood wastes are downsized and dried in a wood processing plant. The wood chips are subsequently transformed to wood gas in a multiple stage process. An innovation is that a proven tar-free gas is produced from wood. This gas can be used without problems in conventional gas engines without any traces of tar in order to produce gas and heat. The complete plant has an electric efficiency of 33%, being substantially higher than the efficiency of conventional wood combustion.

4.5.2 The Decision Making Process

In order to achieve a feasible plan for the wood gasification plant, a series of decisions had to be made. In this Section, this process shall be described in order to offer a basis for the comparison to similar processes in other cities. The different planning steps will be described in chronological order as given by the time line in Appendix B.

4.5.2.1 Initial Motivation

Unterberg (2005) states the following: *"the starting point of the planning process for the wood gasification project was the will of the STAWAG executive board to support the image of the City of Aachen as a pioneering and environmentally conscious city by implementing an innovative impulse project in the field of renewable energies. After several board meetings, the project was approved. The project itself shall create jobs in the region of Aachen. The maturation of the technology shall secure jobs in Germany, and render the technology exportable."*

A need of the population for a specific energy carrier is not given, as there is not (yet) a shortage of electricity, heat or liquid fuels. However, there is a more imminent need to stabilise the economy by investing into future oriented technologies.

4.5.2.2 Preselection of the Resource

(Wirtgen, 2005) states that *"as the renewable energy sources wind power and photovoltaics had already been assessed in detail during the energy supply history of the City of Aachen*[1]*, it was political will to shift the focus to the renewable resource biomass. An advantage of biomass as a renewable resource is that it can easily be stored, which allows a steady and secure supply of the resource, as it is not the case with wind power and photovoltaics".*

Two studies were undertaken in order to investigate the resource potentials for biomass, i.e. wood, in the region of Aachen (see Section 4.3.5). Wirtgen (2005) states furthermore that *"it was established that there is sufficient fresh wood in the region of Aachen and its immediate surroundings in order to use it as a renewable energy carrier. The City of Aachen is thus in the position to meet its fuel wood needs by its own means. Additional costs that would have arisen from importing fresh wood from other regions in Germany or Europe would have threatened the economic viability of the wood gasification project".*

Study on biomass potentials In 1998, a study on biomass potentials was undertaken (Kluttig *et al.*, 1998), investigating in detail the options of energetically using organic wastes, wood and agricultural biomass such as animal manure, straw and energy crops in the region of Aachen. The overall CO_2-reduction potential was estimated at about 40,000 t/a, equaling 2% of Aachen's overall emissions including the transport sector, which is quite a substantial value for a city of the size of Aachen. *"The study clearly illustrated the potentials for biomass based energy applications"* (Meiners, 2001).

[1] see Section 4.3.3

Study on potentials of fuel wood for the area Aachen/Eifel The study on potentials of fuel wood for the area Aachen/Eifel was undertaken by VIKA (2000) for the Kathy Beiss foundation in Aachen. It was aimed to understand the potentials for a fostered use of wood as energy carrier.

The motivation for this study was to acquire additional knowledge on quantities, qualities and prices of the energy carrier wood, as it is a major factor of uncertainty in the decision-making process. The study outlined the current status of the wood sector in the region Aachen/Eifel, concluding that it is not yet adapted to an energetic utilization of wood: a regional market for fuel wood can not yet exist, due to an insufficient number of potential customers.

The study had to be commissioned by the STAWAG, as the City of Aachen is not responsible for matters that extend beyond the city boundaries, as here, the region Euregio Maas-Rhine was considered.

4.5.2.3 Selection of the Conversion Process

As the emphasis of the investments of the STAWAG in the field of renewable energies were to be focused on the energetic usage of biomass, only a restrained number of families of conversion processes was theoretically available (Scahill, 2004):[1]

- Combustion
- Gasification
- Pyrolysis
- Anaerobic digestion
- Fermentation
- Esterification
- Hydrolysis

[1] see Section 2.2.7.2

The different families do have several advantages and disadvantages respectively, which makes it necessary to make a trade-off according to the criteria of the decision-making process.

Wirtgen (2005) states that *"the combustion process has a lower efficiency compared to the gasification process. This is of further importance, as the EEG-subsidization depends on an efficiency minimum. Furthermore, the combustion process only produces electricity and heat, whereas the gasification process enables the production of electricity, heat and liquid fuel. The remaining processes, e.g. pyrolysis and hydrolysis, are not yet ready for the market especially on an industrial scale, and are therefore no viable options compared to the gasification process. Eventually, the main reason for the selection of the gasification process was its higher overall efficiency as compared to a classical steam-cycle process"*.

Wirtgen (2005) says furthermore that *"an other utilization option for wood is the production of chemical products"*. Up to the point of writing, no market analysis for chemical products based on wood has been undertaken.

4.5.2.4 Creation of a Coordination Office

The interdisciplinary research and development work within the project includes the acquisition, logistics and processing of the biomass, the thermal process technology as well as the energy production, and the legislation on environment and energy.

As a process at such an order of magnitude represents a novelty, the STAWAG secured itself the competencies of the RWTH Aachen University on a contractual basis via the establishment of a biomass coordination office. The coordination office is led by the Institute for Coking, Briquetting and Thermal Waste Treatment (KoBrA) of the RWTH Aachen University. All research activities related to the wood gasification project between the STAWAG and the RWTH Aachen University are coordinated by this office (Charl, 2005c).

4.5.2.5 Selection of the Conversion Technology

At the time of writing, a series of gasification technologies are available on the market, listed as follows by country of origin of the technology provider (see Gajic, 2005):

- Austria
  - BioCoComb project (Zeltweg, Austria)
  - FICFB plant in Güssing
- Denmark
  - Carbona technology
- Finland
  - Coal power plant Kymijärvi in Lathi, Finland - Biomass gasification for co-combustion
- Germany
  - "Blue Tower" or "Selective Conversion"
  - Carbo-V®-process
- Sweden
  - TPS Termiska Processer gasification technology
  - Värnamo IGCC pilot plant
- USA
  - SilvaGas process

Most of the technology providers stem from Scandinavian countries (Denmark, Finland, and Sweden), followed by Austria and Germany. Only one technology provider stems from the USA.

The STAWAG decided to go for the patented Carbo-V®-gasification process, as represented in Figure 4.4. The choice of the Carbo-V®-gasification technology was made due to a number of technical and econo-political arguments.

A first technical argument is the multitude of potential input feeds, ranging from coal to wood chips over shredded waste wood to organic residues from mechanical-biological waste processing. A second technical argument are the application options for the produced gas, ranging from electricity and heat generation via gas turbines and gas engines to the production of liquid fuels via a Fischer-Tropsch-synthesis. Further advantages of the Carbo-V®-process are the production of tar-free gas, high H_2- and CO-contents, high electric efficiency, cold-gas efficiency of over 80%, and low emissions. Potential disadvantages in comparison to other processes are the necessity of two reactors, the complex combination of the different process steps, the necessity of additional coke processing, and the relatively high costs of the gasification process as such (Gajic, 2005).

According to Wirtgen (2005), *"the contact to the company CHOREN was made on a level of market-economy, most obviously via a personal contact during a technology exhibition; CHOREN is momentarily market leader regarding the Carbo-V®-technology, which means that the selection of the technology provider happened unsystematically"*. In order to acquire the necessary know-how, the STAWAG secured its access to the Carbo-V®-technology through a license agreement with the company CHOREN Industries GmbH in Freiberg/Saxony.[1]

At the point of decision making, the Carbo-V®-process appeared to be the best possible technology. It is at the point of writing that critical voices rise claiming that the license agreements have been made too early, as there are doubts about the suitability of the process for the achievement of the defined goals. (Meiners, 2005) states the following: *"At the point of licensing, the process was considered as the best available technology, however the technology is a non-standardized process. This appeared to be a weak spot afterwards, as the process is still not operating stable at the moment of writing. It was an act of entrepreneurial risk-taking of the STAWAG to make an early decision for the CHOREN-process."*

Technology description The following passage has been summarized and translated from (Gajic, 2005) and is based on Wolf (2001), Wolf (2002), CHOREN (2005), Bandi & Specht (2004), FVS (2003).

In the Carbo-V®-process as depicted in Figure 4.4, an autothermal low-temperature gasification is coupled to an autothermal flue gas gasification, in

[1] See Section 4.5.2.12 for details on tendering process.

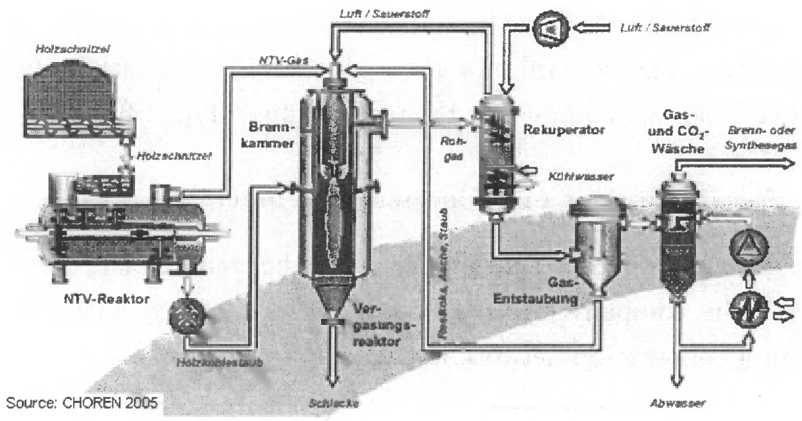


Figure 4.4: CHOREN's Carbo-V®-Process

which the generated products of the low temperature gasification - pyrolysis gas and coke - are converted.

The input feed biomass (wood) is pre-dried to a moisture content of 15-20% by means of recovered process heat. The feed is then converted through partial combustion with air into bio-coke and tar-containing flue gas in the low-temperature gasifier at temperatures between 400-500°C. The flue gas is then fed into a high-temperature gasification unit. In this unit, the flue gas is partially oxidized with air and oxygen at temperatures between 1,300-1,500°C. During this reaction, unwanted long hydrocarbon chains such as tar are cracked.

A gas is formed which is mainly constituted of nitrogen, carbon monoxide, hydrogen, carbon dioxide, and steam. Through the released heat and the high temperatures in the 2nd gasifier, the ash compounds melt and flow along the inner wall into the water bath at the bottom of the reactor. The glasified, eluate free ash can be utilized in form of slag granulates e.g. in road construction. The high temperatures of the downwards streaming gas contains the necessary energy for all subsequent endothermic reactions with the ground coke.

The bio-coke is retrieved from the low-temperature gasifier, cooled-down, ground to fuel dust and subsequently pneumatically blown into the hot gas stream of the combustion chamber. Via the heavily endothermic reaction occurring during the gasification of the bio-coke, a lowering of the gas temperature to about 800-900°C is achieved in a couple of seconds. Due to this chemical quenching, a tar-free raw gas with a high content of carbon monoxide is obtained. Afterwards, the produced gas can be used in a gas engine for the generation of electricity, or in a Fischer-Tropsch-synthesis for the production of liquid fuels.

4.5.2.6 Establishment of a Cooperation Network

After the creation of a coordination office and the conclusion of the license agreements with the company CHOREN, all parties involved with the project are included in a cooperation network as depicted by Figure 4.5.

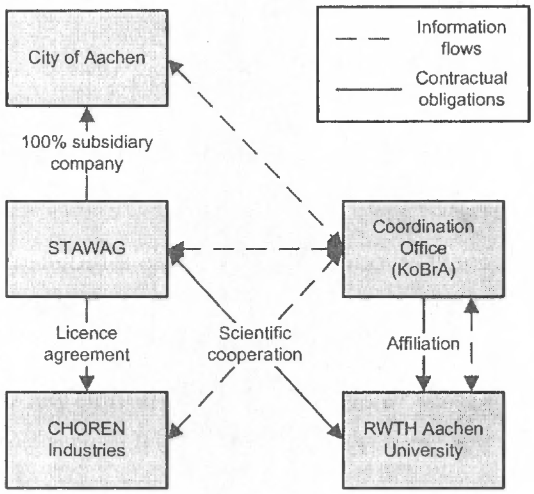


Figure 4.5: Cooperation Network

Whereas all information flows are managed by the coordination office, different contractual obligations exist between the involved parties. The STAWAG is a wholly owned subsidiary company of the City of Aachen. There is a Research and Development (R&D) agreement between the RWTH Aachen University and STAWAG based on scientific cooperation. Finally, there is a license agreement between the STAWAG and CHOREN regarding the provision of the core technology.

4.5.2.7 Selection of the Resource

According to Wirtgen (2005), *"an argument for the utilization of wood as a resource laid in the subsidization by the federal government, as defined by the EEG.*

Based on economical and technical facts, it was opted by the decision makers to go for the resource wood, including fresh as well as waste wood". This decision had to be revised at a later stage of the planning process (see Section 4.5.2.11).

4.5.2.8 Selection of Energy Products

Out of the range of deliverable energy types, e.g. electricity, heat, gas, and liquid fuel, the STAWAG decided to go for the electricity (and heat) option in a first step, as at the point of writing, only electricity is subsidized by the federal government via the EEG-mechanism (Wirtgen, 2005).

According to Wirtgen (2005), *"the wood gas (syngas) which is produced in the process has a comparatively low energy content and a different quality than natural gas (CH_4-content ca. 94%). Furthermore, because the wood gas has a high content of ballast (high N_2-content), it would not be suitable for being fed into the existing natural gas grid".*

It is however interesting that the generation of electricity (and heat) is only an intermediate goal; the production of liquid fuel is the ultimate goal of the STAWAG. The ASEAG, the public transport utility of the City of Aachen, already agreed on a contractual basis to buy STAWAG's liquid fuel to run Aachen's public transport bus fleet.

In the example depicted in Figure 4.6, back-of-the-envelope calculations of a Biomass to Liquid (BTL) option and a biomass-CHP option are compared in terms of revenues from sales of energy carriers produced from the same amount of input material.

In the BTL option, 70,000 t/a of wood with an approximative energy content of 4,000 kWh/t are being gasified with an efficiency of 72% (CHOREN, 2005) in order to produce 202,000 MWh/a of energy. Accounting for an efficiency of approx. 63%[1], the subsequent Fisher-Tropsh-synthesis yields approx. 127,000 MWh/a of energy. This corresponds to an amount of approx. 12.7 million l/a of liquid fuel. Assuming that the produced liquid fuel is sold at the price for conventional diesel in Germany in 2007 (approx. €1.17 per litre (ARAL, 2007)), sales of the liquid fuel would yield a total amount of €15 million per annum,

[1]Efficiency of 40-47% for overall process (Minrocon, 2005)

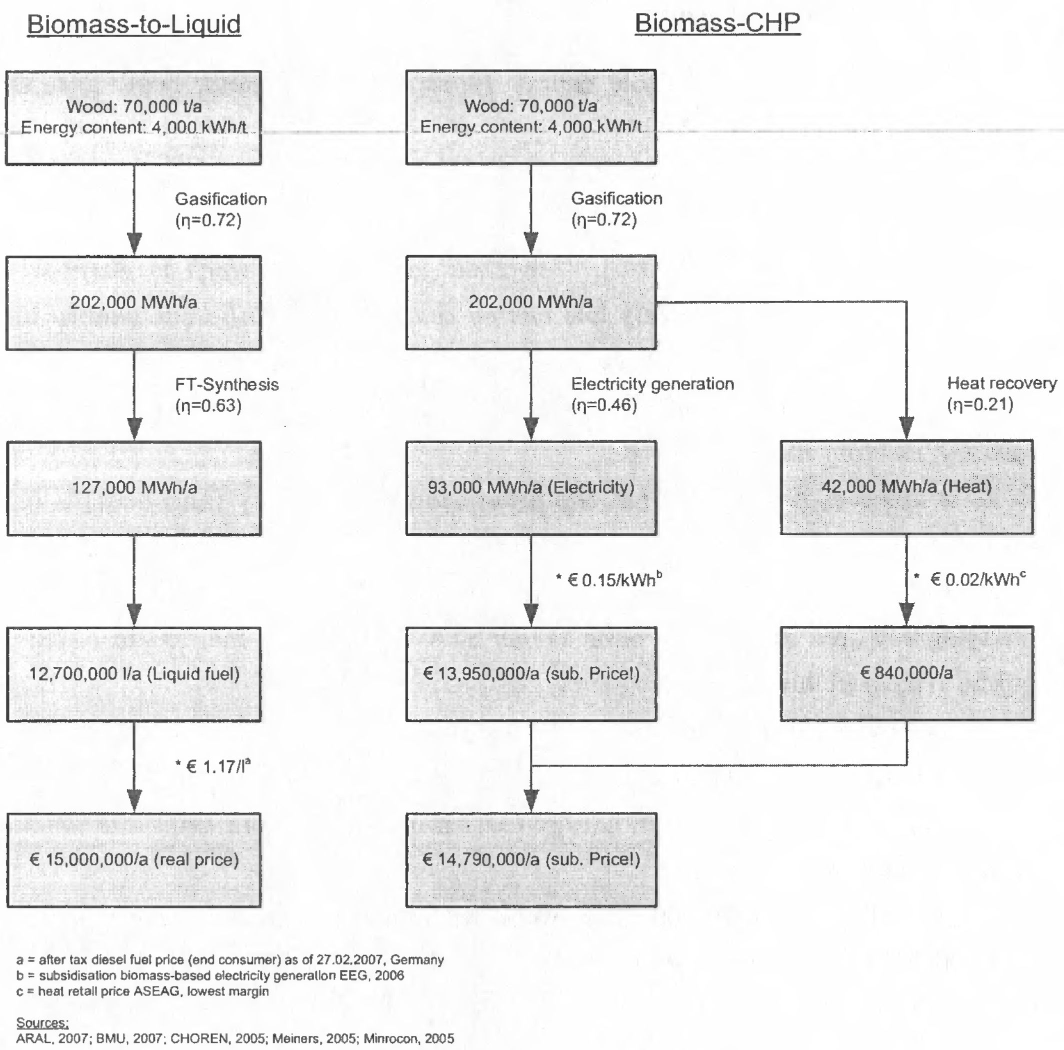


Figure 4.6: Back-of-Envelope Calculation BTL and Biomass-CHP

corresponding approx. to 135 million ZAR. Note that if the liquid fuel was produced based on a fossil resource, e.g. coal, petroleum taxes would have had to be considered, which would have decreased profitability. Note that the price for conventional diesel without taxes would be €0.51/l (ARAL, 2007).

In the biomass-CHP option, 70,000 t/a of wood with an approximative energy content of 4,000 kWh/t are being gasified with an efficiency of 72% (CHOREN, 2005) in order to produce 202,000 MWh/a of energy. Accounting for an efficiency of approx. 46%[1] for electricity generation, an amount of 93,000 MWh/a of electricity is produced. With an efficiency of 21%[2], 42,000 MWh/a of heat are recovered. Assuming a price guaranteed by the EEG in 2006 of €0.15 per kWh of biomass based electicity, earnings would amount to approx. €13.95 million. Additionaly, earnings for heat sales would amount to approx. €840,000 million. Total sales would thus amount to approx. €14.79 million, corresponding approx. to 135 million ZAR.[3]

Although the earnings of both conversion options are of the same order of magnitude, the price for electricity is more unrealistic in the biomass-CHP option, as electricity is subsidized by the EEG. If STAWAG would sell its electricity at the costs of electricity generated based on fossil fuels (€0.05/kWh), final earnings would only amount to €5.5 million.

Therefore, the plant is meant to produce electricity in the medium term, and liquid fuel in the long term in order to remain competitive. It should be noted that capital and operational expenditure for the two conversion options have not been considered. For the production of liquid fuel, the plant might even be upgraded in scale in order to maximize profits (economy of scale). Furthermore, it should be noted that by increasing its own energy generation capacity, the STAWAG ensures itself some independence from large energy providers such as RWE AG and E.ON AG.

Eventually, it can be stated that a potential weak spot lies within the selection of the energy products. The selection of electricity and heat as energy products

[1] 33% for the overall process (CHOREN, 2005)

[2] 15% for the overall process (CHOREN, 2005)

[3] STAWAG calculates the earnings from selling heat with the lowest margin €0.01-0.02/kWh. As heat is not considered in the EEG, free market rules apply. The major earnings will come from electricity sales.

is founded; nevertheless, there was no systematic investigation regarding the potential substitution of industry heat, especially where currently fossil resources are used (LFO, HFO, or gas).

4.5.2.9 Technical Draft of the Supply Chain Concept

The supply chain concept of the wood gasification project of the STAWAG is structured as follows (Charl, 2005a):

- Wood acquisition
- Wood processing, storage and transport
- Biomass processing via Carbo-V®-process to wood gas
- Gas storage and transport
- Decentralised electricity and heat generation

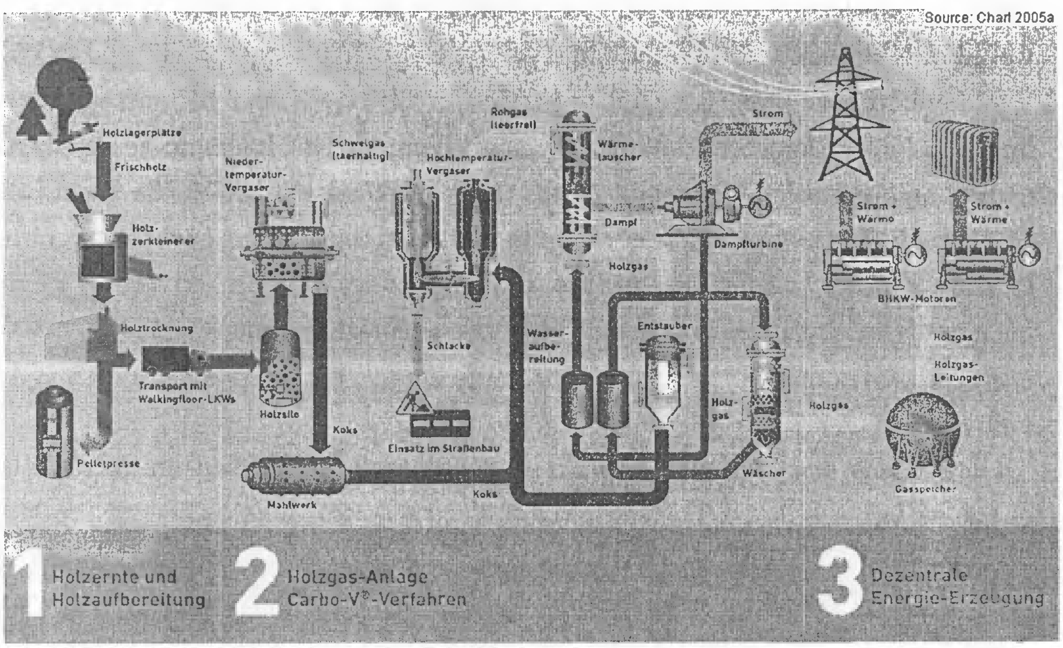


Figure 4.7: The STAWAG Wood Gasification Project

The wood gasification project as described in Figure 4.7 contains, in addition to the locations for the CHP plants, two plants which have to be erected in the City of Aachen area, which are as follows (Charl, 2005a):

- A wood processing plant for ca. 75,000 t/a assuming the following tasks:
  - Wood reception (wood is stored at gathering spots in the forest)
  - Processing and drying (output ca. 58,000 t/a, w=15%)
- A wood gasification plant (fuel capacity: 30 MW_{th}) on location RWTH Melaten-Seffent consisting of:
  - Two low-temperature gasifiers
  - One high-temperature gasifier
  - Wood gas cooling, cleansing, and storage
- A wood gas distribution grid and five locations for energy generation consisting of:
  - Ca. 5 km conductor length
  - 4 decentralised locations:
    * Location electric power transformation station STAWAG Seffent:
      · CHP-module, 1 MW_{el}
      · CHP-reserve, 2 MW_{el}
    * Location CHP plant Laurensberg-Rahe
      · CHP-module, 1MW_{el}, 1.13 MW_{th}
      · Heat supply for student residence Rütscher Strasse
      · Heat supply for 300 households
    * Location CHP plant Kastanienweg:
      · CHP-module, 1 MW_{el}, 1.13 MW_{th}
      · Heat supply for student residence Kastanienweg
    * Location CHP plant Bendplatz

- CHP-module, 2 MW_{el}, 2.25 MW_{th}
- Heat supply for company Lindt&Sprüngli GmbH (chocolate factory)

– 1 central location of wood gasification plant:

* Location RWTH Melaten-Seffent
  - Condensation steam turbine, 3MW_{el}
  - CHP-module, 2 MW_{el}

As a district heat grid is prone to substantial losses, only buildings and industry in close proximity are supplied with heat from the CHPs plants. Note that excess heat is utilised within the wood gasification process itself.

Dimensioning of the Plant The limiting factor for the dimensioning of the overall plant is the wood gasification reactor. (Wirtgen, 2005) states the following: *"In Freiberg/Saxony, a 1MW-plant was tested. Aachen's plant has been dimensioned at 30 MW. This is already a challenge from a process systems engineering point of view, as the plant has been dimensioned a factor 30 bigger. An even bigger plant would bare too many technical risks, as there are no experiences yet for such dimensions. A smaller plant would not be economically viable, as generally, the bigger the plant is, the more financially viable it is (economy of scale). The splitting of the electricity generation to 4 distinct locations is based on the higher subsidisation through the EEG, and the utilisation of heat".*

4.5.2.10 Feasibility Study

The costs of the project are estimated as shown in Table 4.4. The major share of the costs are allocated to the wood gasification plant, accounting for €27 million. The costs for the CHP plants and the gas grid are estimated at around €12 million, whereas the wood processing only accounts for approx. €5 million. Thus total costs for the wood gasification project are estimated at around €45 million.

The detailed cost calculation could not be accessed, as it contains economically sensitive data. Unterberg (2005) says that *"the financing model is based on bank loans over 10 years time. Financing sources are the subsidisation through the*

Section	[million €]
Wood gasification plant	27.0
Blockheizkraftwerk (BHKW) and gas grid	11.8
Wood processing	4.9
Total	43.7

Source: Charl 2004

Table 4.4: Cost Estimation: Wood Gasification Project

EEG, the earnings from selling heat to local customers, and possible additional funding from the Department of Environmental Affairs [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)]".

Approval Process Heckmann (2005) says *"not the municipal government, but the regional government is responsible for the approval process based on the 4^{th} German Federal Immission Protection Ordinance (4. BImschV[1]) due to the dimension of the project. The approval process is lead by the regional government of Cologne as approving authority. The start as well as the end of the approval process is published in the federal report and local newspapers".*

During the approval process, emission and material cycles are analysed amongst other things. CO_2-emissions are not considered, as CO_2 is a contributor to the global warming phenomenon, but is not considered as a toxic substance as such. Noise emissions have also been considered; it can already be stated that noise emissions will be minimal.

Environmental Impact Assessment Heckmann (2005) says furthermore that *"within the framework of the approval process, a pre-assessment of the single case has been undertaken, proving that an environmental impact assessment is not necessary, as the construction and the operation of the plant do not implicate meaningful environmental impacts. As the STAWAG went public at an early stage in order to introduce its project, all objections and ambiguities could be clarified with the citizens beforehand".*

[1](BMU, 1985)

During the approval process, objections to the project can be made public within 14 days. As the wood gasification plant can be considered as a closed system during normal operation, emissions occur when it comes to the wood gas combustion in the CHPs plant. Though, the emissions lie substantially below the levels of standardised CHPs plants which are run with fossil fuels. As opposed to conventional power plants, the wood gasification process has a neutral CO_2-balance. Per year, 45,000 t of CO_2 are saved. Also, the amount of nitrogen-emissions from the CHP plants are low, as the nitrogen-compounds in the feed material wood are low. The high content of carbon monoxide in the wood gas is diminished through catalysts in the CHP-engines, so that the emission levels are below the required levels here as well. Furthermore, the growth of wood exceeds the amount of used wood in Europe since the 1950s, which means that the threat of potential deforestation has been neutralised as well.

4.5.2.11 Further Limitations Regarding the Resource

The wood which will be used as input material for the wood gasification plant will mainly stem from within a radius of ca. 70 km. A transport from forest areas further than that would not be economically and ecologically viable. Type and source of the wood is given by a certificate from the provider. The background is that the EEG from August 2004 only supports the generation of electricity from biomass if the biomass has exclusively been harvested for the purpose of electricity generation. In the case of wood, one talks about fresh wood, as opposed to other untreated wood such as wood chips. In order to harvest the fresh wood from the forest of the Euregio, ca. 20 jobs are created. *"Via the certification mechanisms, the STAWAG can produce evidence from harvest to processing as to where the wood comes from in order to apply for subsidisation via the EEG"* (Wirtgen, 2005).

A further reason for the selection of fresh wood as feed material is the residential area directly surrounding the plant. The utilisation of treated waste wood would have increased the costs for the reduction of pollutants by air cleansing on the one hand. On the other hand, the adjacent residents would have formulated complaints during the licensing procedure.

	[m^3/a]	[MWh/a]
Soft wood	69,855	153,600
Hard wood	109,000	258,700
Total	178,855	412,300

Source: VIKA 2000

Table 4.5: Fuel Wood Quantities and Energy Content for the Region Aachen/-Eifel

The plant will be fed with 70,000 t/a of fresh wood, requiring a cultivation area of 20,000 ha. As can be seen in Table 4.5, a total amount of ca. 400 GWh/a of energy are bound in softwood and hardwood in the region Aachen/Eifel.[1]

4.5.2.12 Implementation Phase

(Unterberg, 2005) states the following: *"The STAWAG set itself the target to achieve a renewable energy capacity of 20 MW_{el} by the year 2011. This goal would have been achieved by installing the first 10 MW_{el} of the wood gasification plant by the end of 2006. Every following year, the capacity would have been increased by another 2 MW."*[2]

In order to implement the project in the set timeframe, STAWAG had firstly to officially tender the wood gasification project, as it is an enterprise of the public authorities. The core technology - the Carbo-V®-process - has already been confirmed; the technology supplier CHOREN has been confirmed as well. Although the provision of the core technology does not have to be tendered, all standardized services must be tendered. This is embodied in the assignment right. The invitation to tender for the wood gasification project has been issued on the European level. However, the implementation process has been stopped at the moment of writing, as the the project is not yet economically viable.

(Wirtgen, 2005) states that *"the lowest quotation ranged at about €55 million. This exceeds the initially calculated price by ca. €10 million. The main reason is the implementation of the Carbo-V®-technology from a process systems point*

[1]In the study undertaken by VIKA (2000), wood wastes from the wood processing industry were not taken into account, as it is considered being a cross-regional issue.

[2]The project plan could not be accessed as it is a protocol of a management board meeting.

of view, which rose from €20 million to €30 million". (Meiners, 2005) argues furthermore that *"the commissioning of the plant has been rescheduled for two years, as economic viability was not yet given. On the other hand, this leaves a time window of two years during which the Carbo-V®-technology can be optimised, as the stableness of the continuous operation (7,500 full load hours/a) has not yet been verified. A similar plant has not been commissioned in Germany so far".*

4.6 Further Potentials for Energetic Wood Utilisation

Besides the amount of fresh wood which has been considered as fuel for the wood gasification plant as described in Section 4.5.2.11, there are other wood fibre based material streams within the boundaries of the City of Aachen which are potentially suitable for energy recovery.

In the following Section, two documents will briefly be analysed regarding data availability on further wood-fibre based resources suitable for energetic utilisation. These documents are[1]:

- Study on biomass potentials for the City of Aachen (Kluttig *et al.*, 1998)
- Waste management concept for municipality and City of Aachen, 1993, as amended in 2001 (AWA, 2001)

The purpose here is to investigate the level of detail regarding the collection of data - which is an integral part of a renewable energy planning process - for renewable resources within the City of Aachen. These insights are of importance regarding the comparison of the renewable energy planning processes of two cities respectively of the North and South in Chapter 5, and the Material Flow Analysis (MFA) in Chapter 7.

Furthermore, the wood bank initiative of the City of Aachen will briefly be introduced and analysed regarding its potentials regarding the avoidance of CO_2 emissions.

[1] See Section 4.3.5

4.6.1 Wood Fibre Based Material Streams

As given by Table 4.6, a total amount of approx. 70,000 t/a of wood is potentially available in Aachen itself (as opposed to the region Aachen/Eifel). Considering the amount of energy being made available via these sources without previous drying during storage, a total amount of 115 GWh/a are available. Including a preliminary drying period, the available energy would amount to approx. 140 GWh/a. The biggest amount of woody material stems from sawmills (wood chips), accounting for approx. 27,000 t/a, followed by Aachen's total growth of wood in forests, parks and gardens of about 20,000 t/a, and wooden materials within Aachen's waste streams, accounting for approx. 9,000 t/a.

Interestingly, due to a moisture content of approx. 7%, the energy yields from wooden materials within Aachen's waste streams are high compared to those from sawmills or Aachen's total growth, accounting for approx. 30 GWh with or without previous drying (storage). This said, it might be interesting to have a closer look at the waste streams within the City of Aachen, as depicted by Table 4.7.

Approx. 3,000 t/a of waste wood as a separate fraction is generated yearly, whereof the majority is being reutilised or recycled. Only 34 t/a is being thermally treated, and 34 t/a is being disposed. This leaves an amount of approx. 6,000 t of wood waste (9,000 t/a - 3,000 t/a) which is included in the categories MSW, bulky waste, market waste, street swipings, builder's rubble, gully cleansing and paper & cardboard.

Summarily, it can be said that wooden material streams the most attractive for thermal utilisation are those that arise in high amounts, neat fractions, and having a low moisture content. In this case, the most attractive material streams would be wood chips from sawmills and clean wood wastes fractions which are not mixed to other waste materials.

However, Meiners (2005) states that *"all available material streams have been analysed regarding their recovery potentials, and that material streams are being recovered where this is economically viable. This means in other terms that by 2005, none of the remaining material streams is suitable in terms of quantity and/or quality for energetic recovery from an economic perspective"*.

Source	Moisture content w [%]	Quantity [Mg/a]	*excl. storage* Heating value, w as such [MWh/a]	Usable heat[2] incl. annual efficiency [MWh/a]	*incl. storage* Heating value, w=20% [MWh/a]	Usable heat[3] incl. annual efficiency [MWh/a]
Total growth (Forests, Parks, Gardens, etc.)	50	20,000	44,000	27,700	50,000	38,500
thereof deficient forest rest woods		2,000	4,400	2,800	5,000	3,850
Sawmills (wood chips)	50	27,000	58,000	36,600	63,360	49,400
Sawmills (bark)	50	5,800	12,700	8,000	13,900	10,900
Waste management	7	8,800	40,480	31,170	39,600	30,490
Composting plant City of Aachen	50	2,400	5,300	3,550	5,830	4,550
Composting plant Gabco	50	2,000	4,400	2,800	5,000	3,850
Landscape gardening	50	1,500	3,250	2,550	3,580	2,760
Exhibition construction	7	0	0	0	0	0
Carpentries	7	0	0	0	0	0
Total		67,500		112,370		140,450

Source: Kluttig et al., 1998

Table 4.6: Quantities & Energy Contents of Potential Wood Sources - Aachen

Table 4.7: Waste Quantities Containing Wood Fibre - Aachen

	Generation	Utilisation-Recycling	Disposal (= a+b+c)	Thermal treatment[a]	Landfill[b]	Mechanical-biological treatment[c]
MSW	37,847	0	37,847	37,632	0	214
Bulky waste	6,122	166	5,956	5,956	0	0
Market wastes	265	265	0	0	0	0
Street swipings	2,058	629	1,428	1,428	0	0
Builder's rubble	151	76	76	61	14	0
Gully cleansing	2	0	2	2	0	0
Comp. wastes	13,318	13,292	27	27	0	0
Paper & card-board	18,020	18,020			0	0
Waste wood	3,062	3,027	34	34	0	0
Total	80,846	35,476	45,370	45,141	14	214

Source: AWA 2001

4.6.2 The Wood Bank

Another initiative which has been developed by the City of Aachen is the wood bank, as given by Vankann (2002). In order to heat a one-family-house under mid-European climatic conditions, ca. 20 m^3/a of fuelwood are necessary. Aachen's fuel wood subscription provides residual wood from the forest cultivation as fuel wood. Precondition for subscribers are an environmentally sound wood combustion device (open fire places are not suitable) outside of the immission threatened city bowl. The wood can be purchased for €10/m^3 from the municipal forestry office. More than 60 inhabitants of Aachen made the subscription, and use approx. 800m^3/a of fuel wood. The environmental advantages are savings of fossil fuel and avoidance of CO_2-emissions.

Back-of-Envelope Calculation: Avoidance of CO_2-Emissions According to Jungmeier (1999), the emissions of CO_2-equivalent of a light oil central heating system based on a Life Cycle Assessment (LCA) is 399.32g/kWh, whereas a modern wood log central heating system emits 32.42g/kWh of CO_2-equivalent, which gives a difference of 366.90g/kWh (ca. 0.35kg/kWh). Based on a wood density[1] (pine) of ca. 0.5t/m^3 and a heating value[2] of approx. 15,000MJ/t, the amount of avoided CO_2-eq emissions by combusting 800m^3/a of fuel wood in a modern wood log central heating system compared to the same amount of energy converted in a light oil central heating system - assuming a similar efficiency for both the conversion technologies - is calculated as follows:

$$800m^3/a * 0.5t/m^3 * 15,000MJ/t * 1kWh/3.6MJ * 0.35kg/kWh$$
$$= 583.33tCO_2 - eq \approx 600tCO_2 - eq$$

4.7 Conclusion

The aim of this Chapter was to investigate the renewable energy planning process of a city in the North, in this case the City of Aachen. It has been shown

[1] www.simetric.co.uk/si_wood.htm
[2] http://en.wikipedia.org/wiki/Heating_value

that the history of energy planning of Aachen is tightly interlinked with the global, European and German history of energy planning. A strong environmental element grew i.a. in the German energy sector over the last decades, which could also be felt in Aachen. This lead to the development of the Aachener Modell at the beginning of the 1990s, which was not a broad strategy, but a practical financing model for renewable energy applications. The Aachener Modell was in turn used as a template for the development of the German EEG.

By considering the legislation regarding the renewable energy sector in Europe and Germany, it was found that the role of municipalities was not addressed explicitly, and that a strong shift towards the reliance on liberalised market dynamics is noticeable. The role of municipalities in the renewable energy market is found as public partner in the implementation of projects. There is no additional legislation on the municipal level in Aachen for the renewable energy sector.

Regarding the renewable energy sector, the City of Aachen shifted from broad strategic planning to the development of partial implementation concepts, as this proved to be more efficient. However, there is no renewable energy target for Aachen. Furthermore, planners rely on a strong bureaucratic infrastructure and a good data basis for the development of projects. Although Aachen made substantial efforts regarding the integration of renewable energy sources - especially wind and solar - into its total energy mix, renewables still play a secondary role as compared to fossil energy resources.

The analysis of the example of the wood gasification plant gave good insights into the renewable energy planning process in Aachen. The driver of the planning process is the political will of the city to foster its image as a green and pioneering city in the field of high technology (i.a. in connection with its world renown university), as well as to secure its market place through economic development. A strong planning infrastructure and efficient coordination between the involved parties proved to be necessary for carrying-out a high-technology project at this order of magnitude and this level of complexity, especially against the backdrop of a saturated an ailing economy. Still, the planning process had to be readjusted several times, i.a. due to changes in the subsidisation model (EEG) in order to secure the project's economic viability.

The renewable resource 'wood' was chosen based on technical and economic facts, as well as its novel nature. The core conversion technology was chosen based on econo-political reasons and entrepreneurial risk at an early stage, whereas standard services were officially tendered at the end of the planning process. The energy products were selected in order to ensure highest profitability. Interestingly, a two-phase plan was developed regarding the types of energy carriers produced. However, a weak spot lies in the lacking systematic consideration of options for fossil fuel substitution in the industrial sector.

Problems emerged at the implementation phase, because of economic and technical reasons, causing a delay of two years. As there is no energy shortage or need for a specific energy carrier, the delay has no immediate consequences in terms of social, economic and/or environmental aspects.

In the following Chapter, the case study presented in this Chapter will be compared to the case study carried out for a city of the South in Chapter 3 in order to identifiy similarities and differences in the renewable energy planning approaches of both cities.

Chapter 5

A South-North Comparison: the Case of Cape Town vs the Case of Aachen

5.1 Introduction

In this Chapter, the cases of the City of Cape Town and the City of Aachen will be compared. Against the background of two different historical, climatic and geopolitical contexts, their respective renewable energy planning processes will be analysed, stressing the role of enabling and inhibiting factors in terms of socio-political aspects.

The outcomes of this comparative analysis are expected to substantiate Hypothesis 1: *"The municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given"*.

5.2 National Background

Energy issues in both Cape Town and Aachen are heavily interlinked with the history and geopolitical position of their respective countries. In the following, these issues shall be addressed and compared, in order to build a strong basis for any subsequent explanations.

5.2.1 Energy, Economy and Geopolitical Situation

As can be seen in Figure 5.1, Germany has a total primary energy supply of 12,238 PJ. Its main energy source is oil with 37%, followed by gas with 23%. In its energy mix, renewables account for 4.6%. Germany is a net energy importer: the dependence of Germany on energy imports has continusously increased, and currently accounts for 100% for uranium, 97% for crude oil, and 83% for gas. For mineral coal, the import share is 61%. Germany relies only for brown coal and renewable energy sources entirely on indigeneous capacity (BMU, 2006).

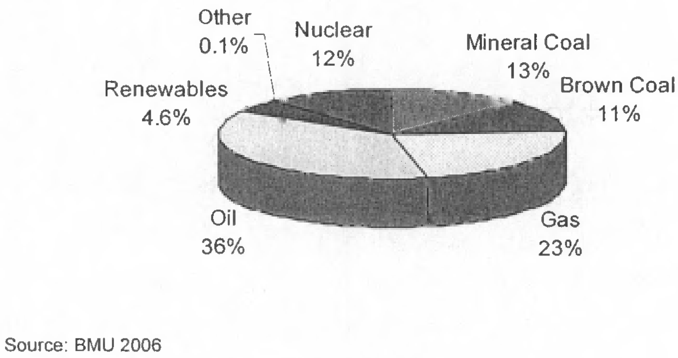


Figure 5.1: Primary Energy Supply - Germany

As can be seen in Figure 5.2, South Africa is a net energy exporter, and has a total primary energy supply of 4,295 PJ (2000), which is three times smaller than Germany's. It possesses huge coal reserves, forming the majority of the 79% of primary energy supply, wich makes it one of the cheapest coal-based electricity producers world-wide. Furthermore, it relies strongly on imports regarding its crude oil supply. Renewables account for 6% of the total primary energy supply (DME, 2005b).

In terms of annual energy consumption per capita compared to GDP in Purchasing Power Parity (ppp) per capita as represented in Figure 5.3 (DME, 2005b),

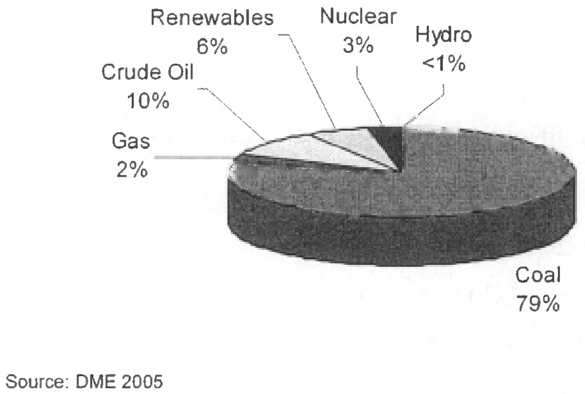


Figure 5.2: Primary Energy Supply - South Africa

it can be stated that South Africa has a GDP per capita three times smaller than Germany's, while its energy consumption per capita is only twice as small. This shows that South Africa is close to other developing countries regarding the energy consumption and GDP patterns, whereas Germany is close to other developed countries. Furthermore, it shows i.a. that Germany has got a higher energy efficiency (lower energy intensity) than South Africa.

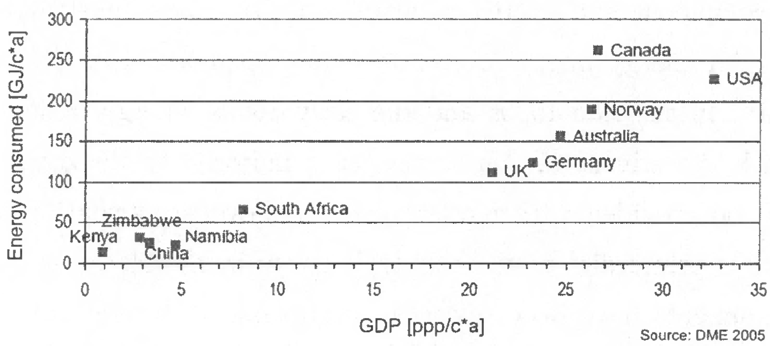


Figure 5.3: Annual per Capita GDP and Energy Consumption (2000) - Selected Countries

5.2.2 History of Energy Policy

For both countries, energy policy has been analysed starting after World War (WW) II. The existing political regimes in both countries heavily influenced energy policy.

In Germany, a young democracy recognized the energy sector as being a key industry delivering a basic product to the whole economy. Energy security and cost-effective energy supply were the axioms around which an internationally competitive industry were to be build. Germany acquired new sources in order to broaden the variety of available energy sources, so that global market fluctuations regarding energy carrier prices could be balanced. This was of crucial importance before the background that the country heavily relied on energy imports. It was only in the early 1980s that a new approach regarding energy issues emerged, based on environmental concerns and a foreseeable decrease of internationally available fossil resources. Renewable alternatives shifted more and more to the centre of the energy-political discussion, and triggered the development of subsidisation schemes such as the Aachener Modell. Ultimately, the EEG was adopted based on the template of the Aachener Modell.

In South Africa, a post-colonial totalitarian regime was concerned by the economic development and energy security of an economy constrained to a white minority. An energy intensive economy developed based on the abundance of cheap coal. In the late 1980s and the early 1990s, energy policy shifted drastically with the advent of democracy, as a majority of disadvantaged citizens needed to be provided with modern energy. Poverty alleviation and economic upliftment is primordial to the country's government. However, legislation and policy documents have been released, addressing renewable energy and energy efficiency issues, as well as BEE in the electricity and liquid fuels sector.

Environmental concerns and social issues stay in sharp contrast, as the poor can be provided with cheap electricity generated from low-grade coal, having drastic environmental consequences.

5.2.3 Discussion

In both countries, energy security and economic development play a basic role. But whereas in Germany, an environmental movement with a strong civil and political tradition and lobby developed, South Africa's priorities lay with social issues related to the country's poor.

It is also due to both the countries geopolitical position that the emerging issues have been dealt with in a specific way. If Germany would not have had to rely on energy imports for developing its economy, it is imaginable that its economy would have been developed around the abundance of indigenous energy resources, as it was the case with the USA (especially during the first half of the last century - see e.g. Heinberg (2003)). It should be noted that a shift to the development of renewable resources is partly due to the scarcity of Germany's own resources, and the possibility to develop a new export-driven technology market. It should furthermore be noted that in the first half of the last century, the scarcity of Germany's resources was one main reason for its expansion will in order to access new energy resources, which eventually lead to WW II (see e.g. Heinberg, 2003). In the case of South Africa, a low availability of own coal resources would have made the internationally embargoed Apartheid regime economically inviable, thus leading to an earlier collapse.

5.3 Climatic and Demographic Framework

5.3.1 Climatic Conditions

The City of Cape Town is located at the southern tip of Africa in a Mediterranean climate, characterised by a wet winter and a dry summer. The temperature range[1] is 7°C and average annual precipitation is approx. 52 cm (Benders-Hyde, 2000).

The City of Aachen is situated in central Europe, being subject to a moist continental climate. Seasonal changes between summer and winter are very large. Daily temperatures also change often. Abundant precipitation falls throughout

[1]Difference between the highest and lowest average monthly temperature over a one year period

the year. The temperature range is about 31°C, and annual precipitation levels at around 81 cm (Benders-Hyde, 2000).

The temperature range in Aachen is 24°C higher than in Cape Town, and annual rainfall is 60% higher in Aachen. From an energy perspective, these important differences in climatic conditions affect energy use patterns especially regarding space heating during the winter months (see Section 5.3), and the prevalent biome. The latter aspect has especially repercussions on availability of quantity and types of biomass, as well as availability of arable land for biomass cultivation.

5.3.2 Demographical Facts

As can be seen in Table 5.1[1], Cape Town has a population of approx. 3 million inhabitants, whereas Aachen only counts approx. 260,000 inhabitants, a factor >10 smaller. Both are urban areas, having a same order of magnitude regarding the population density, with the City of Aachen having a slightly higher density of approx. 1,600 inhabitants per square kilometer, compared to 1,200 in Cape Town.

	Cape Town	Aachen
Population	2,900,000	260,000
Density [inh/km^2]	1,200	1,600
Unemployment [%]	29.2	12.6
Average Income [ZAR/a]	27,000	333,000
Foreigners [%]	3.0	17.3

Table 5.1: Demographic Data - Cape Town/Aachen

From an unemployment perspective, Cape Town has a percentage almost three times as high as Aachen's, with 30% compared to 12.5%. The average (pre-tax) income in Cape Town is more than a factor 10 smaller than Aachen's, with ZAR 27,000/a compared to €37,000/a (approx. ZAR 333,000/a).[2] Furthermore,

[1] StatsSA (2001), CCT (2006b), COJ (2004), LDS NRW (2001), Alleskiar.com (2005)

[2] It should be borne in mind that incomes need to be considered in the context of the prevailing costs of living. Generally, a rough "Big Mac" factor (see e.g. Orley Ashenfelter &

white households in Cape Town earn approx. 7 times as much as African households (COJ, 2004). These numbers give an indication on the important social inequalities prevailing in Cape Town.

5.4 The Local Energy Sector

In this Section, the local energy sector in Cape Town as well as Aachen will be addressed. Energy consumption and generation patterns will be compared, as well as the legislative framework guiding and affecting the urban energy planning processes in both cases. Subsequently, a special emphasis will be laid upon the renewable energy planning process of the two cities. Next, an energy planning model for local authorities will be proposed based on the insights won of the comparison of both approaches. Finally, potential renewable resources will briefly be discussed.

5.4.1 Consumption and Generation Patterns

5.4.1.1 Status Quo

Based on the data on total energy usage in Cape Town and Aachen - 120 PJ/a and 30 PJ/a respectively - the energy consumed per capita and year has been calculated for both cities, amounting to 41.5 GJ/c*a and 125 GJ/c*a, Cape Town's per capita energy consumption being approx. three times smaller than Aachen's. By comparing energy demand by sector for both cities (see Sections 3.2 and 4.4), it appears that Aachen's energy demand is more balanced, ranging from 11%-34%, whereas Cape Town's demand varies from 1%-55%.

Aachen's household energy demand has the biggest share with 34% and accounts for 42.5 GJ/c*a, whereas Cape Town's household sector has a share of 14% and accounts for 5.81 GJ/c*a, a factor 8 smaller than Aachen. The main reason for this difference is the energy demand for space heating during the winter months in Aachen (see Section 5.3.1). Although the share of Cape Town's transport sector is the biggest with 55%, and Aachen's transportation sector only

Jurajda, 2001) of 2 is assumed between South Africa and Germany. This still leaves a factor 5 regarding the adjusted average pre-tax income difference between Cape Town and Aachen.

accounts for 13% of the total energy mix, the respective annual values for energy consumption per capita are of the same order of magnitude: 22.8 GJ/c*a for Cape Town and 18.75 GJ/c*a for Aachen.

By comparing the energy carrier consumption for both cities, it appears that Cape Town's transport sector is responsible for the lion share of energy carrier consumption - Petrol & Diesel - accounting together for a total of 56%. Aachen's combined Petrol and Diesel consumption only accounts for 22%. Interestingly, Aachen has a gas grid, providing 34% of Aachen's energy consumption. This is even high compared to German standards. On the other hand, Cape Town relies on 33% of fossil fuel based electricity for meeting energy demand. Aachen's electricity share is only 16%. Furthermore, LFO accounts for 23% in Aachen. Remarkably, a district heat system exists in Aachen, accounting for 3% of energy delivered. Where in Aachen, the renewables wind and photovoltaics appear already in the statistics, the traditional energy carrier 'fuel wood' still plays a role in Cape Town's energy metabolism.

5.4.1.2 Projections

In the case of Aachen, no huge variations in quantity and variety of energy carrier consumption is expected. The energy market is closely related to the subdued economic situation. In the case of Cape Town, an annual growth rate in energy consumption of 2% is assumed, based on economic development and population growth.

Regarding the role of renewables, it is expected for Aachen that by 2010, the commissioning of the planned wood gasification plant will increase existing renewable energy production by approx. 200%, increasing its share to slightly over 1% of total current energy consumption, or 20-25% of the electricity demand of the household and small enterprise sector. For Cape Town, a challenging target of 10% of renewables has been set for 2020.[1]

Interestingly, wood would reappear in Aachen's energy mix, this time not as traditional energy carrier as in Cape Town's energy mix, but as renewable energy carrier used for sustainable energy generation.

[1] As to the probability with which this target is going to be achieved, no projections are available at the point of writing.

5.4.1.3 Linkages to Waste Management Sector

For both cities, the waste management sector has as such not systematically been integrated in the energy provision sector.

In the case of Cape Town, methane is recovered at the Cape Flats Wastewater Works. It is noteworthy that methane recovery for energy purposes is planned for the Bellville South landfill site. Interestingly, a study has been carried out by Austin *et al.* (2006) looking at potentials for energy recovery from MSW in South Africa, using Cape Town in its case studies.

In the case of Aachen, a waste incineration plant exists with integrated energy recovery for electricity generation; its main purpose is though the waste treatment aspect rather than energy generation.[1] Several other projects have been planned (i.a. Biogas-Anlage Aachen/Vetschau), although these projects have not been realised up to the point of writing. Regarding existing waste streams, waste utilisation for energy recovery is technically imaginable, but economic viability needs to be given.

5.4.2 Legislative Framework

In the case of Cape Town, several national and local policy papers, guidelines and reports describe broad aims and goals regarding the development of the (renewable) energy sector (see Section 3.4.1). For Aachen, two national key documents are of importance, which are embedded within the framework of EU legislation (see Section 4.3.4).

When comparing specifically the two national documents regulating the renewable energy sector, namely the EEG and the White Paper on the Promotion of Renewable Energy, it becomes apparent that the former is a concrete guideline regulating the technology related subsidisation of renewable energy projects, whereas the latter is a broad report describing the country's strategies and goals

[1] 360,000t/a of waste are processed, approx. 20% of which stem from Aachen. The turbine which is run with process steam from waste combustion has an electric capacity of 35MW. Assuming 7,500 full load hours per annum, 262GWh/a of electricity are produced. As Aachen's share of input material is 20%, 52.5GWh/a are produced from Aachen's waste, which amounts to approx. 3.5% of Aachen's total electricity consumption.

in the renewable energy sector. Furthermore, South Africa sets itself a renewable energy target, but does not give any concrete technical implementation guidelines as to how it shall be achieved. These guidelines are not specified on the local level either (here in the case of Cape Town). This issue is being addressed as the implementation gap by Chapel (1977).

5.4.3 The Renewable Energy Planning Process

5.4.3.1 Motivation

For both cities, a political will to support an image as being pioneering and environmentally concerned is the stimulant for renewable energy projects. Financial viability of the projects is a fundamental prerequisite, and economic growth coupled to job creation is a strong motor. In the case of the planned 30MW wood gasification plant in Aachen, short-term viability is based on subsidies, and long-term viability is based on free market dynamics, requiring a switch regarding the delivered energy products. Economies of scale were applied in order to guarantee viability.

In Cape Town, a number of sustainable energy projects are taking place. Efforts are focused on interventions such as the SWHs by-law, the Energy Upgrade Project for 2,300 low-income households in Kuyasa, and the production of a secondary energy carrier and methane recovery at the Cape Flats Wastewater Works. The future supply of 13.2 GWh/a of wind generated electricity has been contractually guaranteed from South Africa's first IPP.

Although the planning approaches for both cities are in line with the principles of LA21, Cape Town needs to address pressing social issues by delivering modern energy services. In Aachen, no pressure regarding the supply of specific services exists. However though, an increasing public environmental awareness has created a market for green energy sources.

5.4.3.2 Planning Infrastructure, Competencies and Capacities

In both cases, the cities mainly act as distributors of energy generated by third parties, as own generation capacities are low.

A decreasing trend regarding Cape Town's interference with the energy sector is noticeable since the restructuring of the EDI, where responsibilities have partly shifted towards the REDs, which are in the process of being created. Similarly, a decreasing trend regarding Aachen's authority over the energy sector is noticeable since the deregulation of the German energy market in 1998.

Furthermore, the role of both cities increasingly shifts to the facilitation of renewable energy projects, and the implementation of energy efficiency policies and by-laws.

In Cape Town, renewable energy planning happens at two different bodies at the city level, namely the Electricity Services and the Development Services. In Aachen, the Office of Environmental Affairs and the Energy Advisory Board are responsible for energy planning issues. A public services company (STAWAG), fully owned by the City of Aachen, has its main purpose in energy distribution. Moreover, the STAWAG is responsible for project planning and implementation, which leads to a clear differentiation of duties between the bodies involved in the energy planning process in Aachen. Whereas an implementation gap has been identified for Cape Town, Aachen has dedicated a whole company for implementation tasks.

5.4.3.3 Data Basis

In Cape Town, data collection is in its start-up phase, providing a narrow set of data which makes it difficult to identify trends and formulate projections. It is noteworthy that the data collection under the State of Energy Report - the first of its kind for Cape Town - happened in partnership with stakeholders from the private sector and academia. However, a limited understanding of renewable resources prevails.

In Aachen, energy planners can fall back on a good data basis regarding existing resources and available technologies. It is estimated that at the point of writing, all feasible renewable energy projects have been identified based on the available data.

5.4.3.4 Decision Making Process

In the global North, an environmental mindset has organically grown over the last decades, which found its place in mainstream politics during the 1980s. Although old democracies as those found in Northern countries are characterized by dualistic political views (e.g. Republicans and Democrats (US), Tory and Labour (UK), CDU and SPD (Germany)), there is a growing fundamental consensus regarding basic issues such as environmental protection, as illustrated by the fact that Germany is currently lead by a great coalition of CDU and SPD. A relative political stability leads to a good basis for an efficient long-term planning process, on the national as well as the local level.

In South Africa, a young democracy is confronted by a multitude of strongly different perspectives represented by a range of parties, having at times different political currents within themselves (e.g. ANC). On the local level, this situation leads to an inefficient short-term planning process due to institutional hurdles and blockages. Furthermore, the planning process is hampered by a missing coordination between the responsible bodies; a lack of strong guidance from national & provincial government regarding implementation plans, funding capacity and financing schemes; and lacking technical skills. Furthermore, Cape Town's government has low influence on the liquid fuel sector. Typical environmental issues in a Northern tradition are of minor priority against a background of pressing social needs in Cape Town.

Renewable energy projects are carried out in both cities in partnerships between parties of the public and the private sectors. In both cases, project implementation is based on a regulated tender process. In Aachen, a private company (STAWAG), fully owned by the City, is responsible for the implementation of projects. The responsibilities of both parties are clearly defined, organized and efficient. Aachen's energy planners can fall back on an efficient financing model for renewable energy projects (EEG). Although the planning process for the wood gasification plant is well organised, it is still an iterative process, as the planning process had to be revisited several times due to changes in legislation. On the other hand, a strongly regulated planning process tends to become old, rigid and bureaucratic. It is therefore that the City of Aachen moved away from strategic planning to the formulation of implementation oriented part-concepts, which led to more flexibility in the planning approach.

In Cape Town, the City undertakes strategic planning, starting with the Integrated Development Plan (IDP), upon which the Integrated Metropolitan Environmental Policy (IMEP) is built. The Energy Strategy is subsequently being formulated as part of the IMEP. This construct lets appear a certain level of complexity, hampering an efficient renewable energy planning process. Moreover, the City of Cape Town formulates challenging sustainable energy goals, which tend to be decoupled from actual facts and lack means for implementation, as illustrated for the case of the SWH by-law. However, sustainable energy projects are carried-out within the city's borders in connection with private partners. These relationships are diverse and not institutionalised. This leads to a dynamic and organic planning process, able to react on currently emerging needs, and in line with the prevailing Zeitgeist. As has been shown for the case of the Kuyasa project, the City, in collaboration with SouthSouthNorth, has linked typical Southern development needs with environmental issues, creating a powerful pilot project, and assuring financing from Northern partners through the Clean Development Mechanism (CDM). It has furthermore been observed that renewable energy projects can be carried out by departments not directly responsible for energy issues within the City of Cape Town.

The planning process for the gasification plant in Aachen lasts several years, and early public awareness campaigns were crucial in order to guarantee a fast and easy approval process. Whereas an aspect leading to delays in the planning process is the tendering of standard services, as a public sector corporation is at the helm of the project. For Cape Town, planning processes last several years as well. However, major delays were recorded for the case of the Darling Wind Farm, mainly due to a lacking case of precedent, but also a lacking local public support. On the other hand, the Kuyasa project is carried out in close collaboration with the affected households.

5.4.3.5 Risk Factors

For Aachen, risk factors regarding the renewable energy planning process have been identified as being i.a. technology maturity, changes in legislation, and security of input supply. In the case of the wood gasification plant, the conversion technology has not yet been proved on commercial scale. Furthermore, changes in legislation have to be integrated in the planning process, as the economic viability in the start-up phase of the project is built on subsidisation guaranteed by the EEG. Lastly, the minimum required input stream must be guaranteed. Therefore, detailed studies regarding the availability of required renewable resources were carried-out beforehand.

In the case of Cape Town, risk factors include the ones stated for Aachen, as well as broader issues such as political and economical stability of South Africa's young democracy (see e.g. Erb *et al.* (1996) and Delany & Varga (2002)). A further important risk factor emanates from the aspect of cost estimation. Up to this point, very few cases of precedence exist for medium- to large-scale applications of renewable energy technology in South Africa, which makes it difficult to develop reliable projections regarding capital expenditure for new ventures.[1]

5.4.3.6 Cooperation

Against the background of Aachen's wood gasification project, the efficient collaboration between the different stakeholders has been identified as a key issue, so that a coordination office has been created. The project is being carried-out in partnership with German parties of the public and private sector, and academia.

In Cape Town, renewable energy projects have been carried-out in collaboration with local and international partners from the public and private sectors. Academia has not systematically been involved. For the realisation of the SWH by-law, the Darling Wind Farm, and the sustainable energy project at the Cape Flats Wastewater Works, parties from developed countries have been involved, addressing typical Northern aspects of renewable energy supply and energy efficiency. In the case of the Kuyasa project, SouthSouthNorth, an international climate-change NGO headquartered in Cape Town, has been involved in order to tackle a typical Southern energy & development challenge.

Against the background of the existing LA21-partnership between both cities, relatively little activity has been recorded regarding renewable energy projects.

[1]This issue is being discussed for the case of biofuels by Amigun *et al.* (2006)

An emphasis has been laid upon the financing of demonstration projects in schools in disadvantaged suburbs of Cape Town.[1]

5.4.3.7 Cross-Cutting Issues

Furthermore, cross-cutting aspects of BEE are integrated in Cape Town's renewable energy approach, embedded within a frameset of national guidelines.[2] In the four projects presented for the case of Cape Town, it is obviously or covertly aimed at job creation, local empowerment, creation of opportunities for Small Medium and Micro Enterprisess (SMMEs), installation of equipment by black labourers, etc., all in line with a broader concept of energy supply coupled to issues of social upliftment and economic development called 'Energisation'[3]. One also tends to speak about 'Black Energy'.

5.4.4 An Energy Planning Model for Local Authorities

The author proposes in Figure 5.4 a model describing dynamics and interactions in the renewable energy planning and implementation process at the municipal level. The model aims not at being ideal, but rather to reflect the planning processes observed for four sustainable energy projects in Cape Town, and one renewable energy project in Aachen.

The driving axis of energy planning and implementation on the municipal level starts with a defined energy demand in a specific development situation, as described by the white arrows in Figure 5.4. A decision making body set up on the local governmental level will decide on which energy supply strategy to be adapted to meet the previously defined specific energy demand. This purpose-optimised energy supply strategy will have to be realised and implemented in order to practically meet the primarily defined energy demand.

Interestingly, it has been observed for the case of Cape Town that the decision making body is not always the same one. It could be seen as a city energy planning desk, where the decision-making process is lead alternatively by different City

[1]see Section 2.2.6
[2]see Section 3.3.4
[3]see Section 3.4.1

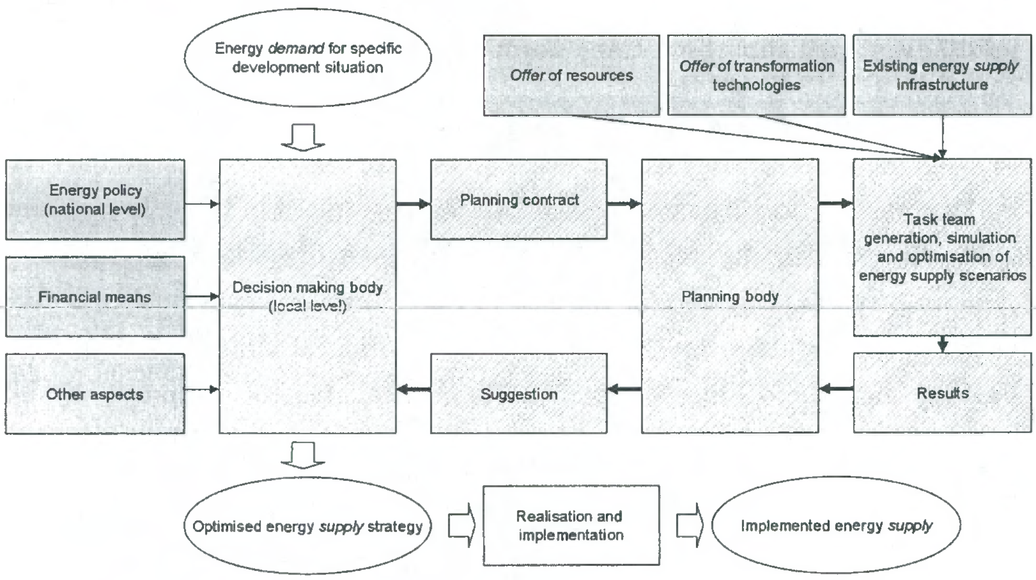


Figure 5.4: Energy Planning Model for Local Authorities

departments, e.g. electricity department, development department, wastewater department, and housing department.

The decision making body may have an energy policy building on that formulated at the national level (and subsequently the provincial level), as well as on the availability of financial means, and on other aspects of importance to their urban constituency, such as local air quality (tying in with "green energy"), or Black Economic Empowerment ("black energy") in the current South African context.

As can be seen in the cross-hatched area of Figure 5.4, a planning body constituted out of experts stemming from the public and private sector, possibly also from academia is formed. Its purpose is to steer the energy planning process and to represent an interface between political decision making and expert opinion. A planning contract formulated by the decision making body will direct the planning body to create a task team responsible for the generation, simulation and optimisation of energy supply and use scenarios. It will base its work on 3 different types of data: the offer of resources, the offer of transformation technologies and the existing energy supply infrastructure. Eventually, the task team will deliver a set of prioritised projects that it will feed-back to the planning body. The planning body will subsequently formulate a suggestion on which projects should be adopted. Finally, it is the role of the decision making body to agree on this suggestion, and to lobby for or provide adequate resourcing for the selected projects. In an affirmative case, an optimised energy supply strategy is released, which will have to be realised and implemented so that the preliminarily defined user demand will practically be satisfied. In a negative case, the planning loop will have to be carried out again.

5.4.5 Current Biomass Utilisation in Cape Town and Aachen

In this section, the current biomass utilisation practices in Cape Town and Aachen will directly be compared.

According to Jeffares & Green (2004), a total amount of ca. 112,000 t/a of biodegradable waste is being generated in the City of Cape Town (CCT), whereof 30,000 t/a (ca. 10 kg/c*a) - 27% of the total biodegradable waste amount - are being composted. This fact lets appear the potentials for further treatment and composting of biodegradable wastes in Cape Town. Biodegradable wastes are not collected separatly on a household level, but an infrastructure of collection spots exists for the capture of biodegradable wastes. Interestingly, the utilisation of traditional biofuels such as fuel wood play an important role especially in Cape Town's informal sector. A detailed investigation of biomass utilisation in formal and informal sectors is carried out in Chapter 7.

According to AWA (2001), ca. 34,000 t/a of biodegradable waste are generated in the City of Aachen. Ca. 2,500 t/a of biodegradable waste are treated at the waste incineration plant MVA Weisweiler, whereas ca. 31,500 t/a of biodegradable waste are handled at the local composting plant - 93% of the total biodegradable waste amount. Broken down to a per capita basis, 128 kg/c*a are being composted in Aachen. This fact lets appear that the potential for the utilisation of biodegradable wastes in Aachen are almost completely exploited. No biodegradable waste is being disposed of (directly) at the local landfill site. All compostable wastes are either collected via the 'Biotonne' (separate bin for the collection of biodegradable wastes), or via different pick-up or bring systems. Furthermore, a biogas-plant and a wood gasification plant were planned for the City of Aachen, but were not realised up to the point of writing. The biomass feedstock considered for these projects would not (only) have consisted of existing biodegradable wastes, but also of biomass cultivated especially for such a purpose.

5.4.6 Potential Renewable Resources

In Aachen, the potentials of wind and PV have been fully investigated. The same statement is applicable for biomass, and more specifically for fuel wood. Regarding other wood fibre based resources, there are recoverable amounts in the MSW stream. The energetic utilisation of green waste has been considered as input feed for a biogas plant. However, the project was not carried out because of political will.

In Cape Town, several studies have been carried out in order to investigate the potentials of existing renewable resources. Regarding wood fibre based resources, no systematic investigation had happened at the point of writing.[1] In contrast to Aachen, there are no nameable commercial forest plantations in proximity to the City.[2]

5.5 Insights and Recommendations

Due to their historical national backgrounds and their different climatic, demographic and economic settings, both cities are faced with challenges different in nature regarding the renewable energy sector. Whereas in Aachen, environmental concerns and economic growth are key factors of the development of the renewable energy market, Cape Town is faced with important social tasks regarding energy provision of the poor.

[1] A detailed MFA is therefore presented in Chapter 7, showing theoretically the potentials of energy recovery from existing material streams.

[2] Note that the Ukuvuka campaign (www.ukuvuka.org.za) aims at reducing the fire risk in the Cape Peninsula emanating from alien vegetation by cutting down specific wood types. This activity releases certain amounts of potentially recoverable wood. At the point of writing, no information regarding the recovered amounts of wood were accessible.

In Cape Town, environmental consciousness is not necessarily the prime driver regarding the integration of renewable energy options. It is rather believed that in Cape Town, renewable energy options are under specific circumstances more suited to meet energy service demands than existing fossil-based options, specifically regarding social and economic development needs. It was found that Cape Town's per capita transport energy requirement exceeds that of Aachen's, whilst in the remaining categories, Cape Town's energy requirements account for only 1/3 to <1/10 of Aachen's on a per capita basis. A recommendation would be for Cape Town to focus on sustainability measures regarding its transport sector, preferably in terms of energy efficiency options such as a modal shift to public transportation means, rather than renewable energy options such as the introduction of biofuels.

Moreover, it is recommended that Cape Town continues with its efforts to set-up its renewable energy planning infrastructure, although responsibilities regarding electricity distribution will shift to the RED. Based on Aachen's example, Cape Town should act more like a dynamic corporate organ with public duties instead of a rigid public institution with steering and control functions. As local government is at the intersection between strategic planning and implementation of projects, it could become a meaningful player in South Africa's renewable energy scene. On the other hand, Aachen could seek to find new project opportunities in collaboration with new national and international partners, e.g. via the existing but neglected LA21-partnership with Cape Town. A challenging task would be to couple insights won during the realisation of renewable energy projects with developmental needs of the South.

Furthermore, the creation of pilot projects on local governmental level has shown in the case of Aachen and Cape Town that they can potentially be utilised as templates for reproduction in other cities, or even federal government.

Finally, a point of argument is the financing of subsidisation models such as the Aachener Modell and the EEG in the context of Cape Town. For both approaches, costs are redistributed to the totality of energy (electricity) consumers. For Aachen, concerns were already formulated regarding the additional burdening of low-income households. In the case of Cape Town, the redistribution of costs should exclude low-income households, as the additional financial burden would not be bearable. Remember that social tariff structures have already been developed for electricity distribution to poor households in order to make supply affordable to them. Theoretically, such a subsidisation model is believed to be applicable for Cape Town, but the economic feasibility must be proved beforehand. Furthermore, financing schemes of renewable energy applications in developing countries exist already, such as the Clean Development Mechanism (CDM), illustrated by the case of the Kuyasa project.

5.6 Conclusion

In this Chapter, a comparison of the case studies on the City of Cape Town and the City of Aachen has been carried out.

Firstly, the different national backgrounds of both cities have been discussed. It has been shown how fossil energy reserves influenced past and present energy policy, and lead to different priorities in the energy planning sector. Germany has been identified as a net energy importer, having a strong tradition regarding environmental matters. South Africa has been identified as a net energy exporter, having high priorities regarding social and economic upliftment of previously disadvantaged population groups. Cape Town is prone to high inequalities in terms of income along previous racial segregation lines.

Energy consumption patterns for both cities have been compared. Analysis showed that Cape Town's energy consumption per capita is three times smaller than Aachen's. Whereas Cape Town's main energy demand stems from the transport sector, domestic demand accounts for the highest share in Aachen's energy mix. The biggest difference in per capita energy consumption has been identified for the household sector, caused by a need for heating during the cold winter months in Aachen. However, per capita energy consumption for the transport sector in both cities is of the same order of magnitude. In both cases, the share of renewables is $< 1\%$.

Regarding the projections of the city's energy sectors, Cape Town is affected by economic development and population growth, whereas Aachen's energy market is predicted to be rather stagnant. Cape Town set itself a challenging renewable energy target without any concrete implementation plans, whereas Aachen's renewable energy share will rise above 1% with the realisation of the planned wood gasification plant.

For both cities, the waste management sector has not systematically been integrated in the energy sector. However, Aachen possesses a waste incineration plant that generates energy by-products, accounting for 3.5% of Aachen's consumption for the case of electricity. For Cape Town, a secondary energy carrier is produced at the Cape Flats Wastewater Works, along with the energetic recovery of methane.

An implementation gap has been identified regarding energy related legislation relevant for Cape Town. Regarding potential renewable resources, a deep understanding of available resources is prevalent in Aachen.

Cape Town's renewable energy planning process can be qualified as dualistic, as on the one hand, it is not fully coordinated and strategic regarding its public component. Its efficiency is decreased due to complexities in the planning infrastructure, as well as a lack of technical skills and financial means. On the other hand, the planning process is flexible and improvised, especially in its collaboration with different partners in order to tackle challenges of different natures. It has been demonstrated that the City of Cape Town possesses capacities such as an active City council, and can fall back on a pool of experts stemming from the private sector and academia, enabling the City to get actively involved in the realisation of RE projects, whilst simultaneously tackling social issues.

Aachen's planning process is efficient, and the relationship to its private partner is well established and organised. Aachen's energy planning process can furthermore be qualified as mature[1], rigid[2], and institutionalised[3].

[1]The implemention of environmental issues is well understood, and developed over the last three decades (see Section 4.3.2 and 4.3.3).

[2]It is strongly based upon guidelines such as the EEG (see Section 4.3.4.3), and relies on a regulated approval and tender process (see Sections 4.5.2.10 and 4.5.2.12), yet still being driven by the vision of a pioneering city (see Section 4.5.2.1).

[3]Decision-making is undertaken by steady bodies within the City and the STAWAG (see Section 4.3.5), and planning and implementation requires efficient coordination between the involved parties (see Section 4.5.2.6). However, it has been shown for the case of the planned biogas plant in Aachen-Vetschau that an institutionalised planning process offers opportunities for political blockages (see Section 4.3.6.2).

Cape Town is faced with important challenges regarding socio-political aspects due to its population heterogeneity, and risk factors including cost estimation, as well as economic and political stability. It has been demonstrated i.a. by the case of the Kuyasa housing project that clear social consequences of energy decisions or inactions are given. In order to optimise energy provision to low-income population groups, and achieve the target of poverty alleviation and economic upliftment, a detailed understanding of energy needs must be developed, coupled to the implementation of adequate and sustainable energy supply chains. These issues will be discussed in the following Chapter.

An energy planning model has been proposed for local authorities, and insights and recommendations have been formulated. The importance of local government as a key player in the energy scene has been stressed, and options for the improvement and the development of the renewable energy planning sectors have been formulated in both directions. Finally, a brief discussion on the economic viability of subsidisation models in the Capetonian context has been carried-out.

Based on the background given on the link between energy and poverty in Section 2.2.2.4, the presentation and discussion on urban planning approaches in Section 2.2.4, the national backgrounds presented and compared for both case studies in Section 5.2, and the results obtained for the comparative analysis of the energy planning approaches for both case studies in Section 5.4, it is claimed that Hypothesis 1 - *"The municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given"* - has been sufficiently substantiated, so as to make a significant intellectual contribution to the addressed topic.

Chapter 6

Renewable Energy for Sustainable Urban Development: Employing the Concept of Energisation

6.1 Introduction

In the previous Chapter, it has been identified that socio-political aspects play a far greater role in the urban renewable energy planning processes of cities of the South than cities of the North. An implementation gap has been identified for sustainable energy projects in the South, which could be addressed by integrating an understanding of the linkages between socio-economic development needs and energy supply.

It has been stated as second Hypothesis of this dissertation that *"[b]y focusing strongly on detailed socio-economic development needs and coupling these directly to renewable energy supply options, environmentally sustainable and socially meaningful development can be enabled by the energy planning process"*.

In order to substantiate this Hypothesis, the concept of energisation will be analysed by means of a literature review, with the aim to identify the existing linkages to sustainable development issues. Based on the findings of this review, the concept of energisation will be extended in order to fill potential gaps. Furthermore, the extended approach will be translated into an economic model in order to visualise the multiple effects of energisation. Eventually, the new understanding of the concept of energisation will be integrated into the technical energy planning process, by means of a checklist for energy planners.

Note that a general background regarding the linkage between energy and poverty is given in Section 2.2.2.4.

6.2 The Concept of Energisation

OED (1989) defines the verb "to energize" as follows: *"[...] b. To infuse energy into, supply with energy. (Now esp. in technical use.)"*.

In the field of energy planning, the term 'energization' (or 'energisation'), the substantive of the verb 'to energize' (or 'to energise'), has been utilised in the literature in different ways and different contexts, not being bound to a clear and unambiguous definition. The term energisation is also employed as a trendy catchphrase, often more in a figurative manner, inducing progress, boost and stimulation. In the following Section, definitions of the term 'energisation' as well as contexts in which it has been utilised will be presented, so that eventually, quintessential findings regarding the concept of energisation can be formulated.

6.2.1 Definitions and Contexts of Energisation

In the 1980s, Hosier & Dowd (1987) introduced the concept of an "energy ladder" in the context of developing countries, a basis for the concept of energisation. They defined it as follows: *"The underlying assumption is that households are faced with an array of energy supply choices which can be arranged in order of increasing technological sophistication. At the top of the list is electricity, while the low end of the range includes fuel wood, dung, and crop wastes. As a household's economic well-being increases, it is assumed to move 'up' the energy ladder to more sophisticated energy carriers. If the economic status decreases, through either a decrease in income or an increase in fuel price, the household is expected to move 'down' the energy ladder to less-sophisticated energy carriers. Thus, the* *energy ladder serves as a stylized extension of the economic theory of the consumer: as income rises (falls) households consume not only more (less) of the same goods, but they also shift to consuming higher (lower) quality goods."*

In Figure 6.1, the relationships between fuel usage and prosperity are being represented on the energy ladder. At that point in time, energisation could have been understood as climbing rungs on the energy ladder.

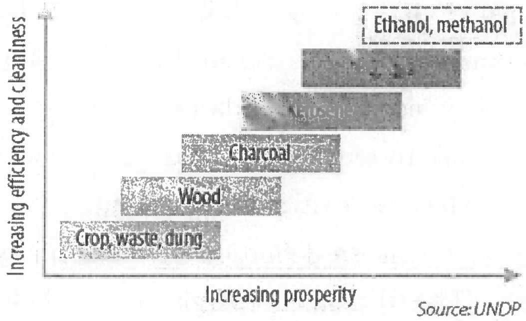


Figure 6.1: Relationships Between Fuel Usage and Prosperity

Ramakumar (1996) stated that *"the concept of* energization, *in which all the available renewable resources are used in an integrated fashion with proper resource-need matching, is preferable to straight-forward electrification"*. Interestingly, the application and design of Integrated Renewable Energy System (IRES) for the energization of rural areas of developing countries is discussed in the same paper.

Laing & Rosselli (1998) defined a theoretical framework for the concept of energisation, which is called the four forces model, without giving a concise definition of the term. Their framework is based on the concept of Sustainable Development, and is defined as follows: *"To build on this definition [Sustainable Development], a Four Forces Model has been developed by the authors, formalising the interrelationships between the critical components. For success, each element of the Four Forces must be aligned with one another. The process of this alignment is termed* Energization.*"*. The Four Forces consist of *Energy Demand*, *Energy Supply Chain*, *Energy Substitutes*, and *Critical Enablers*. *Energy Demand* covers the aspects of the needs of the community for heat, cooling, light and motive power; the income levels and affordability of the community; the extent of the individual household involvement in community decisions on energy supply; the cultural needs of the different parts of the community; and the aspirations of the community. The *Energy Supply Chain* covers the quantity and choice of fuels available; the price thereof; the availability and reliability of energy infrastructure; the price and financing thereof; safety of the end user; the linkage between the different elements. *Energy Substitutes* cover the aspects of the current choice of fuel; its cultural value; and the availability and cost, both socially and monetary. The *Critical Enablers* are the cultural acceptability; expectations of the community; energy policy; access to affordable finance; government commitment; supplier willingness; access to technology; locus of control; training programmes; and record keeping and basic statistics development.

It is only later that a concise definition of the term appeared in the literature. Rosselli & Laing (2000) defined energisation as follows: "Energization *is the matching of (energy) supply side resources with (community) energy demand requirements and optimising it to form a combined energy offering which can provide economic growth opportunities for long term viability."* and continued by stating that "Energization *is not new, it is a concept that has been practiced overseas for decades, but has not been implemented in South Africa."*, without giving any further references. Regarding the way in which energy needs are met, it is stated that *"It [energisation] involves balanced energy solutions, which means a combination of different energy sources that take into account their efficiencies and costs. LPGas, for example, is an excellent energy source for thermal applications such as cooking while electricity has a competitive advantage in the applications of lighting, entertainment, refrigeration and the running of motors."* Eventually, Rosselli & Laing (2000) stated, somewhat in contradiction to the first statement, that "Energization *is a method of bringing energy upliftment to rural communities in the short term. It is a means of addressing the needs of these communities in the here and now."*

DME (2001) uses the term energisation in its strategy on Capacitating Local Government for the Rural Energy Development in the following context: *"For the Department of Minerals and Energy, the vehicle that will underpin what is envisioned by the strategy is* energisation. *This requires the supply and access to* *[the] complete energy mix - renewables, non-grid electricity and conventional energy carriers. However, it is stressed that efficient, clean and sustainable energy carriers must be used in the* energisation *strategy. Additionally, the uneven distribution and affordability of energy carriers make the* energisation *process rather difficult."*

In the White Paper on Renewable Energy, DME (2003b) utilises the concept of energisation in the following manner: *"The DME is spearheading the implementation of the concept of* 'Energisation' *in the rural areas in conjunction with the rural electrification programme in order to address the energy needs of communities in a sustainable and consistent manner. The services will be available locally through a chain of integrated energy centres and one-stop energy shops to increase ready access and cut down on transport costs to distant towns. This will also lessen the dependency on fuel wood and contribute to environmental conservation. It is intended that ready access and lower prices will shift domestic demand towards cleaner and more efficient fuels and energy technologies."*

Gaunt (2003) uses energisation in the following context: *"A key characteristic [of electrification] in this thesis is that it is electrical and not inclusive of other energy, despite some approaches to broader 'energisation' "*. In this context, energisation is being understood by the author as the provision of someone or something with energy, in contrast to electrification, which would then be defined as the provision of someone or something with electricity.

SEA (2003b) uses the concept of energisation in the title of its brochure "Energising *South African Cities & Towns: A Local Government Guide to Sustainable Energy Planning"*, where energisation is equated to sustainable energy planning. Importantly here, energisation is used in the context of cities and towns, viz. an urban context, rather than the usual rural context.

WLPGA (2003) gives the following definition: "Energisation *is a process whereby communities progress from a restricted use of traditional fuels to a broader range of modern fuels such as diesel, kerosene, LP Gas, natural gas and electricity."*

From the view point of another developing country, Mohan & Kumar (2005) states in the Indian context that: *"Biofuels as a domestic and renewable energy source, can significantly reduce India's dependence on foreign oil, can minimize* *the environmental threat caused by fossil fuels, and it is the best ever alternate in securing the energy needs of the country. The other advantage is in meeting rural* energisation, *and empowerment of village community through enhanced livelihood opportunities and thus controlling migration."* Against the specific background of biofuels for rural empowerment, Mohan & Kumar (2005) further state that *"[...] government is focusing mainly on biogas and biomass based producer gas for the* energisation *of rural poor. Apart from providing much relief from power shortages, power projects based on biomass would also open up new avenues for employment generation in rural areas in collection, storage and handling of biomass materials. Each 5MW project could generate at least 100,000 man-days per year of employment in rural areas."*

Sebitosi & Pillay (2005) say *"At project level, the choice of an appropriate energy conversion technology is also critical. The most inefficient way to use electricity is by applying it for a purpose that could more efficiently be performed by a different form of energy or fuel."*, and continues by stating: *"What is needed is* energisation *in contrast to conventional electrification"*.

UNDP (2005) uses the verb form of the term 'energisation' in its report "Energizing *the Millennium Development Goals - A Guide to Energy's Role in Reducing Poverty"* in a more figurative manner, implying the fostered implementation of the MDGs and its linkage to energy. Note that the report gives a systematic and concise overview on the linkages of energy to the achievement of the eight MDGs, stating that *"while there is no MDG specifically on energy, access to energy services is a prerequisite to the achievement of all eight MDGs. [...] Unfortunately, much greater quantities and much greater quality of energy services will be required to meet these goals than are presently available in developing countries"*. The emphasis of this report is particularly on the poor, reducing poverty, and sustainable development, furthermore making a clear distinction between energy carriers and energy services, as well as energy service quantities and qualities.

Prasad (2006) says that *"the terms* 'energisation' *and 'integrated energy provision' have become popular in the South African energy sector in recent years. They refer to improving energy provision by using a combination of different fuels, rather than a single energy carrier such as electricity. These terms reflect* *a switch in thinking away from an almost exclusive focus on electrification. The term 'energisation' has also developed connotations of a more political notion of empowerment and local community activism around energy and development issues".*

UN (2006b) states in the context of external constraints to the energy sector, that *"low education is spread across African societies, however its highest density is found in sub-Saharan rural areas, the same regions where access to energy is the lowest. Implementing* energization *programmes in rural areas, with full participation by local population is constrained by the level of education of the population. This reduces their ability to act as agent of change for the design of local energy solutions including the development of local entrepreneurship for installation and maintenance of decentralized energy systems, as well as for the development of productive use activities.".*

The Wuppertal Institute (2006) introduces an energisation project carried out by the company Parallax in a remote village in South Africa, and describes its aim as follows: *"The overall goal of the project was to show the extent to which* energisation *of rural communities can limit the negative contribution of energy use to climate change whilst offering a means for sustainable development. It aimed to determine whether a user-owner model of energisation was effective in the rural South African context, and whether it could be implemented on a commercial basis. A successful demonstration would provide the evidence necessary for widespread replication."*

6.2.2 Critique of Current Definitions and Usage of the Concept of Energisation

The previously presented definitions and contexts contain important information regarding the concept of energisation. The essential findings are summarised in the following points.

General Observations From the previous review, a number of basic statements could be made in terms of precision of the definition, as well as basic notions. These observations are as follows:

- More than one definition (four alone in this review), and variation in contexts
- Synonym: 'Integrated Energy Provision'
- Basis: Notion of 'Energy Ladder'

Aim Moreover, it was found that there were similarities and variations regarding the aim of the different definitions and contexts. These points are given as follows:

- Matching of energy needs with appropriate energy resources
- Improved energy provision in terms of quantity and quality of energy services supplied
- Away from traditional energy carriers, and towards combination of cleaner and more efficient modern fuels
- Mainly aimed at household issues (e.g. cooking, lighting, space heating), but in some definitions also including local economic development and empowerment (see 'Political Connotations')

Focus Furthermore, similarities and variations were identified regarding the focus on target groups, as well as energy supply options. These aspects were summarised as follows:

- Developing country contexts (e.g. South Africa, India)
- Mainly rural and poor communities, but also cities and towns
- Inclusive of and broader than merely electrification
- Includes (not necessarily) renewable energy sources

Political Connotations The concept of energisation was identified as being broader than just a technical approach to energy provision. The extension to which the concept of energisation embraces aspects of sustainable development remains fuzzy. The following observations were made:

- Political connotations regarding empowerment and community activism
- Enabler of economic development through job opportunities in- and outside energy sector
- Connection to notion of sustainability
- Underpins MDGs (supporting poverty alleviation, economic development, education, gender equality, health care, environmental sustainability, and global partnerships for development)
- Emphasis on cultural and social aspects

Implementation A number of elements were identified as being critical regarding the implementation of the concept of energisation. They include technical, economic, social and political aspects. These elements have been summarised as follows:

- Energy service decoupled from final energy carrier and end-user device
- Integration of existing energy supply networks
- Main challenges: accessibility and affordability
- Commercial viability critical issue: user-owner models and Integrated Energy Centres (IECs) (i.e. public-private partnerships) are practical examples
- Education enabler of energisation through development of local entrepreneurship
- Critical enablers: i.a. energy policy, government commitment, markets for private investors
- Local government is key player

Dynamics Against the backdrop of energisation, a number of dynamics were identified, linking issues of energy provision to specific development aspects. The following links were identified:

- Link between income and fuel choice (extension of the consumer model)
- Low education coupled to low energy access
- Reduction of environmental threats by decreased reliance on fossil fuels
- Impact on migration control and security of supply

6.3 Energisation in Practice: Three South African Examples

6.3.1 The Electrification Programme

Regarding the objective of South Africa's electrification programme, Davidson & Winkler (2006) state the following: *"The National Electrification Programme was implemented between 1994 and 1999. Its objective was to electrify rural and urban low-income households which had been deprived of access to electricity during the apartheid period. The Programme expected that newly electrified households would switch from using fuelwood, candles and batteries to using electricity for their household needs".*

Gaunt (2003) reports that *"over 3 million new domestic customers (households) in South Africa were connected during the past decade. This significant electrification programme raised the proportion of households with access to electricity from 36% in 1991 to 69% in 2001. [...] However there are still many households without access to electricity and politicians have stated goals of achieving universal access by 2012".*

Regarding the evaluation of the success of the electrification programme, key findings have been formulated, amongst other things (Gaunt, 2002):

- Electrification in low-income areas is not financially viable

- Electrification has significant social impact, but the benefits are constrained by lack of access to the network, lack of appropriate appliances for those connected, and a poor understanding of tariffs.

- Achieving the desired impacts of electrification requires a broad approach to setting targets in terms of benefits, with implications for management, evaluation and regulation.

If one looks specifically at the degree of sustainability achieved regarding the satisfaction of energy service needs, major issues become apparent.

Prasad (2006) argues against the background of extending the range of rural electrification through a weak grid approach, that *"households depending primarily on non-commercial fuels like wood and dung are likely to continue with these to save costs, although it is hoped that some will switch to cleaner fuels. [...] What will these households choose if grid electricity becomes cheaper than kerosene or LPG for cooking, especially households adopting the proposed electricity basic support tariff? The demand to use electricity for cooking could then rise substantially, especially among those households presently using kerosene and LPG"*.

It is furthermore stated in the White Paper on Renewable Energy (DME, 2003b): *"An electrification programme, particularly if it has a strong non-grid component, has to form part of a holistic approach to energy provision, if it is to succeed. Electricity supply through photovoltaics (solar home systems) is (economically) insufficient to cater for thermal energy requirements of households, while experience shows that even if grid-electricity is supplied the energy intensive thermal requirements are often satisfied through fuel wood and conventional fuels (e.g. paraffin, LPG)"*.

These two statements make clear that the initial expectation that newly electrified households would switch from using fuelwood, candles and batteries to using electricity for their household needs was not met.

It appears that choices for specific energy carriers coupled to end-user devices are highly dependent on their pricing, making electricity less competitive especially against alternatives such as free traditional energy carriers, e.g. fuelwood and dung. It also becomes apparent that energy service needs must be understood in the first place, in order to be able to meet them efficiently, and to trigger the desired effects of energisation (see Section 6.2.2).

It should be noted that there is almost no mention regarding issues of energy service needs outside of the household sector (e.g. for local production) nor of local economic participation in distribution or equipment retailing/installation against the backdrop of the South African electrification programme. Furthermore, the goal against which the success of the electrification programme was measured was the number of households supplied with electricity. The consideration of social and economic development aspects were by definition not considered for the measurement of the programme's success. An apt comment on the South African electrification programme was thus (see e.g. Ward, 2002):

"Electricity is the Answer! - What was the Question?"

6.3.2 Integrated Energy Centres

Prasad (2006) describes the purpose and advantage of an IEC as follows: *"Through bulk buying, IECs would be able to obtain fuels at a lower cost and thereby reduce the cost overheads associated with transport and multiple-step distribution chains. Besides bringing energy services 'closer to the people', they could stimulate active local participation in relation to both energy issues and economic development initiatives and social services."*

Up to this point, IECs are mainly focused on rural areas, especially poverty nodal areas, being based on the principles described in the Integrated Sustainable Rural Development Strategy (ISRDS). According to Subramoney (2004), the purposes of an IEC are the following:

- One-stop energy shop
- Provide energy solutions to communities
- Attract attention of service providers, government and financing agencies to local level energy problems

- Besides servicing communities, focal point for DME, other government departments, and municipality's own activities

DME (2003b) states that IECs will be set up by government in cooperation with stakeholders. It states furthermore that *"like the energisation concept, the Government will be seeking to bring energy services (fuels and appliances) to the disadvantaged communities, as well as to address health, environmental, economic and other needs"*. Eventually, it is said that *"IECs encourage the development of cooperatives, and thereby enhance economic development activities"*.

Prasad (2006) states that *"The proposed energy centres are designed to be public-private-community partnerships, with funding assistance mainly from Sasol and a high level of participation by local government and community groups. Two have so far been established, and more are at various stages of planning and organisation"*.[1]

The establishment of IECs and the development of related activities is an ongoing process. Updated information on i.a. the number of established IECs, the number of jobs created, and the number of energy safety trainings performed is available from the website of the DME.[2]

Note that an interesting concept stated furthermore by Subramoney (2004) is to utilise IECs as a *"base for local level energy planning, identification of public and private investment opportunities"*.

6.3.3 Unplanned Energisation: A Wood Fuelled Local Economy in Khayelitsha

In the following Section, the results obtained by the author during the investigation of the dynamics of Cape Town's wood and paper sector (see Chapter 7) will be analysed regarding their insights into energisation in an urban context, emphasising the dynamics between the formal and the informal market sectors.

[1]In the lead-up to national elections in 2004, it seems that there was a swing towards establishing IECs in peri-urban locations, to serve poorly serviced communities living around towns. Possibly this was because these areas have a higher voter density.

[2]http://www.dme.gov.za/energy/planning.stm

Although the primary aim of the data collection was to identify the existing wood & paper streams in Cape Town, it was found that a meaningful informal wood market has established itself in the informal settlements of the city, i.e. Khayelitsha. A series of interviews was performed with assistance of Fikiswa Mahote from Development Action Group (DAG), based on a questionnaire developed in English and Khosa (local African language), in order to collect the necessary data for the MFA of wood & paper (see Annexure G). These interviews were revisited in order to extract the information relevant for this Section.

A quantitative analysis of material streams has been performed in Chapter 7; thus, the following explanations will be of a rather qualitative nature.

6.3.3.1 Patterns of Energy Usage

Khayelitsha is a large, mainly informal settlement about 30 km from the centre of Cape Town, having an estimated population of 400,000-900,000 (StatsSA, 2001). 80% of Khayelitsha's households are electrified (Prasad & Visagie, 2006). Cowan & Mohlakoana (2005) state that two thirds of the households which have access to electricity use it for cooking. This finding challenges the conventional view that low-income electrified households tend to use alternative energy carriers such as LPGas, paraffin, or fuel wood for their main cooking tasks.

However though, fuel wood and used timber are utilised for commercial cooking purposes, viz. meat 'braaing'[1] and sheep head preparation (see e.g. Qase, 2000).

The devices used for meat braaing are open grills with very low thermal efficiency. Sheep head vendors prepare their food on open fires as well, boiling it using pots. The difference to meat braaing is that the food does not come in contact directly with the open flame, and fumes generated by the combustion of the energy carrier. Therefore, used construction wood (timber) such as planks partially substitutes fuel wood. Interestingly, in the case of meat braaing, the aroma of burned wood is desired by the customers. Used construction wood is

[1] A 'Braai' is the Afrikaans term referring to the preparation of food with the heat and hot gases of a fire made with wood or charcoal (equivalent to grilling or barbecue).

not adequate for serving that latter purpose, as it may contain chemical treatment residues, and thus would pose a health threat as fumes come in contact with the food.

Ncasa (2005), a meat vendor in Khayelitsha, states: *"I buy and use generally 4 bunches of 20 pieces of wood per day, sometimes even 6-7, when it is very windy. I buy mainly Port Jackson, either from local people, or from fuel wood traders with bakkies [pick-up trucks]. They collect the fuel wood either from surrounding forests in Khayelitsha, or Eersterivier".*

The disadvantages of this type of commercial utilisation of fuel wood and timber in Khayelitsha are i) its low efficiency, and ii) local emissions, fuel wood combustion being one of the main contributors to bad local air quality, as well as the Capetonian Brown Haze phenomenon (see e.g. Spalding-Fecher, 2005).

From an environmental perspective in South Africa, the cutting down of alien vegetation such as Port Jackson for fuel wood is supported, as it poses a threat to indigenous vegetation (e.g. Fynbos), as well as groundwater resources. However, fuel wood collectors must bridge ever longer distances, as vegetation regresses.

Interestingly, fuel wood is sometimes used for previously unexpected purposes. Mandaba (2005), a fuel wood collector and seller in Khayelitsha, states: *"I collect one [supermarket] trolley of fuel wood per week. I sell the wood to neighbouring households. They use the wood for boiling water. They sell the water to a church in J Section, Khayelitsha, which uses it for healing purposes".*

Note that charcoal is being manufactured locally based on fuel wood, which is used for energetic purposes as well (see e.g. Azorin, 1992).

6.3.3.2 Existing Networks

Fuel wood is collected at the surroundings of townships and sold to commercial meat braaing places and sheep head vendors. The advantage of fuel wood is its free availability. Job opportunities are being created regarding the collection and selling of fuel wood and timber, charcoal manufacturing based on fuel wood, as well as jobs related to commercial meat braaing and sheep head preparation.

Temba (2005), a fuel wood collector and trader in Khayelitsha, states the following: *"I collect and sell one [supermarket] trolley of fuel wood per day. I* *collect mainly Port Jackson in the Mfuleni area, on the way to Bellville. One trolley takes five bunches of wood, each bunch counting 6-7 pieces of wood. I sell it to private households for cooking and commercial meat braaiers. I don't make any big profits: What I earn is sufficient for my survival"*. The turnover is estimated at approx. ZAR 150 per week.

The amounts of wood traded by individuals having access to proper transport, e.g. 'bakkies' (pick-up trucks), is substantially higher. Amos (2005), a fuel wood trader in the Strand area (Cape Town), states the following: *"I buy the fuel wood from a collector in Hermanus [ca. 200 km from Cape Town]. I sell around 150-200 bags of wood per week, which makes a turnover of ca. ZAR 1,500 per week"*.

An interesting interface is created to the first economy, as used construction materials can be collected in the formal areas, or bought from scrap yards, such as the one run by Ross Demolition (Lansdowne/Cape Town), a demolition contractor. Some businesses in the informal areas live from the trade of second-hand construction materials. E.g., Mpokwana (2005), a trader of second-hand construction materials, states the following: *"I sell second-hand doors, windows, frames and furniture. Each item costs between ZAR 50-150. I buy my materials either from Ross Demolition, or collect them from demolition sites around Cape Town. I own a bakkie [pick-up truck] for transportation, but for bigger loads, I hire a truck for ZAR 300. I sell about 6 items per week, which earns me more or less ZAR 2,000 per month"*.

Note that second-hand construction goods are utilised for the building of informal dwellings (i.e. shack or "wendy" houses). Mguli (2005), a builder of "wendy houses", says: *"I build and sell around 6 to 7 'bungalows' per month, at approx. ZAR 3,500 each. The framing is made of rusty pine [wood], and the roofing is made of corrugated iron. The ceiling is made of rhinoboard [wood], and the walls are either made of zinc sheets or wood pannels. I currently sell more 'bungalows' with zinc walls, as wood became more expensive during the last couple of years"*.

A valuable argument is that as long as wood is kept bound in construction, it has a certain value in terms of carbon sequestration.

An advantage of "wendy" houses against the backdrop of the current political situation in South Africa is their mobility. According to Hillary (2005), a coloured "wendy" house owner in Blackheath/Cape Town, states the following: *"I bought my house 10 years ago, and I moved with it already four times. The problem with coloured people is that they are often too rich to qualify for the state's People's Housing Process (PHP), but too poor for owning their own land. We have to move from the places we settle when the land is reclaimed by its owners".*

6.3.3.3 Findings

In the case studied here, the utilisation of fuel wood has largely been suppressed on a household level by energy carriers such as electricity. However, wood remains an important fuel for commercial activities, thus contributing to economic development.

It has been shown that a diversified network of especially informal jobs already exist around the materials fuel wood, charcoal and timber. The means of transportation have been identified as playing a crucial role regarding the development potentials of certain commercial activities. Furthermore, important linkages have been build to formal market sectors. By substituting woody material streams or diverting them for other (energetic) purposes, a list of jobs would be suppressed.

Product pricing has been found to be a main factor influencing the customer's choice of energy carriers and construction materials. The quantities of fuel wood and timber used are strongly linked to their price competitiveness against other commodities. In the case studied here, an argument for using a specific energy carrier (i.e. fuel wood) for food preparation is related to the customer's demand for a specific flavour.

A list of alternatives exist for using woody material streams energetically (see Section 2.2.7.2). Logistics might play an important role if existing networks were to be integrated, as informal fuel wood and timber collection and utilisation has a decentralised character.

6.4 Redefining Energisation

Based on the critique in Section 6.2.2 regarding existing definitions and contexts of energisation, and the analysis of three South African examples, it is the aim of this Section to develop a new definition of the term energisation. In the following, explanations regarding the target group, energy service needs and sustainable development will be given.

6.4.1 The Target Group

It is argued that potentials for energisation will mainly be found in developing countries, where the majority of the world's poor live (UNDP, 2004a). Note that the concept of energisation would also be applicable to developed countries, although one would then rather refer to the term 'development' or 'growth'.

In the South African context, it is of particular importance to distinguish the targeted community, as governmental development programmes have often been focused on rural areas, e.g. by means of the ISRDS, including the rural electrification programme, easily leading to equating rural communities with poor communities. Gaunt (2003) thus argues in the context of his thesis that *"rural electrification is based on the segregation of customers, addressing the needs of both the poor and not-poor in the rural areas. On the other hand, electrification for social objectives is directed to meeting the needs of the poor and, although most poor people live in rural areas, many people in urban areas are also poor."* It shall therefore be emphasised that the definition of energisation will apply to poor communities, independently from their location (viz. rural or urban).

However though, it shall be noted that the focus of this thesis will be on the poor in (peri-)urban areas, as this field has not yet been analysed in detail from an academic perspective, and promises to bear interesting findings, especially regarding potential synergies between the so-called 'first' and 'second' economies.

It is furthermore believed that the term 'community' is naive and romantised. Therefore, it is proposed to refer instead to a poor economic subgroup of the South African economy, which will be called 'second economy' (Mokopanele, 2006a), consisting of consumers and producers stemming from the domestic, and commercial/industrial sectors (see economic model developed in Section 6.5).

6.4.2 Energy Services

As can be seen in Figure 6.2, increase of energy consumption in developing countries is directly coupled to an increase of the HDI, accounting next to the economic performance (GDP) for the level of education and health as well (Wikipedia, 2007b) (see also Section 2.2.2).

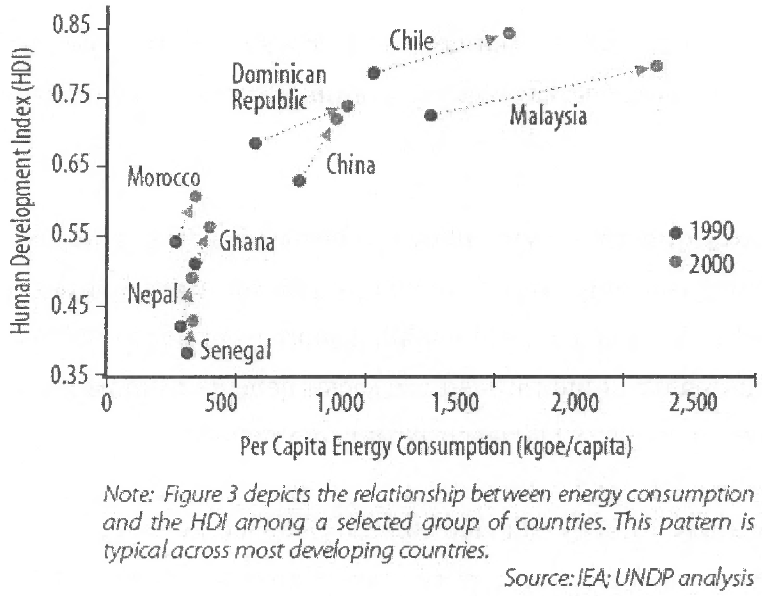


Figure 6.2: Relationship Between HDI and Energy Consumption

In this representation, the energy quantity consumed has been used as a proxy for the quality of energy service supplied, which might lead to a distorted interpretation of results. It is therefore suggested to replace the quantity of energy consumed by the number of energy services met. According to UNDP (2005) *"the term 'energy services' is used to describe the benefits that energy use offers. [...] From the perspective of the consumer, it is the availability and affordability of energy services, not merely the source of energy itself, that is important"*.

The number of energy service needs met is represented on an x-axis as shown in Figure 6.3. Moreover, the x-axis has been split into two areas, namely the realms of primary and secondary energy service needs. The definition for the types of energy service needs has partly been based on the Hypotheses given by

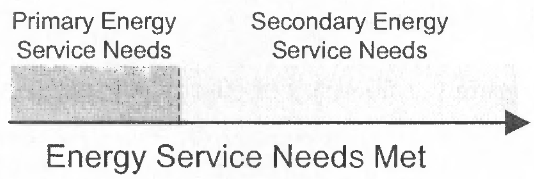


Figure 6.3: Energy Service Needs Met - X-Axis

Gaunt (2003) for the differentiation of objectives of electrification, and extended to the focus on energy services rather than final energy carriers (e.g. electricity) against the background of energisation:

- **Primary energy service needs:** The nature of the energy service required is entirely consumptive, not making significant contributions to financial or economic development, but enabling short-term poverty alleviation and improved quality of life through the social benefits from using modern energy services in terms of efficiency, cleanness and safety.

- **Secondary energy service needs:** The energy service required, coupled to a prerequisite capacity of the target group in form of income, skills and infrastructure, contributes to productive output, thus enabling mid- to long-term economic development.

Only the transitional process from meeting primary energy service needs to secondary energy service needs in developing country contexts will be referred to as 'energisation'. In developed country settings, one will rather refer to 'growth' or 'development'.

It shall be noted that there are overlaps between the two groups of energy service needs. For instance, the energy service 'cooking' can help to alleviate poverty, but it could also be turned into a commercial activity, where it would enable economic development. Precision is therefore recommended regarding the definition of energy service needs, e.g. cooking for household needs, and cooking for commercial purposes.

6.4.3 Sustainable Development

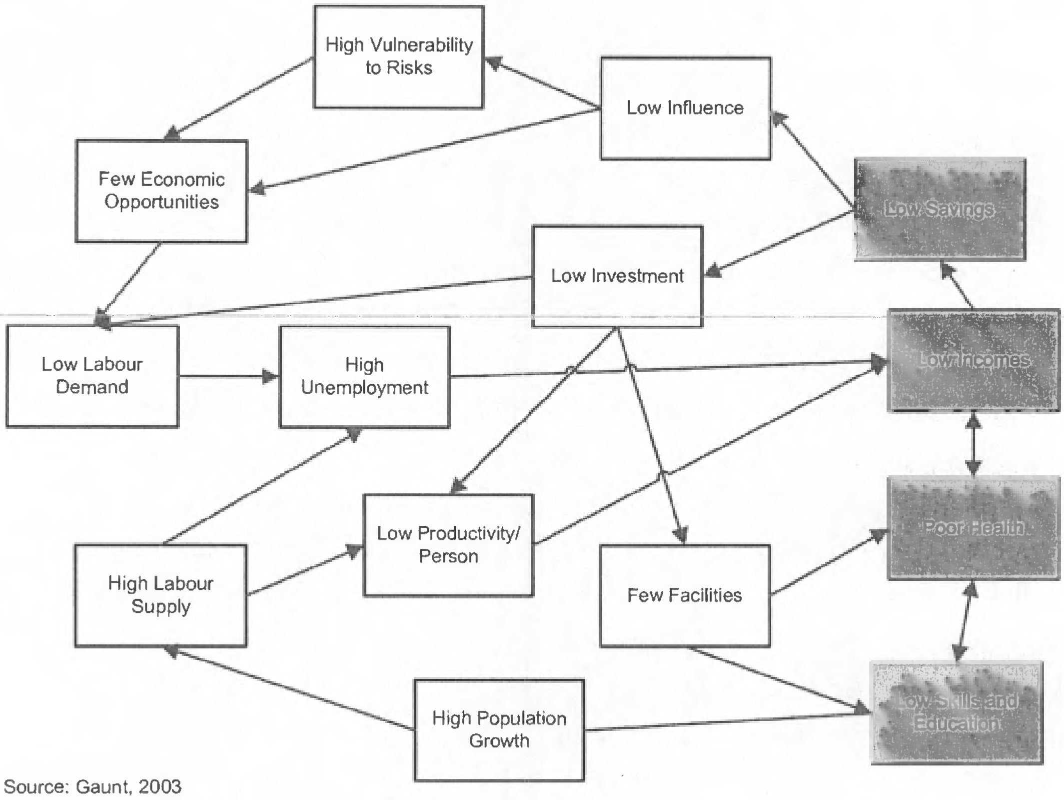
Zomers (2001) argues against the background of electrification of households in rural areas that *"bringing electricity to the people is, in itself, not a contribution to reducing poverty nor does it lead to rural development"*. This problem has been addressed by considering energy service needs (primary and secondary) instead of final energy carriers (e.g. electricity - see Section 6.4.2). This implies that energy planners will avoid by definition to supply final energy carriers without meeting the wanted effects of poverty alleviation and economic development. However, it can be stated that meeting an energy service need does not yet imply sustainable development *per se.*

In order to achieve sustainable development, two points need to be considered. Firstly, a life-cycle approach must be adopted based on the concept of sustainability (see Section 2.2.2) for each energy service provided, accounting for social, economic and environmental impacts of the entire energy service supply chain. This implies that, even though the energy service provided might bring poverty alleviation or economic development to the target group, the negative effects of the entire supply chain might outweigh its benefits, thus leading to less or even un-sustainable poverty alleviation or economic development. One will refer in this case to 'sustainable' or 'unsustainable' energisation. This aspect highlights as well the necessity of embedding the energisation process into MCDM, as the importance of environmental, social and economic effects might differ according to the stakeholders involved in the decision-making process.[1]

Secondly, meeting secondary energy service needs can lead to sustainable development, viz. it enables the full economic development potential, only once the prerequisite capacity of the target group is given. As depicted in Figure 6.4, a number of reinforcing loops hamper the economic development of a poor target group, with the characteristics of poverty shown in shaded boxes (Gaunt, 2003).

This issue becomes particularly complex when one considers that the linkages between energy services and other development enablers such as skills and education often work in both directions. Education is not only a prerequisite for

[1]See Section 2.3.2.1. The detail discussion regarding MCDM lies beyond the scope of this thesis.



Source: Gaunt, 2003

Figure 6.4: Relationships Reinforcing Poverty

energy service supply to trigger economic development (see Section 6.2.2, 'Implementation'), but energy services such as lighting after daylight hours support better education (see Section 6.2.2, 'Dynamics'). Furthermore, the linkages between income and choice of energy carriers have already been investigated. Not only would the provision of certain energy services bear the potentials for job opportunities and higher income (see Section 6.2.2, 'Political Connotations'), but also would a higher income influence the choice of energy carrier (see Section 6.2.2, 'Dynamics'), thus the opportunity to broaden the array of energy services available. Against the background of energisation, it will be of particular importance to integrate an understanding of these feedback loops to the planning process in order to achieve the highest degree of sustainable development.

As can be seen in Figure 6.5, the dotted lines represent possible pathways of a developing country. Line number 1 describes the process of meeting primary

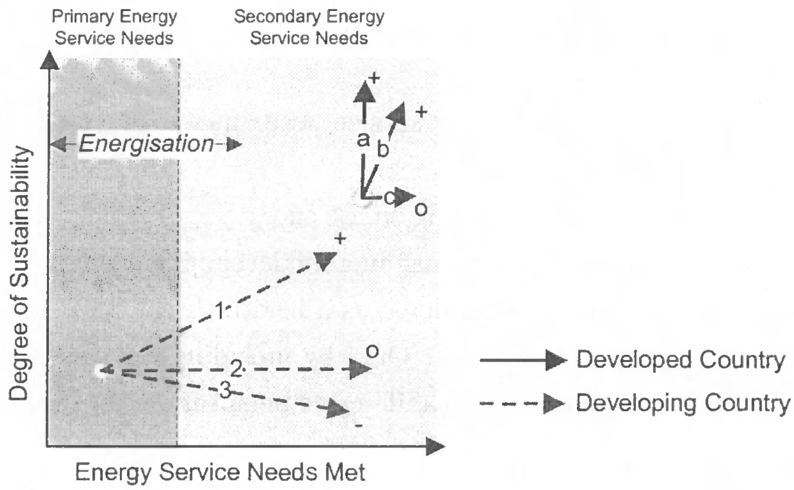


Figure 6.5: Scenarios for Meeting Energy Service Needs

and secondary energy service needs in a manner consistent with sustainable development. In this case, one will refer to sustainable energisation. Line number 2 represents a process of energisation which does not lead to an increased degree of sustainability. This is imaginable when primary energy service needs such as cooking are met by energy carriers having a moderately negative impact on e.g. human health and the environment, which would balance the benefits of the energy service. The third line represents a pathway of unsustainable energisation, where the energy needs are met in such a way that the negative impacts of the energy service far outweigh the benefits.

The straight lines represent possible pathways of a developed country. Preliminarily, it can be noticed that the lines are shorter than the dotted ones, indicating a generally lower potential for development, as the majority of energy needs have already been met. A rise in the degree of sustainability as represented by line a is imaginable for a scenario where a factory decides to switch for an existing energy service need from coal-based electricity to electricity generated based on renewable resources, thus triggering an environmental benefit. Line b represents a situation where an emerging energy need is met in a sustainable manner, leading to sustainable development, e.g. recovery of process heat for feeding a new drying unit. Line c represents the satisfaction of emerging energy needs in a manner that does not affect the degree of sustainability, i.e. where benefits are balanced by negative impact.

Note that a regression in energy service needs met is imaginable, e.g. in the case of a shortage of fossil fuels.

It should be noted that by focusing on the energy services delivered, mainly the social and economic dimensions of sustainable development are being considered (indoor air pollution is being considered as a health threat, thus being more of a social than an environmental issue). Only by including the consideration of the energy service supply network from a life-cycle perspective can the environmental dimension be included.

6.4.4 Energisation: A New Definition

Based on the findings in Sections 6.2.2 and 6.3, as well as the explanatory steps regarding the target group, energy services and impact on sustainable development in Sections 6.4.1-6.4.3, the author proposes in the following a definition for Sustainable Energisation.[1]

> *Sustainable Energisation* is the transitional process of progressively meeting primary and early secondary energy service needs of a poor economic subgroup (second economy) through the delivery of an enhanced quantity, quality and/or variety of accessible and affordable energy services, enabling the sustainable development of the considered subgroup based on poverty alleviation and economic development, as well as the optimisation of the energy service supply network from a life-cycle perspective.

The newly defined concept of sustainable energisation integrates and excludes specific points listed under the critique of current definitions and the usage of the concept of energisation in Section 6.2.2.

The new definition basically marries the elements of the different **aims**. However, the emphasis has clearly been removed from household issues, and put on

[1]A detailed discussion on the terminology utilised in the definition is given in appendix C.

the broader notion of an 'economic subgroup', including domestic and commercial activities.

Furthermore, although the **focus** remains on the poor in developing countries, rural as well as urban contexts are equally concerned. The whole variety of available energy resource, incl. all renewable alternatives, should be considered in order to guarantee a sustainable energy supply.

The points identified as **political connotations** have been summarised under the notion of sustainable development, emphasising socio-economic aspects. It was found that generally, the environmental perspective was neglected by the current definitions and contexts of energisation, and was therefore added specifically by considering the energy service supply chain from a life-cycle perspective.

In terms of **implementation**, accessibility and affordability have explicitly been integrated to the definition, as well as the notion of energy service, decoupled from final energy carrier and end-user device. The remaining **implementation** aspects and **dynamics** will help to translate the concept of sustainable energisation into the economic model under Section 6.5.2, as well as to integrate the concept into the local energy planning process under Section 6.6.2.2.

Note that, although the newly defined concept of sustainable energisation equally applies to rural and urban contexts, only the urban component will be considered against the backdrop of this thesis. The literature review under Section 2.2.2.4 and 6.2.1 showed that relatively small focus had been given to the urban energisation process from an academic perspective up to the point of writing. However, the example of unplanned energisation in Khayelitsha (see Section 6.3.3) suggests a more profound investigation to be worthwhile, especially because of potential linkages between formal and informal market activities, as well as the variety of available inner-city resources (see also Chapter 7).

6.5 An Economic Model for Energisation

In this thesis, energisation is being considered against the background of an urban ecosystem (see Section 2.3.1.1). In the following Section, a basic economic model will be developed. Its purpose is to serve as a basis upon which the newly defined approach of energisation will be demonstrated.

6.5.1 Model Development

Figure 6.6 represents a basic economic input-output model, its main elements being boxes and arrows. The boxes represent sectors of production/provision or consumption of commodities within the economy. The arrows represent the flow of commodities in form of goods (incl. waste) or services in the direction indicated by the arrows, and the flow of financial commodities in the opposite direction of the arrows.

The basis of the economic model is a free market approach, based on the dynamics of supply and demand, where consumers and producers are the main players. These dynamics are well understood.[1]

As can be seen in Figure 6.6, specific elements regarding the energy sector as well as the waste management sector have been added to the system, as both influence each other, and have furthermore an impact on the economic macro-system. IEA (2004) states the following with regards to the integration of aspects of the waste management sector: *"[...] Energy-environmental planning, which until now has focused primarily on energy and productive systems, also deals with waste management problems. Here it has to deal with the feedback of energy and material flows from the waste disposal system into the energy and production system. To fulfill these requirements energy models have been expanded to also include waste and material flows."*

The producers buy resources (arrow 1) in order to produce goods and services that are bought and used by the consumers (arrow 2). On the other hand, households lend their labour force to the producers in exchange of a salary (arrow 5). Furthermore, the firms of the formal sector produce goods and services that are consumed by firms in the informal sector, and the firms in the informal

[1]According to Rothbard (1977), *"free market is a summary term for an array of exchanges that take place in society. Each exchange is undertaken as a voluntary agreement between two persons or between groups of people represented by agents. These two individuals (or agents) exchange two economic goods, either tangible commodities or nontangible services. Thus, when I buy a newspaper from a newsdealer for fifty cents, the newsdealer and I exchange two commodities: I give up fifty cents, and the newsdealer gives up the newspaper. Or if I work for a corporation, I exchange my labour services, in a mutually agreed way, for a monetary salary; here the corporation is represented by a manager (an agent) with the authority to hire".*

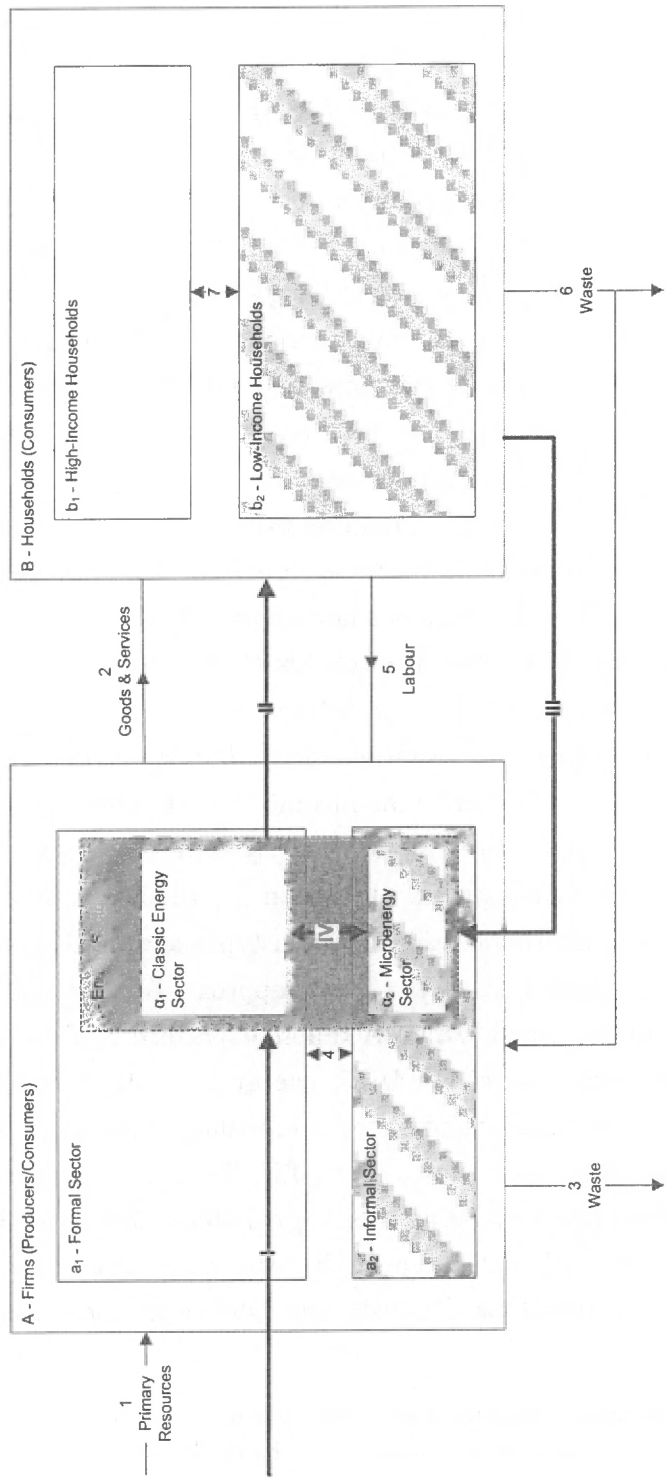


Figure 6.6: Economic Model - Energisation

sector might act as suppliers for the firms in the formal sector (arrow 4).[1] An exchange of goods and services is also observed between high-income and low-income households (arrow 7). The sole exception to the exchange of goods and services for financial commodities might be the case of waste flows (arrows 3 & 6), where consumers might have to pay for getting rid of waste materials generated.

Households, which have been qualified strictly as consumers, can be divided according to their average income, featuring specific characteristics, i.a. differing consumption patterns in general - and energy consumption patterns more specifically -, differing access to energy services, and differing waste generation patterns. Furthermore, they have a different level of skills and education, and have access to a different level of health care services.

As can be seen in Figure 6.7 (adapted from Winkler *et al.*, 2006b), the useful energy demand by household type for each end use has been represented (South Africa - total: 130 PJ). Six different household types have been defined, namely Urban High-Income Electrified Households (UHE), Urban Low-Income Electrified Households (ULE), Urban Low-Income Non-electrified Households (ULN), Rural High-Income Electrified Households (RHE), Rural Low-Income Electrified Households (RLE), and Rural Low-Income Non-electrified Households (RLN). These household types represent respectively 36%, 11%, 12%, 11%, 10%, and 20% of a total number of approx. 10 million households in South Africa.

As can be seen for the urban household types specifically, meaningful differences lie in the quantity of energy used: approx. 75 PJ for UHE and approx. 5-15 PJ each for ULE and ULN. A different pattern is also noticeable for the purpose of the energy usage. For UHE, energy is mainly used for water heating, followed by space heating and cooking; interestingly, there is a demand of approx. 10 PJ for other electrical purposes. For ULE, the main energy usage is dedicated to water heating, followed by approx. equal shares for space heating, lighting and cooking. For ULN, water heating has the lowest energy usage, whereas the most energy is consumed for relatively equal shares of space heating, lighting and cooking.

[1] The goods produced and consumed by the firms of the formal sector have not been represented by an arrow for the sake of transparency; the same applies to the firms in the informal sector.

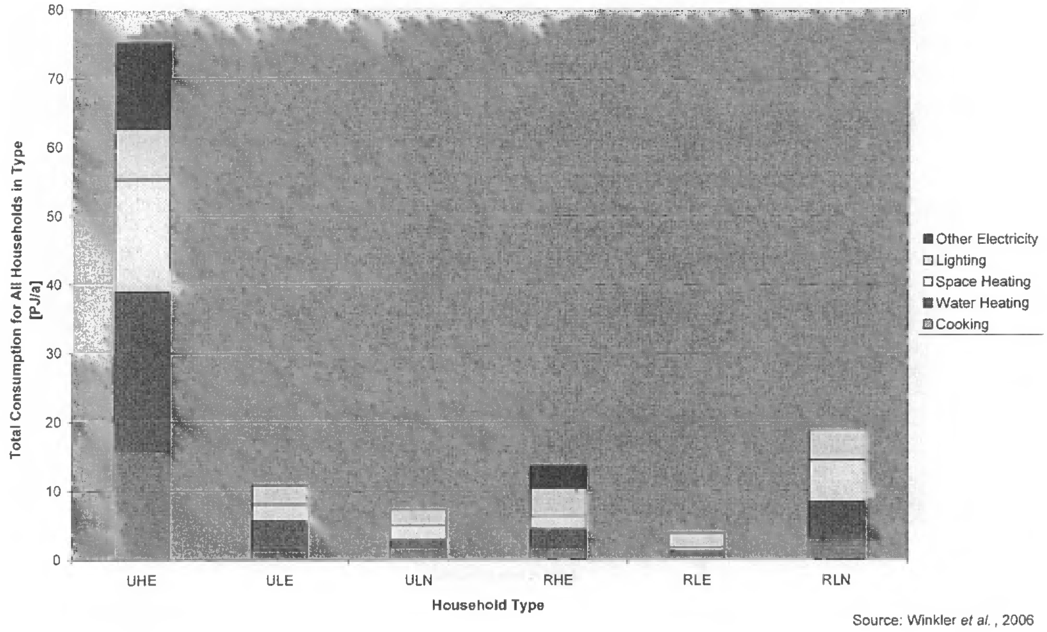


Figure 6.7: Total Annual Energy Consumption by Household Type (South Africa - 2001)

Moreover, the types of energy carriers consumed by income group differ. As can be seen in Figure 6.8 (adapted from Prasad, 2006), an increase of electricity usage from 30% to 95% and a decrease of wood and kerosene usage from 30% to <5% respectively are coupled to an increase of the average income per household.

From a waste generation perspective, different generation patterns are noticeable. Jeffares & Green (2004) states that waste generation figures for South Africa vary from 0.5 kg/c*d up to 2.5 kg/c*d respectively for low-income up to high-income households. As can be seen in Figure 6.9, there is a difference especially in the share of organic waste. For high-income households, the share of organic waste represents approx. 30%, whereas for low-income households, the share represents approx. 60%.[1]

However, as an urban context is being considered, household groups with different average incomes share several similarities due to their geographic proximity,

[1] Waste generation patterns for low-income households in Khayelitsha have been confirmed by Brill et al. (2006)

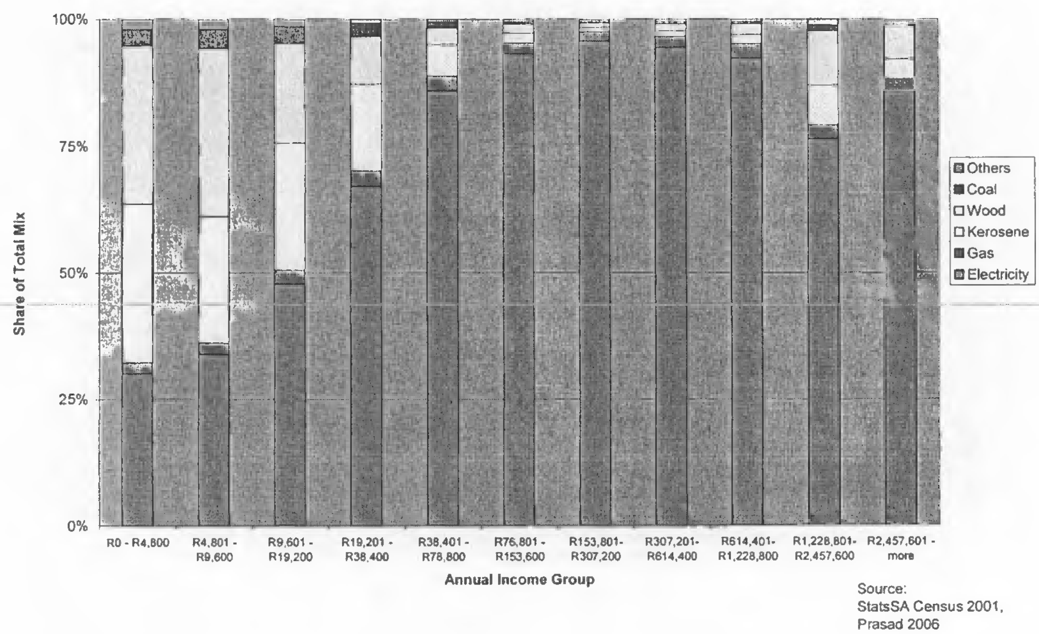


Figure 6.8: Energy Carrier Consumption by Household Income (South Africa - 2001)

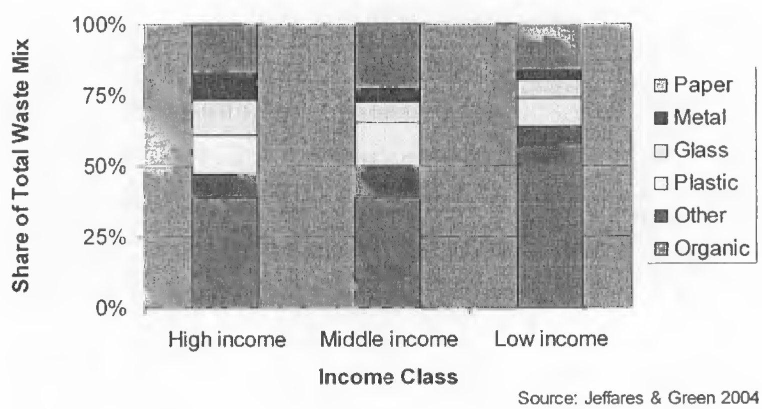


Figure 6.9: Waste Generation Patterns by Income Group (Cape Town - 2004)

which would not necessarily be given in a rural context. These similarities are i.a. the same service infrastructure (to some extent - e.g. roads, energy supply, waste management, access to shops), the same ecological environment, and the same overall economy.

ClusterPlus[1] segments the South African population into 10 main groups, which are further divided into 38 clusters. These groups and clusters have been defined in terms of the socio-economic rank, life stage, and dwelling type (Knowledge Factory, 2005). In Cape Town alone, 11 different clusters can be identified, illustrating the meaningful variety of specimen (consumers) populating the considered urban ecosystem, implying an important number of potential synergies to be exploited against the background of energisation. It has been chosen for the sake of clearness to reduce the number of considered elements for the economic model to high and low-income households.

By looking closer into the energy sector (shaded box of Figure 6.6), one identifies a classic energy sector within the first economy, being characterised by central actors, international networks, formal business activities, and competition (Kebir, 2003). On the other hand, the microenergy sector has a rather decentralised character, being constituted of many actors, practicing informal business, and being limited in choice (Kebir, 2003). The energy sector in general produces energy services that are bought by consumers (e.g. households and firms - arrows 3 & 4). At the same time, the microenergy sector buys energy services from the classic energy sector, whereas at the same time, the former could act as supplier to the latter (arrow 6).[2]

Eventually, the following classification must be understood. According to president Thabo Mbeki, South Africa's economy can be divided into a first and a second economy (Mokopanele, 2006a). The first economy contains the firms in the formal sector (incl. the classic energy sector) and high-income households, being characterised by being rich and well developed, being constituted of middle to large firms acting in the formal business sector, which can produce or import all necessities. The second economy (cross-hatched boxes) contains firms in the

[1] According to Knowledge Factory (2005), *"ClusterPlus is a geo-demographic segmentation system which provides remarkable insight into the behaviours, characteristics, lifestyles and locations of the people of South Africa. Developed at a suburb level, ClusterPlus is an essential component of any micro-marketing model allowing for the meaningful targeting of prospects in specific areas"*.

[2] The energy services produced and consumed by the formal sector have not been represented by an arrow for the sake of transparency; the same applies to the informal sector.

informal sector (incl. microenergy sector) and low-income households, and is characterised by being poor and marginalised, being constituted of either small or micro enterprises. This classification is important, as in the following Section, the emphasis will be laid upon the second economy, as only here, (sustainable) energisation can take place as previously defined (see Section 6.4.4).

6.5.2 Translating Energisation into the Economic Model

The aim is now to translate the concept of energisation into the defined economic model in a qualitative manner. The main focus of sustainable energisation is on the second economy (informal sector including microenergy sector, and low-income households), which will be subject to the primary effects of the process. Secondary effects will have repercussion on the remaining elements of the system.

In Table 6.1, the impact of Sustainable Energisation has been represented for each element of the economic model (see Figure 6.6). Firstly, the impact on the different sectors of production/provision and consumption are considered (boxes in Figure 6.6), followed by the flows of commodities (arrows in Figure 6.6).

#	Name of Element	Impact of Sustainable Energisation
A	Firms (Producers/Consumers)	Growth Diversification of Activities Job opportunities Fluctuations in Energy Tariffs (Higher Demand vs Higher Supply) Fluctuations in Waste Disposal Tariffs (Higher Recovery Rate, Higher Generation Rate)
a_1	Firms - Formal Sector	Creation of Market Gaps for Informal Sector
a_2	Firms - Informal Sector	Economic Development New Enterprise Opportunities Higher consumption of goods & services Higher waste generation rate Higher supply to formal sector
B	Households (Consumers)	Better social environment (less unemployment/criminality) Impact on local air pollution (cleaner fuels vs higher consumption)

		Environmental impact through higher waste generation (disposal vs recycling) Fluctuations in Energy Tariffs (Higher Demand) Fluctuations in Waste Disposal Tariffs (Higher Generation Rate)
b_1	High-Income Households	Supplementary Income Source (Supplier of Second Hand Market)
b_2	Low-Income Households	Poverty Alleviation Better Health Better Education and Skills Better job opportunities Higher Income Consumption of higher quantity, quality and variety of (energy related) goods and services Higher waste generation rate Different waste generation pattern
α	Energy Sector	Growth Diversification of Activities Job Opportunities Higher Conversion Efficiency Fluctuations in Energy Tariffs (Higher Supply)
α_1	Classic Energy Sector	Creation of Market Gaps for Microenergy Sector Fossil Fuel Substitution by Renewable Resources (incl. Waste)
α_2	Microenergy Sector	Economic Development New Enterprise Opportunities Utilisation of renewable energy sources Supplier to Classic energy sector Supplier to Low-Income Households esp. where not viable for classic energy sector
1	Primary Resources	Increase in Quantity
2	Goods & Services	Increase in Quantity, Quality and Diversity
3	Firms - Waste	Increase in Quantity
4	Firms - Goods & Services	Increase in Quantity, Quality and Diversity (both directions)
5	Labour	Increase of skilled labour Decrease of unskilled labour
6	Households - Waste	Increase in Quantity Change in quality (less organic matter in MSW) Higher Recovery Rate
7	Households - Goods	Increase Second-Hand Energy Devices and secondary energy carriers ($b_1 \rightarrow b_2$)
I	Primary Materials & Energy Resources	Increase in Quantity, Quality, and Diversity Shift to more sustainable, renewable energy resources

II	Energy Related Goods and Services	Increase in Quantity, Quality and Diversity
III	En. Rec. Waste & Energy Related Second-Hand Goods	Higher Waste Recycling Rate (Energetic Usage) Increased Reuse of Second-Hand Energy Devices
IV	Energy Sector - Goods & Services	Increase in Quantity, Quality & Diversity (both directions)

Table 6.1: Impact of Sustainable Energisation on Economic Model

As can be seen in Table 6.1, impacts that will affect firms as a whole (A) are economic growth, diversification of activities, both of which will engender job opportunities. Fluctuations in energy and waste disposal tariffs will be noticeable, respectively because of a balance between higher energy demand (low-income households and informal sector) and higher supply (energy sector), and a balance between higher waste recovery and waste generation rates. Note that firms are also producers, and as such will trigger higher consumption and waste generation rates.

An impact specifically on the formal sector (a1) is the creation of market gaps for the informal sector.

Furthermore, the informal sector (a2) will profit of economic development, including the setup of informal market infrastructures, enabling new enterprise opportunities. In contrast, economic growth is used in this context as merely the increase of growth rates, whereas economic development focuses specifically on the start-up phase. Furthermore, there will be an increase in supply opportunities to the formal sector.

It is worthwhile stressing the paramount importance to identify opportunities for the informal sector to supply the formal sector. Mokopanele (2006b) writes: *"Believing that small businesses [informal sector] would create more jobs than big firms [formal sector], the government has set up parastatals to support them. These include Ntsika for training and Khula Enterprise Finance to provide microcredit. However, Mike Schussler, an economist at T-Sec, says the strategy has not worked well. Khula has failed because its strategy is based on the assumption that there are enough linkages between the first and second economies to generate credit demand for micro enterprises [informal sector] to act as suppliers to first economy. Schussler says these linkages, however, are just not there in sufficient quantity."*

Impacts that will affect households as a whole (B) are a better social environment through lower unemployment rates, thus resulting in less criminality. Moreover, local air pollution will either increase or decrease, depending on the balance between a higher share of cleaner fuels and the increased quantity of total energy carriers consumed. It might be that a shift from local to global emissions will be noticeable (less particulate emissions, but higher CO_2 emissions). In a similar manner, local environment will be affected by a higher waste generation rate; here the balance between recycling and disposal rate will be of importance. Furthermore, a higher energy demand from low-income households will affect the pricing structure of energy carriers for all consumers, i.a. electricity tariffs. The same statement is valid for waste disposal tariffs.

An impact specifically on high-income households (b1) will be an additional revenue source through the increased sale of (energy related) second-hand goods such as used fridges or stoves. The transactions can happen either through middlemen (e.g. second-hand shops, e-waste initiatives - firms) or with low-income households directly.

For the low-income households (b2), Sustainable Energisation (SE) implies poverty alleviation, better health standards, better education and skills, which results in better job opportunities and a higher income. A higher income will entail the consumption of a higher quantity, quality and diversity of (energy related) goods and services (see Section 6.2.2, 'Dynamics'). Eventually, a higher consumption will lead to a higher waste generation rate and a change in waste generation patterns (proportionally less organic matter in MSW, see Jeffares & Green (2004)).

When one focuses specifically on the energy sector (α), the following impacts become apparent. Due to economic growth and diversification of activities there will be an increase in job opportunities. As for SE, the whole energy supply chain must be considered from a sustainability perspective, leading i.a. to higher efficiencies in the conversion processes (see Section 6.6.2). Fluctuations in energy tariffs will also be noticeable especially through higher energy supply.

Regarding the classic energy sector (α_1), gaps will be created for the microenergy sector. Furthermore, a shift from fossil to more sustainable, renewable sources will take place, including waste.

Specifically for the microenergy sector (α_2), economic development will take place with increased opportunities for new enterprises. Many new enterprise opportunities will emanate from the renewable energy sector (see e.g. India). The microenergy sector will act more and more as a supplier to the classic energy sector (e.g. IEC), and as a supplier especially to low-income households, where the market is not viable for the classic energy sector.

Regarding the system flows, a rise in quantity of primary resources will occur (1). Furthermore, goods & services provided to households (2) will increase in quantity, quality & diversity. There will be a noticeable increase in the volumes of waste produced by firms (3), as well as the quantity, quality and diversity of goods & services exchanged between the formal and the informal sector (4). There will be an increase in skilled labour, and a decrease in unskilled labour (5).[1] However, this aspect needs to be balanced with urban influx and population growth rates. It is worthwhile noticing that the availability of skilled and unskilled workers has an effect on the viability of new ventures, but that only the former is rate limiting in a developing economy.

Regarding the waste produced by households (6), there will be an increase in quantity and a change in quality due to a decrease of organic matter in MSW. A higher recovery rate will also be observed, as firms shift to renewable energy source, as well as start-up ventures based on the collection and trade of second-hand/used goods.

Moreover, there will be an increased flow of second-hand (energy) devices and secondary energy carriers from high-income to low-income households (7).

Focusing on the energy sector, there will be a rise in quantity, quality and diversity of primary materials and energy resources, especially because of the shift to more sustainable, renewable energy resources (I). Regarding the provision of energy related goods & services, an increase in quantity, quality and diversity will occur (II). Regarding energetically recoverable waste & energy related second-hand goods (III), an increase of the energetic recovery rate of specific waste fractions will occur, as well as an increased reuse of second-hand energy devices. Finally, the exchange of goods & services between the classic energy sector and the

[1] In this context, Gaunt (2003) states that *"the most abundant resource of the poor [low-income households] is labour, and other resources are in short supply"*.

microenergy sector will increase in both directions in terms of quantity, quality & diversity (IV).

Regarding the overall system, a growth and diversification of activities and flows is noticeable, meaning that the system as a whole becomes more complex. It will be of paramount importance to balance the system in order to keep it efficient. For instance, new ventures created through the collection and/or retail of energy carriers have a benign effect because of generating income opportunities and rendering energy carriers more accessible. However, too many middlemen would increase the cost of energy carriers in such a way that they are no longer affordable by certain consumers. In this case, the system would become too complex and less efficient (see e.g. Tainter, 1988).

6.6 Integrating Energisation into the Planning Process

6.6.1 The ALEP Approach

Against the background given in Section 2.2.4.2 regarding the Advanced Local Energy Planning (ALEP) approach, the main emphasis in this Section will be laid upon the main study phase. According to IEA (2004), the main study deals with the comprehensive analysis of the energy system, aimed at a medium to long-term strategic planning. The different steps of the main study phase are the following:

1. Definition of the structure of the comprehensive model (e.g. the RES)
2. Compilation of the model database
3. Calculation of scenarios and strategies
4. Integration of subsystem analyses
5. Sensitivity analysis

According to IEA (2004), the interaction between comprehensive studies and subsystem analyses must furthermore be accompanied by the use of models (see Section 2.2.5), which are simplified mathematical representations of the energy flows and costs of an actual (technical) energy system.[1]

Against the background of this thesis, the challenges of modeling energy supply alternatives for poor economic subgroups will be stressed. It is postulated that, because of the mathematical/technical nature of energy models, the multi-dimensional issues of specific energy supply objectives such as energisation tend to be marginalised by the usage of models such as MARKAL. The latter is a typical linear programming tool, whose primal problem deals with the minimisation of the total discounted cost of the antrophogenic activities system (Cosmi *et al.*, 2003). In other terms, scenarios are being optimised in order to obtain a least cost solution.

It has been recognised by Howells *et al.* (2005) that there are common limitations in low-income (rural) energy modeling, who describe these as having impacts i.a. on the structuring of the model. It has been found that a common problem is to overestimate the market penetration of electric appliances and hence electric consumption, traditional fuels remaining important energy carriers. Furthermore, it is stated that *"the simplification is often made that a demand device such as wood oven [...] is modeled to meet a single energy service such as cooking. In reality, devices such as ovens are often used to provide several services, meeting space and water heating as well as cooking. This significantly reduces the costs incured compared to the use of several electrical devices to meet each specified energy demand"*. Moreover, it is stated that *"behavioural aspects of the energy usage by the poor are often not comprehensively captured by current means"*. These behavioral aspects include status, convenience, health and other welfare, being of importance in terms of choosing between options with similar costs. In a modeling approach, where cost minimisation is considered to be the objective function, behavioural aspects tend to be neglected. Eventually, Howells *et al.* (2005) state

[1]In most of the ALEP studies, the energy system model MARKAL was used for the comprehensive analysis, whereas many subsystem models were used for the analysis of specific problems. The author is familiar with the usage of MARKAL as well as LEAP.

that *"the availability of energy data such as usage profiles and appliance penetration for rural households is limited"*, and continue regarding external cost data by stating that *"Models are often used to capture the environmental, health and welfare effects [...], and are referred to as external or externality costs. They may be given different weight in countries of different economic wealth"*.

6.6.2 An Extended Approach

Based on the previous explanatory steps and findings, it is stated that the definition of the structure of the comprehensive model (e.g. the RES), which is at the basis of the main study and any further steps regarding calculations and modeling, is crucial in terms of capturing and integrating the objectives formulated in the preparation and orientation phase in a technical and mathematical manner. Against the background of this thesis, an extended approach is therefore proposed in order to integrate the multiple aspects of energisation into the structure of the comprehensive model.

By translating the concept of energisation into an economic model (see Section 6.5), it has been shown that the sustainable energisation of a poor economic subgroup is embedded in a complex system of reinforcing loops. The aim is to compile a concise checklist for energy planners in order to technically implement the multiple aspects of energisation into the design of the structure of the comprehensive model for each tier in the energy service supply network.

6.6.2.1 The Energy Service Supply Network

In Figure 6.10, a flowsheet superstructure[1] is introduced representing the different tiers in the energy service supply network, stretching from the energy service demand to the sources (a similar approach regarding the differentiation of tiers has been used in UNDP (2004b)). The flowsheet superstructure is similar to the structure of comprehensive models, and can be used as a template for setting-up a RES.

As can be seen in Figure 6.10, seven different tiers of elements have been defined, namely sources (S), primary energy carriers (s), conversion/distribution

[1] see Section 2.3.2.2

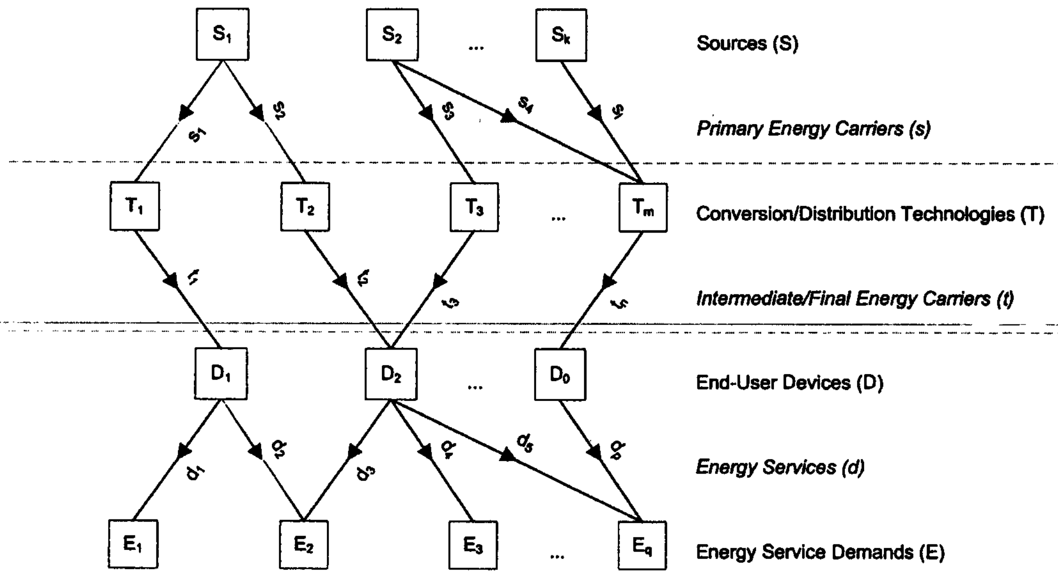


Figure 6.10: Flowsheet Superstructure

technologies (T), intermediate/final energy carriers (t), end-user devices (D), energy services (d), and energy service demands (E).

Moreover, there are two different types of elements:

- Boxes, representing processes of provision, conversion, distribution or consumption
- Arrows, representing flows of energy carriers or services

The elements of the tier 'Sources' represent the sources of primary energy carriers (e.g. coal mines, oil wells, forests).

The elements of the tier 'Primary energy carriers' are raw energy products that generally need processing and can not be used as such in an end-user device (e.g. crude oil, wind, trees).

The elements of the tier 'Conversion/Distribution Technologies' are processes that either convert primary energy carriers into intermediate/final energy carriers (e.g. oil refineries, gas turbines, wood gasifiers), or distribute energy carriers (e.g. gas grids, electricity grids, district heat networks). These processes can be coupled to each other in numerous ways.[1] Each energy carrier emerging from one conversion/distribution process and entering a subsequent conversion/distribution process is qualified as an 'Intermediate Energy Carrier' (e.g. syngas, process heat, Direct Current (DC)). Each energy carrier emerging from a conversion/distribution process ready for being used in an end-user device is called a 'Final Energy Carrier' (e.g. electricity, heat, LPG, biodiesel). Conversion/distribution processes are technically realised in form of medium to large scale applications. The elements of the tier 'End-User Devices' are appliances that convert final energy carriers into energy services on a household or small-micro company level (e.g. stove, light bulb, internal combustion engine), or commercial/industrial level (e.g. furnace, drying unit, cooling equipment). The appliances are generally smaller than conversion/distribution technologies. The elements of the tier 'Energy services' represent the useful services delivered by end-user devices (e.g. space heating, heat for cooking, motive power). More than one energy service can be delivered by one end-user device. The elements of the tier 'Energy Service Demands' represent energy related needs of the end-users. Energy services are being consumed for the satisfaction of end-user needs.

By following the arrows from sources to energy service demands, the different routes or pathways through the energy service supply network are identified. A practical example of such a pathway is represented in Figure 6.11. The primary energy carrier 'Fuel Wood' has been collected from the source 'Forest'. After having converted it to the intermediate energy carrier 'Wood Gas' by gasifying the fuel wood, the final energy carrier 'Biofuel' is produced via the conversion technology 'Fischer-Tropsch Synthesis'. By feeding the biofuel into the end-user device 'Internal Combustion Engine', the energy service 'Motive Power' is obtained, which is ultimately employed for satisfying the end-user demand 'Transport'.

6.6.2.2 An Energisation Checklist

Based on the previously defined flowsheet superstructure, each tier will be analysed regarding the integration of the concept of sustainable energisation. As can

[1]This aspect is represented by the two dotted lines in Figure 6.10, implying that the area between the two dotted lines is expandable.

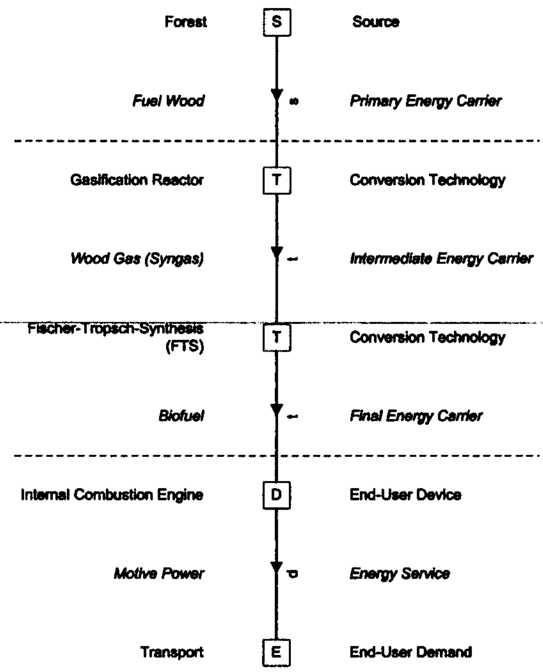


Figure 6.11: Energy Service Supply Pathway - Transport

be seen in Table 6.2, a checklist has been developed, which shall allow planners to integrate the aspects of the concept into their RES. The checklist has been developed in form of a matrix, classifying the checkpoints into poverty alleviation and economic development issues, considering each tier of the energy supply chain from resource harnessing up to the end-user demand.

The information gathered is based on a detailed review of available literature, working out and adding essential aspects of the concept of sustainable energisation in an urban context in a developing country. A special emphasis has been laid upon the creation of synergies between the four different actors identified within the urban ecosystem based on the economic model developed under Section 6.5, namely producers stemming from the formal and the informal sector, and consumers split-up into high-income and low-income households.

As can be seen in Table 6.2, a series of conditions have been gathered for each tier of the energy service supply network (see Figure 6.10). If a condition applies to an element of the respective tier, it will affect one or more of the five impact categories. These five categories are Affordability (AF) and Accessibility

(AS), being both critical enablers for sustainable energisation, Poverty Alleviation (PA) and Economic Development (ED), the two principal effects being achieved via Sustainable Energisation (SE), and Environmental Protection (EP), being included in the process of SE.

Proximity to end-user This aspect applies to the source, as well as to conversion and distribution technologies. It supports the reduction of transport distances between the different elements, as well as related costs and emissions. Thus, there is an improvement of AF, AS and EP. Note that a source in close proximity to the end-user is generally less prone to global market fluctuations, as it is the case for the fossil resources. Hence, an aspect of security of supply is included. Furthermore, the closer the source or the conversion/distribution technology is to the end-user, the more likely it is that local job/enterprise opportunities are created (see 'Employment').

Employment This aspect applies to all tiers of the energy service supply network except energy service demand, and focuses specifically on job opportunities for low skilled labour and venture opportunities for small and micro enterprises. For the source, employment can be created regarding the harnessing of the resource. For the primary, intermediate/final energy carriers, job and enterprise opportunities might be available regarding collection, transport, and retail of these commodities. For the conversion/distribution technologies, job and enterprise options might lie in the operation and maintenance sector. For the end-user devices, job and enterprise opportunities might lie in the transport and retail branche. In each case, existing job networks should be respected, and integrated where possible. It is suggested in connection with the existing infrastructure regarding LPG and paraffin, that retail activities could be borne by local SMMEs (Ward, 2002).

Existing Infrastructure The integration of existing infrastructure applies for the sources and the conversion/distribution technologies. In an urban area, service infrastructure such as sewage plants exist, which can be integrated as energy sources. Furthermore, existing electricity, gas and heat grids can be integrated for

S	s	T	t	D	d	E	Aspect	AF	AS	PA	ED	EP
x		x					Proximity to End-User	x	x			x
x	x	x	x	x	x		Employment	x			x	
x		x					Existing Infrastructure	x	x			x
x	x	x	x	x			Costs	x			x	
x	x	x	x	x			Ease of Processing/Handling	x	x			x
x	x	x	x	x	x		Diversity	x	x	x	x	x
x	x	x	x	x	x		Efficiency	x	x	x	x	x
x		x		x			Waste Management	x	x		x	x
x		x		x			Maintenance	x			x	
	x		x				Traditional Fuels	x		x	x	x
			x	x	x		Bulking	x	x			x
			x	x	x		Safety/Cleanness			x		
				x	x		Misuse Potential		x	x		
			x	x	x		Substitution	x	x	x	x	x
					x		Passive Measures	x		x	x	x
						x	Priority of Energy Needs			x	x	
						x	Hidden Demand			x	x	
						x	Culture & Market Compliance			x	x	

Table 6.2: Checklist for Sustainable Energisation

the distribution of intermediate/final energy carriers. For instance, the existing petrol station infrastructure could be used for the distribution of biofuels.

Costs The cost factor is the key to the final Affordability (AF) of the energy service, and should thus be considered for every element of the energy network, except for the energy service itself and the final energy demand.

Generally, low-cost energy service supply systems should be considered, where harnessing, conversion and distribution include low capital investment and operational costs, while operating with a high technical efficiency, i.a. reducing further costs.

In the context of a developing country, cost estimation for the erection of plants and establishment of energy systems is difficult, as long-term investments are prone to risks (e.g. political stability - see Delany & Varga (2002) and Erb *et al.* (1996)), there are few cases of precedent, and cost estimations must happen based on proxy factors such as location factors (see e.g. Amigun *et al.*, 2006).

As a rule-of-thumb, it should be aimed at settling labour-intensive industries in developing countries, as a typical characteristic for developing countries is high (unskilled) labour availability and low investment capacity. However, this approach has the danger to oversimplify micro-economic reality. According to van de Ven & van Luijk (1986), labour-intensive industries can be advantageous in under-developed countries only if a number of rigorous conditions is satisfied, i.a. a minimum local labour productivity, and a high ratio of indirect/direct workers.

Economic viability for investors is a further issue. While securing affordability for end-users, markets must remain attractive for investors. A means for achieving this goal is the creation of Public-Private Partnerships (PPPs), where financial support from the public side due to its responsibilities towards the population can attract private investment into unattractive markets.

Furthermore, markets unattractive for formal business activity might still bear potentials for informal activities or micro and small enterprises. A conscious coupling of these two business spheres can lead to high synergetical effects. In this context, DME (2003b) states that *"In order to provide affordable access and to attract the market and banking sector to service communities with a package of* *energy services (photovoltaic systems, paraffin, LPG, and renewable alternatives such as gel fuel and solar cookers) sustainable, effective and efficient micro-credit schemes and other financial support mechanisms have to be developed and implemented."*

Furthermore, there are financing schemes and subsidies for the different tiers in the energy service supply system in order to render the realisation and implementation economically viable.

In a non-Annexure A country under the Kyoto protocol (e.g. South Africa), the setup of energy service supply measures according to the requirements of the CDM qualifies for extra support based on the trade of Certified Emissions Reductions (CERs) (see e.g. Tyler, 2005). Note that it is more efficient to integrate such requirements in the planning phase of a project, than to upgrade existing projects to fit the requirements. In South Africa, further potential funding for sustainable/renewable energy options is available via Eskom's DSM fund, or the DME's Renewable Energy Finance and Subsidy Office (REFSO)[1].

Social tariffs for electricity might increase the affordability of electricity. However, a high misuse potential is given (see Section 6.3.1).

Microcredits for the purchase of energy supply technology might be a better option. Microfinancing schemes for the start-up of microenterprises are believed to be the best solution regarding economic development from a long-term perspective, as they include the prospect of job creation in the local energy sector (see e.g. Kebir (2003) and E+Co (2004)).[2]

External costs regarding threat to human health and environment should also be considered. However, these issues are discussed elsewhere in this Section.

Ease of Processing/Handling A low technical expenditure regarding the harnessing and processing of energy carriers reduces costs, improves efficiency, decreases health risks and environmental impacts.

[1] `http://www.dme.gov.za/energy/renew_finnace.stm`

[2] Interestingly, the 2006 Nobel Peace Prize was awarded to Dr. Muhammad Yunus and the Grameen Bank *"for their efforts to create economic and social development from below"* (Nobel Foundation, 2006). Yunus and his bank have meaningfully contributed to the development of the concepts of microcredit and microfinancing (see e.g. Yunus, 1999).

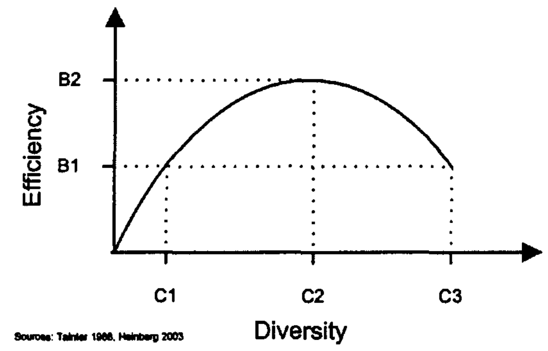


Figure 6.12: Relationship Diversity/Efficiency

Moreover, according to the physical state and the harmfulness of the energy carrier, adequate technical measures must be taken regarding the means of transport. By focusing on easily transportable energy carriers, related capital expenditure and potential threats to human health and environment are kept low.

Diversity The question of diversity applies to all tiers of the energy service supply network, except for the energy service demand. A diverse energy service supply network secures energy service supply firstly in terms of being less vulnerable to global market fluctuations esp. regarding fossil energy carriers, due to the systems capacity to balance instabilities regarding pricing and availability (Heinberg, 2003). Furthermore, a diverse energy supply network is a prerequisite for meeting the diversity of the end-user's energy service demands. Finally, a diverse energy service supply network bears a higher variety of job and venture opportunities, esp. regarding low skilled labour and informal business activities.

A threat is though that the system tends to become less efficient the more diverse it gets after passing a critical point. According to Figure 6.12 (adapted from Tainter, 1988), prior to point C1/B1, the system is efficient. Between points B1/C1 and B2/C2, efficiency gradually decreases. After a system passes point B2/C2, efficiency becomes negative, and the system becomes vulnerable to collapse. As a rule-of-thumb, it should be thrived to render a system as diverse as possible without passing the critical point.

By focusing more specifically on conversion technologies and end-user devices, the option more diverse in its energy products (e.g. CHP, cooking stove) should be favoured and recognised as such.

Efficiency From a technical point of view (e.g. thermal and electrical efficiency), sources should be easily harnessed, primary/intermediate energy carriers should be efficiently converted and distributed, and final energy carriers should efficiently be transformed into energy services. The reduction of related emissions, as well as the reduction and reuse of emerging by-product/waste streams contribute to the decrease of malign environmental impacts (see 'Waste Management'). These considerations could be summarised under the concept of "Cleaner Production" (see e.g. Fijal, 2007).

The ratio of Energy Returned On Energy Invested (EROEI) gives a good approach for measuring the efficiency of specific energy service supply pathways (see e.g. Heinberg, 2003). Effects are not only lower costs, but also a positive environmental impact. It should also be noted that EROEI does not necessarily remain constant over time, but might vary according to the level of depletion of finite sources, or improved conversion efficiency due to technological progress.

As a rule-of-thumb, energy carriers with higher energy content and higher density should be favoured, as they are easier to transport, and allow higher efficiency rates for conversion processes.

Waste Management By reducing/reusing by-products and waste, conversion pathways can be rendered even more efficient. Furthermore, waste and by-products can be used as sources for other energy service supply pathways (see e.g. von Blottnitz *et al.*, 2006). In both cases, waste streams are being diverted from local landfill sites, and environmental impacts as well as related costs are being reduced. Note that here, meaningful business opportunities exist esp. for informal approaches, e.g. paper waste collectors (see Section 7.3.4).[1]

[1]Interestingly, Zablon Karingi Muthaka (Nairobi, Kenya) won the Youth Business International Entrepreneur of the Year 2006. Williams (2006) says *"Frustrated by the scarcity of official waste disposal sites and the accumulation of rubbish at every street corner of his city, Muthaka spotted a business opportunity and set up Beta Bins Waste Management, a domestic*

Maintenance This aspect applies to the source, conversion/distribution technologies, and end-user devices. The ease of maintenance is derived from the nature of the process technology/appliance as such, as well the availability of spare parts and personnel qualified for the task. A simple conversion process or end-user device is in general easier to maintain than a complex one, thus causing lower maintenance costs. On the other hand, the maintenance infrastructure necessary for more complex harnessing/processing technologies and devices bears job and enterprise potentials. These two aspects must be balanced.

Traditional Fuels A big competitor to primary and intermediate/final energy carriers are traditional fuels such as wood and dung, esp. because of their very low costs. This makes it very difficult for other energy carriers to compete, as affordability is one of the critical enablers for SE. An option would be to subsidise cleaner and safer (final) energy carriers such as electricity. It has been shown that that option has a high risk of misuse (Gaunt, 2003). A further alternative would be to use traditional energy carriers (incl. related job networks) for feeding more efficient/different transformation technologies and end-user devices (e.g. small and large-scale gasifiers). A concern would remain regarding the environmental impact of the collection/harvesting of traditional fuels, e.g. deforestation.

Bulking This aspect applies to intermediate/final energy carriers, as well as energy services. The bulk/grid supply of energy carriers has a favourable effect on affordability due to lower prices, and accessibility due to reduced transport distances. If final energy carriers had to be purchased individually by each end-user at the point of production, transport distances, and related costs and emissions would be much higher. The usage of intermediates such as retailers (e.g. IECs - see Section 6.3.2) is an option. The same is applicable for the purchase of end-user devices.

The statement applies for the delivery of energy services as well. For instance, the bulking of transportation such as in public transport systems is more efficient

waste collection company. [...] [T]he business proved so successful that its remit has been expanded to include recycling plastics, cottons, paper, bones, metallic products, composite manure and foodstuffs."

in terms of costs and emissions than individual transportation. However though, end-user behavioural aspects such as convenience play an important role (Howells *et al.*, 2005).

Safety/Cleanness Safety and cleanness refer to the health impact on the end-user, and thus apply to final energy carriers, end-user devices and energy services. The safe storage of final energy carriers, the safe operation of end-user devices, as well as the safe delivery of energy services are included in the aspect of poverty alleviation. Especially the fire hazard associated with end-user energy supply plays a critical role regarding township fires, and annually causes important toll numbers in terms of material and human damage (CCT, 2006c).

Health impacts can be caused by leaking storage devices for final energy carriers, as well as emissions from the conversion processes of the end-user device and the delivered energy service (e.g. indoor air pollution - see von Schirnding *et al.* (2002)). Evidently, options with lower health impacts should be favoured.

Misuse Potential Final energy carriers and end-user devices should have a low misuse potential in terms of delivering energy services.

As the energy planner has little impact on end-user behaviour, the focus on the delivery of specific energy services via the complex of final energy carrier/end-user device should be integrated in the planning/design stage. E.g. the replacement of electric two-plate stoves with gas stoves incl. a bottle of LPGas had an immediate effect on the energy use pattern for cooking for affected households (Faniso, 2006).[1]

Another example is the introduction of SWHs as promoted by the by-law on solar water-heaters in Cape Town (Nielsen & Bengtsson, 2006)[2]. By focusing on a (transformation technology/) end-user device delivering a specific energy service, viz. hot water, the misuse potential has been reduced.

[1]However, the subsidisation (substitution) of end-user appliances such as the distribution of gas stoves and CFL bulbs (see e.g. (Faniso, 2006) and Shlensky (2006)) are believed to be exceptional, as the intervention was motivated by an urgent energy saving need, which would have resulted in much higher costs to Escom if not met immediately.

[2]see Section 3.4.5.2

Substitution This condition applies specifically to final energy carriers, end-user devices and energy services. The level of appropriateness of an alternative energy carrier, end-user device or energy service can be compared to the level of appropriateness of the elements to be replaced, regarding i.a. costs, efficiency, safety, cleanness and environmental impact. If this level is higher than the one of the elements to be replaced, the substitution is advisable. In this context, one can also refer to the concept of "Opportunity Costs", as being the cost balance of alternatives compared to the option in place (Wesseler, 2007).

Passive Measures The delivery of energy services can be improved via the integration of passive measures such as house orientation and insulation (see e.g. UNDP, 2000b, Chapter 6). Not only does the integration of such measures improve the efficiency of delivered services, but also reduce costs and environmental impacts. Furthermore, the installation of such measures bear job and enterprise opportunities.

Priority of Energy Needs An energy planner should first identify and prioritise energy service demands as being primary and secondary energy service needs. By doing this, the energy planner prioritises these energy needs, and assures that the wanted effects of poverty alleviation and economic development are achieved. As a rule-of-thumb, energy demand should drive the design of an energy service supply network. Furthermore, misuse potential is being reduced, as energy service demands for less important purposes (e.g. leisure) are being deprioritised.

Hidden Demands Besides the first purpose of an energy service demand, there might be other demands that could be satisfied simultaneously. The energy planner must identify these hidden demands in order to render the energy service delivery as efficient as possible, and optimise the impact of SE.

Culture & Market Compliance Energy service demands should be consistent with the cultural values of the concerned population groups, as well as the market requirements in the case of energy service demands for commercial purposes. In the former case, e.g. cooking is a task that has traditionally been carried out by women, and women measured their position in society according to this aspect (see e.g. Laing & Rosselli, 1998). In the case of cooking for commercial purposes (see e.g. meat braaing), a market demand besides the cooked food is the flavour of burned wood, thus having an impact on the final energy carrier (see Section 6.3.3). The entirety of the aspects concerning culture & market compliance must be understood when identifying energy demands.

6.6.3 Observations, Discussion and Recommendations

Whereas some aspects are of a more general nature with regards to energy planning, the emphasis has been laid upon issues related to the concept of sustainable energisation for the compilation of the checklist.

The development of the checklist has shown that the concept of SE touches on a multitude of issues with regards to the set-up of the comprehensive technical planning model, requiring some prerequisites in order to be implemented successfully. It is therefore that the following five points are being recommended for implementing effectively the concept of SE into the local energy planning process:

1. Integration of goals of energisation into MCDM, i.e. ALEP phases A & B
2. Identification and prioritisation of energy service demands according to primary and secondary nature
3. Data collection regarding existing sources according to proximity to end-user
4. Data collection regarding all existing pathway options for meeting energy demand based on identified sources
5. Set-up of energy service supply network structure incl. the required level of depth regarding energy service demand
6. Control and adaptation of energy service supply network according to checklist

Several aspects of energisation are conflicting, e.g. job creation and final energy carrier affordability, or global emissions and economic growth. These issues need to be traded-off in an MCDM process according to the importance allocated to these issues by the different stakeholders.

It has been identified that the knowledge of all possible technological options for meeting energy demand is at the basis of a rich and efficient energy planning process that fully integrates the concept of SE. An innovative way of tackling this task is the creative generation of options, which will be discussed in depth in Chapter 8.

Furthermore, a tendency to shift from local to global issues has been observed the higher the considered tier in the energy service supply network. Whereas final energy carriers and end-user devices have a direct impact on the end-user, distant conversion processes will have more global repercussions.

A similar trend is noticeable regarding energy carrier consumption. An increasing household income is coupled to an increasing quality of energy carriers, but also to a higher total energy consumption. Indoor and local air pollution tend to decrease, but rising CO_2 emissions have a greater global impact.

By keeping the energy supply network as local as possible, job and enterprise opportunities can be maximised for the considered population subgroup.

It is believed that a local energy service supply network would also bear an awareness effect, as it would make the environmental issues related to the energy supply process more visible to the end-user, resulting in a public pressure for rendering the system even more sustainable.

It is believed that especially local government should take an active role in rendering investment more attractive in SE, e.g. by means of PPP or subsidies. It should be noted though that, from a macroeconomic perspective, it is not the ultimate long-term solution to make a business sector grow on the basis of subsidies. In this context, The Economist (2006) argues that: *"Subsidies distort investment: since the German government fixed the price for solar power at munificent levels, the country has been sucking in huge numbers of solar panels that could be put to better use in sunnier climes. A global carbon tax would be a more efficient way to close the price gap between fossil and alternative fuels. In the meantime, subsidies for alternatives are probably better than no action."*.

It should also not be forgotten that energy usage patterns are tightly linked to income levels. Thus, economic growth as such can lead to the usage of cleaner and safer fuels. A means for boosting economic growth especially for previously disadvantaged population groups in South Africa is BEE.

It has also been understood that the energy planner might have to compromise between short-term interventions for alleviating dire poverty, and mid- to long-term options for economic development. By developing and understanding for the nature of the energy demand (poverty alleviation and economic development), the energy planner can design an energy service supply network that mutually includes both aspects.

It is believed that renewable energy alternatives are more adequate for meeting the (technical) requirements of SE as fossil resources, especially regarding the previously discussed aspects of proximity to the end-user, diversity, environmental impact, integration of traditional fuels incl. related networks, as well as waste management. It should be noted that the Renewable Energy target of the City of Cape Town (see Section 3.2) merely applies to the increased supply of unspecified final energy carriers produced from renewable sources, and makes as such no systematic contribution to the process of SE.

Finally, it should be noted that energy planning for SE must be a dynamic process. Even if it has been demonstrated that by considering different economic subgroups in an urban context, a rich number of synergies can be developed, it should be borne in mind that poorer households will become richer, and that informal business activities will grow and will eventually become formal business activities. This might have repercussions on energy supply networks in terms of number and skill of labourers, but also on securing supply of certain sources, such as waste streams. These potential developments must be integrated in the planning process, and monitored on a regular basis.

6.7 Conclusion

At the beginning of this Chapter, the current notion of energisation was introduced by means of definitions and contexts based on a detailed literature review. Key findings were formulated.

The benefits and limitations of the current definitions of energisation were analysed based on three South African examples. The case of the electrification process showed the importance of defining end-user related goals for energy supply initiatives. The concept of Integrated Energy Centres demonstrated the importance of affordability and accessibility in terms of enabling energisation. Furthermore, PPP might play an important role in rendering energisation initiatives economically viable for investors. The case of a wood fuelled local economy in Khayelitsha demonstrated the importance of a detailed understanding of energy use patterns and market requirements, as well as the collection of data regarding available local energy sources.

Based on the findings of the literature review and the insights won from the three examples, the existing concept of energisation has been adapted and extended in order to achieve the intended goals of environmental sustainability and social development. By refining the target group, prioritising energy service needs, and the conscious integration of the concept of Sustainable Development, a new definition of energisation ('Sustainable Energisation') was given.

In the next step, an economic model was developed, based on which the newly defined concept of Sustainable Energisation was demonstrated. Against the background of an urban ecosystem, insights into the linkages between the different elements of the model were won.

The last step consisted in analysing how the concept of Sustainable Energisation can be implemented into the local energy planning process. Based on the ALEP approach, an energy service supply network in form of a flowsheet superstructure was introduced, consisting of seven tiers stretching from end-user demands to energy sources. Thereupon, a checklist for energy planners was developed, considering the multiple facets of Sustainable Energisation for every tier of the energy service supply network. Eventually, a discussion was presented in order to formulate observations and recommendations.

In summary, it has been demonstrated based on a newly defined concept of Sustainable Energisation, which focuses by definition on socio-economic development needs, that environmental sustainability and social development can be enabled by the local energy planning process. The development of an economic model and the integration of Sustainable Energisation to the local planning process showed that renewable energy supply options are more adequate than fossil alternatives for meeting the requirements of the newly defined concept.

A prerequisite for releasing the full potential of Sustainable Energisation is the identification of possible local renewable energy sources. This aspect will be addressed in the following Chapter.

Chapter 7

Urban Renewable Resources: A Material Flow Analysis of Wood and Paper in Cape Town

7.1 Introduction and Rationale

As has been established in the previous Chapter, a detailed understanding of socio-economic development needs is one necessary element for enabling an environmentally sustainable and socially meaningful development by the energy planning process as stipulated under Hypothesis 2.

A second element is the understanding of available renewable energy resources as well as technological conversion options. In this Chapter, an inventory of potential urban renewable energy resources will be established by means of the emerging method of MFA. A case study will be developed based on a single type of renewable energy resources, viz. wood-based materials (including paper), within the boundaries of the Cape Metropolitan Area (CMA). The reasons are as follows:

- According to CCT (2003), it has not yet been identified what the potential of energy generated from wood and paper is in the CMA, and how this potentially new energy source can improve the sustainability of energy provision in the focused area.

- Wood and paper materials are significant contributors to the waste disposal problematic of the CMA.

- The wood and paper network is a complex system within the CMA, covering market dynamics and interactions of first- and third-world type.[1]

7.2 Background and Methodology

In this Section, the background and methodology utilised for the developement of the MFA of wood and paper in Cape Town will be presented. The method of MFA is introduced under Section 2.3.2.3.

Based on an approach taken by Hashimoto & Moriguchi (2003), an inventory of wood and paper resources, stocks, sinks and material flows shall be produced for the Cape Metropolitan Area (CMA). The purpose of the wood network system developed by the author in Figure 7.1 is to give an overview of two main wood and paper processing chains and the relationships to the respective sources and sinks, as well as the matching options between the different process modules.

As described by Beck *et al.* (2004), the wood and paper network system is constituted by three types of modules. The first type of modules (white) represents sources, the second type (grey) represents sinks, and the third type (hatched) represents process steps. Two main process chains are being considered:

- the energy conversion chain of wood and paper,

- and the manufacturing & construction chain for wood and paper products.

A functioning wood and paper manufacturing & construction sector exists in the Cape Metropolitan Area (CMA), including its own infrastructure and market dynamics. On the other hand, existing and potentially new energy conversion options will be analysed, including their logistics and own dynamics. Already here, a range of interactions between both the process-chains will be identified, which will deliver options on rendering the wood and paper network system more sustainable.

[1] see Section 6.3.3

Additionally to this, a significant third-world aspect will be included to the system. Wood plays an important role in two distinct ways for previously disadvantaged population groups living in informal settlements:

- Wood is used as an energy carrier for cooking and space heating.
- Wood is used as a construction material.

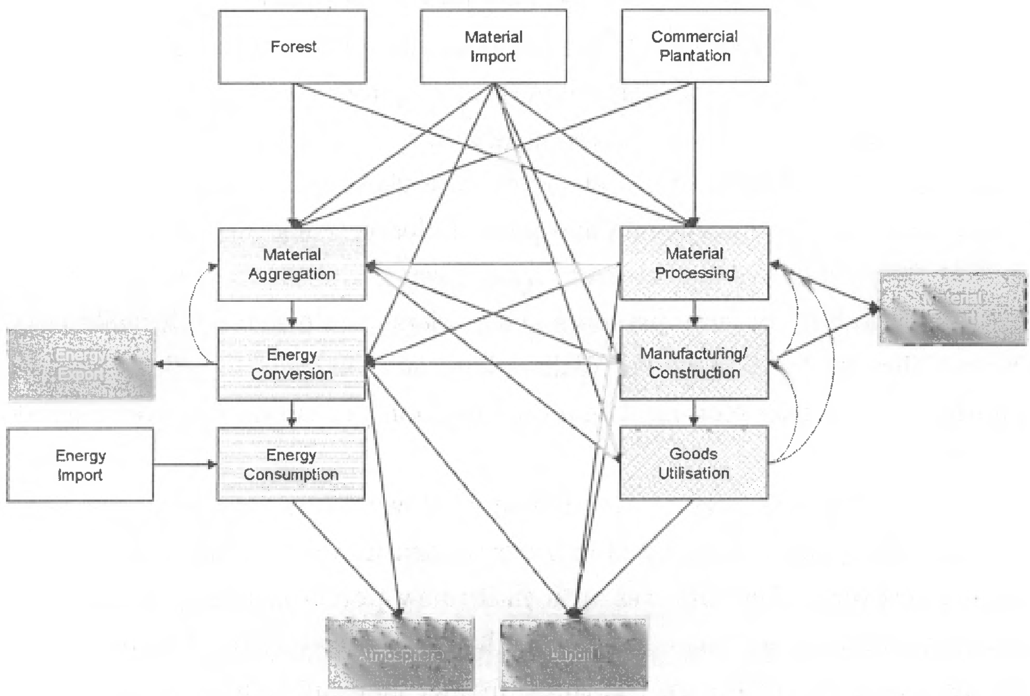


Figure 7.1: Wood and Paper Network

Wood utilised for energy purposes is collected in an informal manner and represents therefore a free energy carrier (traditional biomass). Wood for manufacturing or construction purposes stems mainly from either informal harvesting or the second-hand market.

The dimension that this third-world aspect adds to the system offers an option on investigating dynamics of economic, socio-economic and political type in an open system such as the Cape Metropolitan Area (CMA), and to seek out the potentials to innovatively link-up material and energy streams in order to render the considered system more sustainable.

7.3 Data Collection and Processing

The approach used for carrying out the MFA includes the collection and processing of data from a broad variety of sources, as a comprehensive and centralised collection of data on wood fibre based materials in Cape Town does not exist at the point of writing. Data were drawn from existing publications (integrated waste management plan, state of energy report, etc.), public databases (statistics South Africa, air pollution control database, RSC levy database, the business development agency WESGRO, etc.), telephonic interviews and site visits at companies (wood processing industry, pulp and paper industry, construction and demolition industry) for the formal sector of Cape Town. Interviews were conducted on site with inhabitants, entrepreneurs and traders in informal settlements in Cape Town (Khayelitsha, Gugulethu, Wallacedene, etc.) in order to collect data for the informal wood-using sectors. The data collection was conducted over a period of two years.

As can be seen in Figure 7.2, a flowchart of wood-fibre based material streams in Cape Town has been collated in order to identify material streams suitable for energy recovery. The aim was to identify new potential energy sources within existing material and waste streams of the city's metabolism. As can be seen on the left hand side of Figure 7.2, three distinct material sources (nodes 1-3) have been identified. Every source is a starting point of at least one material stream. The imports consist of all materials stemming from outside of the city boundaries. Peri-urban forests are non-commercial forests mainly being constituted of alien species such as Blackwattle (*Acacia Mearnsii*) and Port Jackson (*Acacia Saligna*) (Azorin, 1992). Parks and Gardens (or inner-city forests) generate a meaningful amount of biomass wastes, e.g. grass, leafs, wood trimmings and branches. Importantly, it should be mentioned that there are no commercial forest plantations within the boundary of the city.

Furthermore, five different wood-transforming sectors have been identified: the structural (or construction) wood sector (nodes 4-9), the fuel wood sector

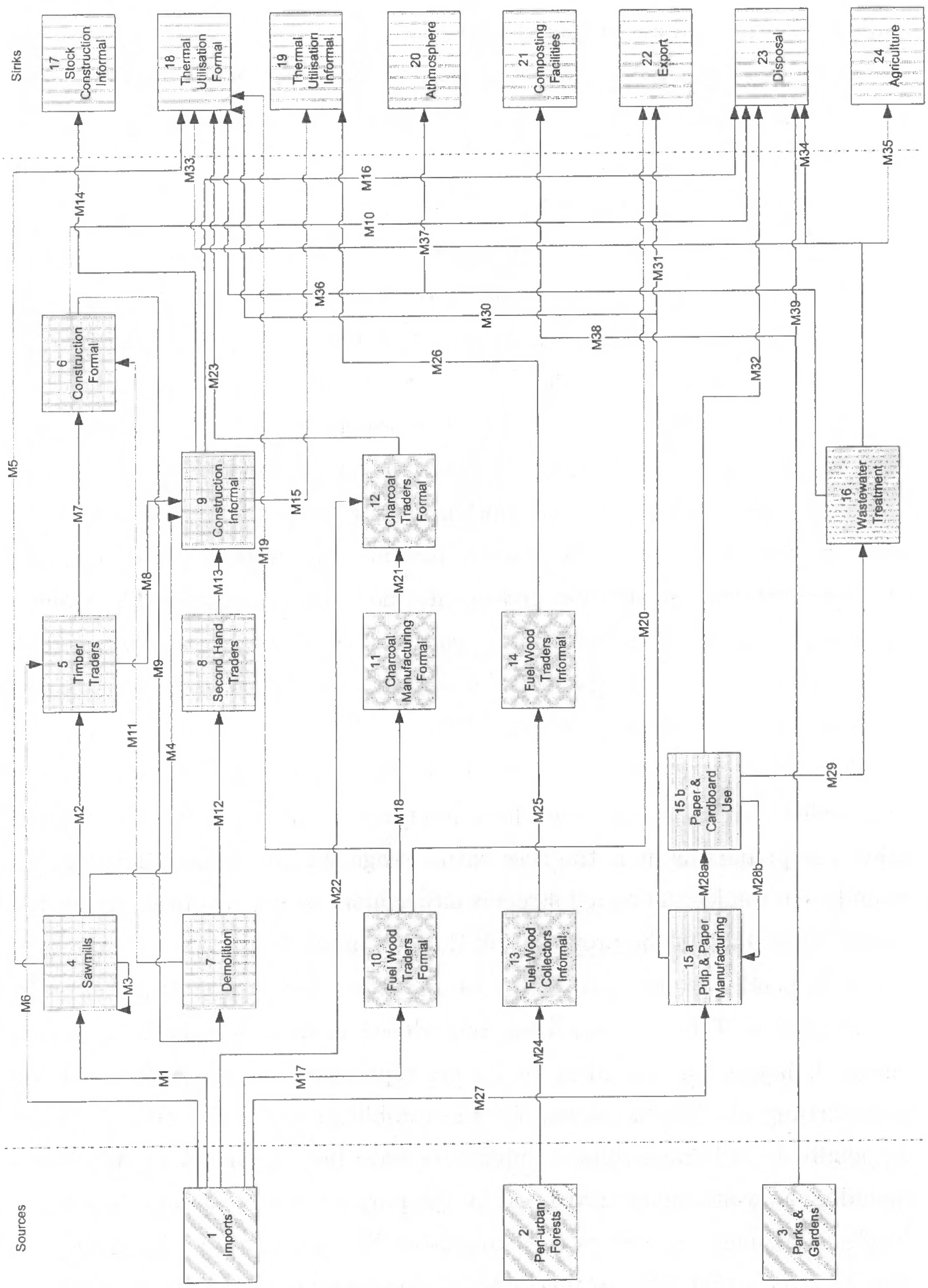


Figure 7.2: Flowchart on Wood Fibre Based Material Streams in Cape Town

(nodes 10-14), the pulp, paper & cardboard sector (node 15), the wastewater treatment sector (node 16) and the woody biomass sector (going straight to sinks). Each of these sectors consists of a number of specific transformation units and will be explained in Sections 7.3.1-7.3.5.

On the right hand side of Figure 7.2, eight different sinks have been identified (nodes 17-24). Every sink represents the ending point of at least one material stream, e.g. thermal utilisation, disposal options, or release into the atmosphere.

As can be seen in Table 7.1, a total of sixteen material streams have been identified within the city boundary theoretically being usable for improved energy recovery technologies. All quantities represent the wood fibre content of the different streams on a dry basis. The streams are emerging from eight different sources, namely sawmills, formal construction, informal construction, formal fuel wood traders, formal charcoal traders, informal fuel wood traders, pulp & paper manufacturing, wastewater treatment, and parks & gardens. The main sink for wood fibres in Cape Town are its landfill sites, receiving an estimated total amount of 231,000 t/a of wood fibre for disposal, followed by the informal thermal utilisation of wood accounting for 142,000 t/a.

This study was constrained to the wood fibre content of the different streams; in a realistic scenario, the wood fibre fraction can often not be separated from other compounds, as it is the case with sewage sludge. These additional compounds can render the mixed streams either more or less favorable for energetic usage, depending on the properties of these compounds.

In Appendix D, the calculation of the wood fibre based material streams represented in Table 7.1 has been reproduced in detail. Complete mass and energy balances corresponding to 7.2 are represented in Appendix E. A Table summarising all data necessary for the establishment of the MFA is given in Appendix F. All transcripts of interviews have been gathered in Appendix G, including a questionnaire developed for the purpose of field data gathering in the English language, as well as the indigenous Xhosa language. Appendices H, I and ?? give further data on the Informal Construction Wood Model, the Pulp & Paper Industry and the Wastewater Treatment sector.

	Energy Carrier	Starting Node	Sink	Quantity	Energy Content
Flows				[t/a]	[GJ/a]
M5	Wood waste	Sawmills	Thermal Utilisation Formal	40,000	876,000
M10	Construction wood	Construction Formal	Disposal	68,000	1,502,000
M15	Construction wood	Construction Informal	Thermal Utilisation Informal	37,000	804,000
M16	Construction wood	Construction Informal	Disposal	10,000	222,000
M19	Fuel wood	Fuel Wood Traders Formal	Thermal Utilisation Formal	43,000	788,000
M23	Charcoal	Charcoal Traders Formal	Thermal Utilisation Formal	12,000	366,000
M26	Fuel wood	Fuel Wood Traders Informal	Thermal Utilisation Informal	105,000	1,921,000
M30	Paper waste	Pulp & Paper Manufacturing	Thermal Utilisation Formal	3,000	40,000
M32	Paper waste	Paper & Cardboard Use	Disposal	139,000	2,227,000
M33	Sewage sludge	Wastewater Treatment	Thermal Utilisation Formal	1,000	12,000
M34	Sewage sludge	Wastewater Treatment	Disposal	3,000	55,000
M36	Methane	Wastewater Treatment	Thermal Utilisation Formal	1,000	53,000
M37	Methane	Wastewater Treatment	Atmosphere	1,000	42,000
M38	Biomass	Parks & Gardens	Composting Facilities	8,000	267,000
M39	Biomass	Parks & Gardens	Disposal	11,000	364,000
Total				482,000	9,539,000
Stocks				[t]	[GJ]
17	Construction wood	Construction Informal	Stock Construction Informal	123,000	2,638,000
Total				123,000	2,638,000

Table 7.1: Wood Fibre Based Material Streams Potentially Suitable for Energy Recovery

7.3.1 Structural Wood

A functioning wood manufacturing & construction sector exists in the Cape Metropolitan Area. Here, wood waste is produced which goes to the landfill site (ca. 23 kg/c*a), is thermally utilised (ca. 13 kg/c*a), or is sold on second-hand markets, forming an important interface to the informal settlement wood market.

Wood for the construction of informal dwellings (shacks) stems from the first and second-hand market. It emerged from an interview with an informal wood trader that the price of wood increased over the last couple of years, making other construction materials more competitive, e.g. metal sheets. Results show that a considerable amount of wooden material is released into the Cape Town energy market due to a steady flux of informal dwellings being replaced by brick houses driven by the national PHP mechanism. According to the City of Cape Town's Housing Department, ca. 4,000 new informal dwellings are built in Cape Town each year, whereas ca. 2,000 informal dwellings are being replaced by brick houses each year. An estimated total amount of ca. 123,000 t of construction wood is currently being bound in informal dwellings (shacks), as given by Table 7.1. This fact might become of substantial importance to the City of Cape Town before the background of planned projects such as the N2 Gateway project, aiming at replacing up to 20,000 informal dwellings by formal brick houses.

Approx. 3 kg/c*a of construction wood stemming from the informal sector go to the landfill sites and approx. 12 kg/c*a are utilised thermally.

7.3.2 Fuel Wood

In the informal settlements, wood utilised for energy purposes is mostly collected at the surrounds of the settlements and represents therefore a cheap energy carrier (traditional biomass) (Azorin, 1992). The wood utilisation for household purposes though decreased over the last couple of years, as wood is being replaced by paraffin and electricity for heating and cooking (CCT, 2003). The main utilisation of fuel wood happens at commercial meat grilling places in the informal settlements (ca. 35 kg/c*a). This means of fuel wood utilisation is a main contributor to local air pollution besides exhaust emissions and sand inflow, which is substantially higher than in the city centre (Ravenscroft, 2005). Fuel wood utilisation in the formal sector is estimated at ca. 14 kg/c*a, and charcoal utilisation at ca. 4 kg/c*a.

7.3.3 Woody Biomass

All wastes from parks & gardens are referred to as woody biomass. As can be seen in Table 7.1, a total amount of 8,000 t/a (ca. 3 kg/c*a) of wood contained in woody biomass is composted, whereas 11,000 t/a (ca. 4 kg/c*a) are being disposed of at local landfill sites (Jeffares & Green, 2004), representing a major loss of recoverable energy or good compost.

7.3.4 Pulp, Paper and Cardboard

There is an active paper recycling market in Cape Town, but all paper fibre ultimately degrades and should preferentially be used to replace dirtier, non-renewable fossil fuels instead of being landfilled (Moberg *et al.*, 2005). This does, however, not happen. In addition, the recycling market periodically suffers saturation, which allows paper manufacturers to choose best paper qualities, releasing at the same time huge quantities of paper to the local landfill sites. Waste streams from recycling (e.g. effluents, sludges, waste paper) are partially thermally utilised at the paper factories (ca. 1 kg/c*a), but a sizable amount of these waste streams are still disposed of by landfill (ca. 46 kg/c*a). Flow diagrams regarding the Pulp, Paper and Cardbaord sector are given in Appendix I.

7.3.5 Sewage Sludge

There are twenty wastewater treatment plants in Cape Town, processing ca. 600 Ml/d of sewage water (CCT, 2001). The total amount of wood-fibre contained in the sludge from these plants is estimated at ca. 4,000 t/a. The sludge is either transported to landfill sites or utilised as a fertilizer in agriculture. A total amount of ca. 2,000 t/a of methane (traced back to wood fibre) is produced in anaerobic digestion processes, ca. 1,000 t/a being utilised as diesel fuel substitute, and the remainder being released into the atmosphere. Furthermore, a total amount of ca. 2,500 t/a of sewage sludge pellets are being produced, a fraction of it currently being co-combusted in a cement kiln (Toll, 2005). The potentials of energy recovery on the sewage plants themselves are high.[1]

7.4 Discussion on Material Flow Analysis

As can be seen in Table 7.1, wood fibre based materials bind sizable amounts of energy which can potentially be utilised for energy recovery. Up to this stage, material flows are either disposed of at landfills, thermally utilised with the carbon then released into the atmosphere, composted, or bound as construction material. In all cases, there are substantial potentials for energy recovery. Note that whilst some material flows are already thermally utilised, the applied conversion technologies are often not appropriate and of low efficiency, e.g. open wood fires for food preparation (thermal efficiency ca. 1%), thus offering large potentials for improved energy recovery. It should also be mentioned that the material streams listed as flows in Table 7.1 occur on a regular basis, whereas the construction wood listed under stocks is only available once, though being released over a longer period of time, in the order of a couple of years.

The estimated energy content of 9.5 PJ/a comes to roughly 70% of the renewable energy target if defined more inclusively, or to double the adopted target. It should be interpreted as the maximum of an order of magnitude estimate. The amount of available energy for end-users is lower, as this number does not yet take into account any energy losses occurring in possible energy transformation & supply systems, or limited availability of wood fibre based material streams caused by infrastructural constraints. If all available recurring streams could be converted via standard technology to electricity at a typical efficiency of 25%, this would still mean that half of the adopted renewable energy target could be met from wood-fibre based materials.

Eventually, once the potential energy resources of a defined system are identified, it is important to be able to use the full potential of existing and especially emerging sustainable technologies for energy conversion. Therefore, there is an

[1] see Section 3.4.5.2

increasing need for tools stimulating the creative development of energy conversion options in order to meet the broad variety of energy needs that emerge in a city like Cape Town.

7.5 Conclusion

In this Chapter, an innovative approach for the identification of potential renewable energy sources within the boundaries of a developing city has been proposed by means of a MFA. A case study has been developed based on wood-fibre based material streams in Cape Town.

Data have been gathered and compiled for the formal and informal fuel wood sector, the formal manufacturing, construction and demolition sector, the informal construction sector, the pulp and paper market, the municipal solid waste management sector, as well as the wastewater treatment sector.

Analysis shows that no more than approx. 70% of an inclusively defined renewable energy target of the City of Cape Town (which aims for 10% of energy demand covered by renewable energies by 2020) could be met via the redirection of wood fibre based material flows within the Cape Metropolitan Area (CMA), and the utilisation of innovative transformation technology.

A novel approach for stimulating the design of technological conversion options which match renewable energy sources and energy service demand will be presented in the following Chapter.

7. URBAN RENEWABLE RESOURCES: A MATERIAL FLOW ANALYSIS OF WOOD AND PAPER IN CAPE TOWN

Chapter 8

Creative Web-Based Option Generation

8.1 Introduction and Rationale

Over the last decades, the necessity grew for innovative option generation in order to move away from supply-side driven, electricity based energy planning (see e.g. Geller, 2003). In order to design a sustainable energy product, the markets (needs) should be known and drive the product design and selection process, as it is applied in the field of e.g. Chemical Product Design (Cussler & Moggridge, 2001). The procedure for doing so should follow the steps of identifying energy demands before considering potential supplies, and generating a superstructure and intermediates linking demands to supplies. The last step is often neglected, as all possible technological options are seldom known, and/or its crucial importance is under-estimated.

As has been shown in Chapter 6 and 7, a profound understanding of energy service demand has been developed in the context of energisation, and the method of MFA has been applied in order to identify locally available renewable resources.

Up to this point in time, energy planning on the municipal level has happened both without or with the use of computer-aided energy planning tools. The point is that neither the manual nor the computer-enhanced approach embed a systematic concept for the preliminary screening of possible energy transformation pathways relevant within a set system, e.g. an urban context, feeding from a steadily updated set of possible options, and emphasising renewable and sustainable means for meeting energy demand.

The aim of this Chapter is to contribute to the development of an alternative, richer, more powerful and more appropriate planning process, basically substantiating the initially stated Hypothesis in Section 1.4:

> *The transferability of existing western energy planning methods, which are very limited amongst other things because they have only recently started to systematically include renewables into their ambit, will be enhanced by the use of computer-aided synthesis of options, informed from the emerging field of Combinatorial Process Synthesis, and embedded in Multiple-Criteria Decision Analysis.*

Based on the background information given under Section 2.3.2.4, it has been found that meta keywords of an URL are of special interest against the backdrop of this thesis. It is postulated that a semantic link exists between meta keywords of an URL.

In pursuit of substantiating the above stated Hypothesis, the following twofold question needs to be answered:

1. Is it possible, based on the interlinked information currently available in the WWW and a software application using Web 2.0 technology, to create semantically related keyword chains between two different initial starting points over one or more iteration steps?

2. Can this approach practically be implemented in the field of renewable energy planning for Southern urban contexts, by generating stimulants for the design of innovative conversion pathways stretching from end-user demand to inner-city energy resource, enabling a significant process of sustainable energisation?

In order to answer the previously stated questions, an option generation model will be defined based on the approaches of CPS and data mining. A software application integrating the newly defined model will be developed. Furthermore, a series of experiments will be carried out, using the software application, in order to validate the model and its application. Results of the validation experiments will be analysed and interpreted. Subsequently, the outcomes will be discussed, so that finally, conclusions regarding the efficiency of the chosen approach can be drawn.

The examples utilised in Sections 8.2 and 8.3 have only an illustrative purpose in order to explain the developed methodology based on practical cases. These examples represent by no means original outputs of the proposed model and software tool, and have been chosen because of their clarity and familiarity to researchers in the field of biofuel options. In Section 8.4, original results will be proposed based on a set of experiments; The practical implementation potential will be discussed at the end of the Section.

8.2 Methodology

A basis for the option generation model is the approach of data mining (see Section 2.3.2.4). At the core of the option generation model lies a process based on looped and improved web search queries, delivering option networks (option trees) similar in structure and connectivity to the ones delivered by a CPS (see Section 2.3.2.2).

The option generation process is by definition driven by both energy demand and supply, as it generates option trees starting from both ends of the energy system, namely energy resource(s) and end-user demand(s). The obtained option trees are matched where they meet, forming result chains which are ranked according to a set of calculated parameters. These result chains might be of two different natures, on the one hand representing logical technological connections (e.g. input, conversion technology, output), readily implementable in existing energy systems, or on the other hand representing neural connection strings similar to the ones delivered by the process of brain storming as defined in the concepts of e.g. MindMapping (Buzan, 1991), enabling creative thinking processes outside predefined system patterns.

The model realised as a software tool incorporates proved State-of-the-Art technology from the field of web search, such as Google's flagship search service (so-called second generation or Web 2.0 applications (O'Reilly, 2005)). The web is considered as a platform, providing a large, accessible and regularly updated and extended collection of data, counting approx. 8 billion websites of information at the point of writing (Vise, 2005).

The results of the software tool are delivered in a format suitable for both manual or computer-aided energy system analysis and optimisation, as they are presented in form of a summary graphic and a result table.

In the following Section, a more detailed methodological description of the steps of option tree generation, option tree matching, and result processing and display will be given.

8.2.1 Option Tree Generation

8.2.1.1 Generation Model

As given by Figure 8.1, the first task in the option tree generation model consists in triggering a web search based on an initial search query (e.g. end-user energy demand). Out of the generated list of results, a number of websites are selected. For each of the selected websites, a number of keywords is retrieved from the website's keyword list. The process described up to here is referred to as being one iteration level. For each keyword obtained in the first iteration level, a new website search is triggered, and a number of parallel processes consisting out of website selection and keyword retrieval is started as described for the first iteration level. The totality of these subsequent steps is being referred to as the second iteration level. This loop can theoretically be carried on infinitely.

Based on a theoretical example[1], it is demonstrated in Figure 8.2 how the results of an option tree generation exercise are displayed.

[1]This example does not represent an original output of the proposed model and software tool

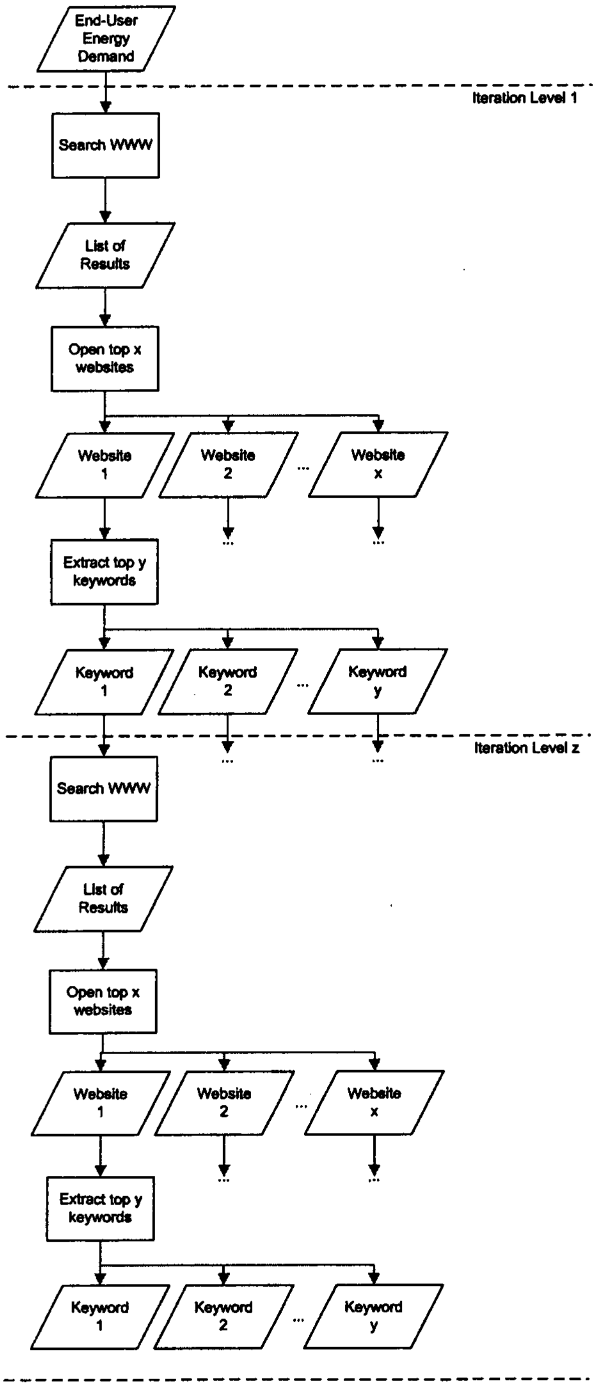


Figure 8.1: Generation of Option Trees

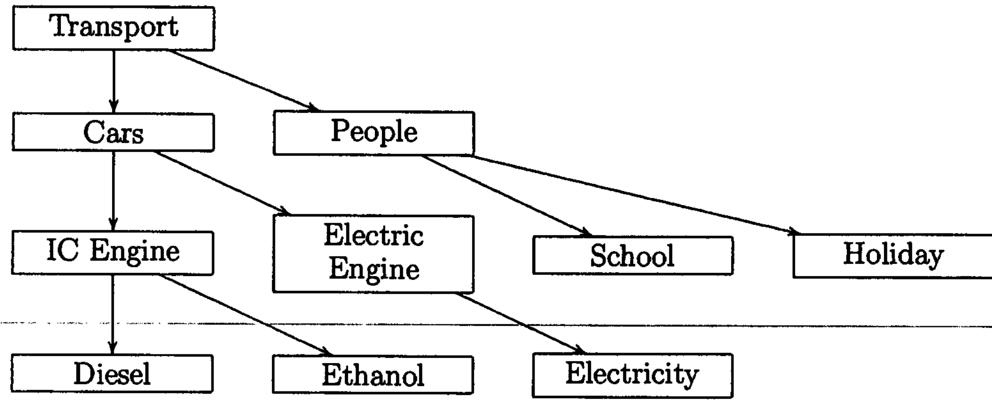


Figure 8.2: Example Option Tree - Transport

8.2.1.2 Parameter settings

Eight parameters[1] have been defined in order to influence the generation of option trees, namely the initial search query, the search context, the number of websites, the number of keywords, the iteration level, the website repetition, the keyword repetition, and the keyword quotation. In the following, these parameters will be described.

The parameter 'Initial Search Query' describes the first search query when the generation of a new option tree is launched. The parameter can take two different values, either 'simple' or 'specific'. In the former case, the initial search query is equal to the research area, and is entered as such, e.g. 'Cooking'. In the latter case, the initial search query is made of the research area, combined with a number of more specific and related search terms, taking into account Google's specific query terms (Google, 2006a).

The parameter 'Search Context' is a constant value that is added to the search query for each new search during the generation of an option tree. Similar to the previous parameter, the parameter 'Search Context' can take two different values, either 'simple' or 'specific'. In the former case, the parameter consists of a single keyword, e.g. 'energy'. In the latter case, a more complex context is formulated, focusing the search on more specific research fields.

[1] The option generation procedure was extended to the parameters 'Language' and 'Country' for the verification phase (see Section 8.4.1.4), allowing the user to restrict his option tree generation geographically.

Note that the maximum number of research terms when combining the initial search query to the search context may not be longer than 10 (or 2048 bytes), as this is one of the limitations of the Google SOAP Search Application Programming Interface (API) at the point of writing (see Google, 2006a). A complete list of specific search queries and search contexts can be found in Appendix O.

The parameter 'Nr of Websites' describes the maximum number of websites considered for each Google search, represented by value x in Figure 8.1. The maximum number of websites delivered by the Google API per search query is currently limited to 10 by the service provider. In experimentation (described later), three different possible values were used for this parameter, namely 1, 5, and 10, covering one median as well as two extreme values.

The parameter 'Nr of Keywords', represented by value y in Figure 8.1, describes the maximum number of keywords to be retrieved from a website delivered by the search engine. Three different possible values were used in experimentation, namely 1, 15, and 25, to be representative for one intermediate and two extreme values.

The parameter 'Iteration Level', represented by value z in Figure 8.1, sets the maximum number of iterations for the generation of an option tree. An iteration level is considered to be the totality of search queries starting with the keywords delivered by the previous totality of search queries. The first iteration level is the totality of search queries using the value of the parameter 'Initial Search Query'. The highest possible iteration level is 5, as the application is at this stage programmatically limited to this value.

The parameter 'Website repetition' is a boolean value, allowing it or not for a website to be repeated within one option tree. In case the parameter value 'Website repetition' has been set to false, already existing websites are skipped, and the next website is being retrieved until the user defined maximum value of websites has been achieved, unless the provider maximum of 10 is being crossed.

The parameter 'Keyword repetition' is a boolean value, allowing it or not for a keyword to be repeated within one option tree. In case the parameter value 'Keyword repetition' has been set to false, already existing keywords are skipped, and the next keyword is being retrieved until the user defined maximum value of keywords has been achieved, unless the number of keywords on the specific website is not sufficient.

The parameter 'Keywords in quotes' is a boolean value, setting or not the keyword(s) of a new search query in quotes, which is of importance regarding the Google query syntax; two separate keywords without quotes are considered as two individual search terms, whereas two keywords in quotes are being considered as one single search term.

8.2.2 Matching of Option Trees

As demonstrated by the theoretical example[1] in Figure 8.3, at least two option trees need to be compared in order to tackle the initially stated problem. The first option tree on top has an end-user energy demand as starting point ('Transport'); the second option tree at the bottom has an energy supply (resource) as starting point ('Biomass').

The process of matching both the trees has the purpose to obtain result chains of keywords leading from energy demand to energy supply. A match corresponds to two identical keywords in the top and the bottom tree. As can be seen in Figure 8.3, identical matches are the keywords 'Diesel', 'Syngas', 'Ethanol' and 'Electricity'. By matching up the keywords with their respective keyword chain chunks leading up to the initial keyword of each tree, one obtains the following result chains:

1. Transport → Cars → IC Engine → **Diesel** → FTS → Syngas → Wood → Biomass
2. Transport → Cars → IC Engine → **Ethanol** → Sugar Cane → Biomass
3. Transport → Cars → IC Engine → **Syngas** → Wood → Biomass
4. Transport → Cars → Electric Engine → **Electricity** → Gas Turbine → Syngas → Wood → Biomass

[1]This example does not represent an original output of the proposed model and software tool

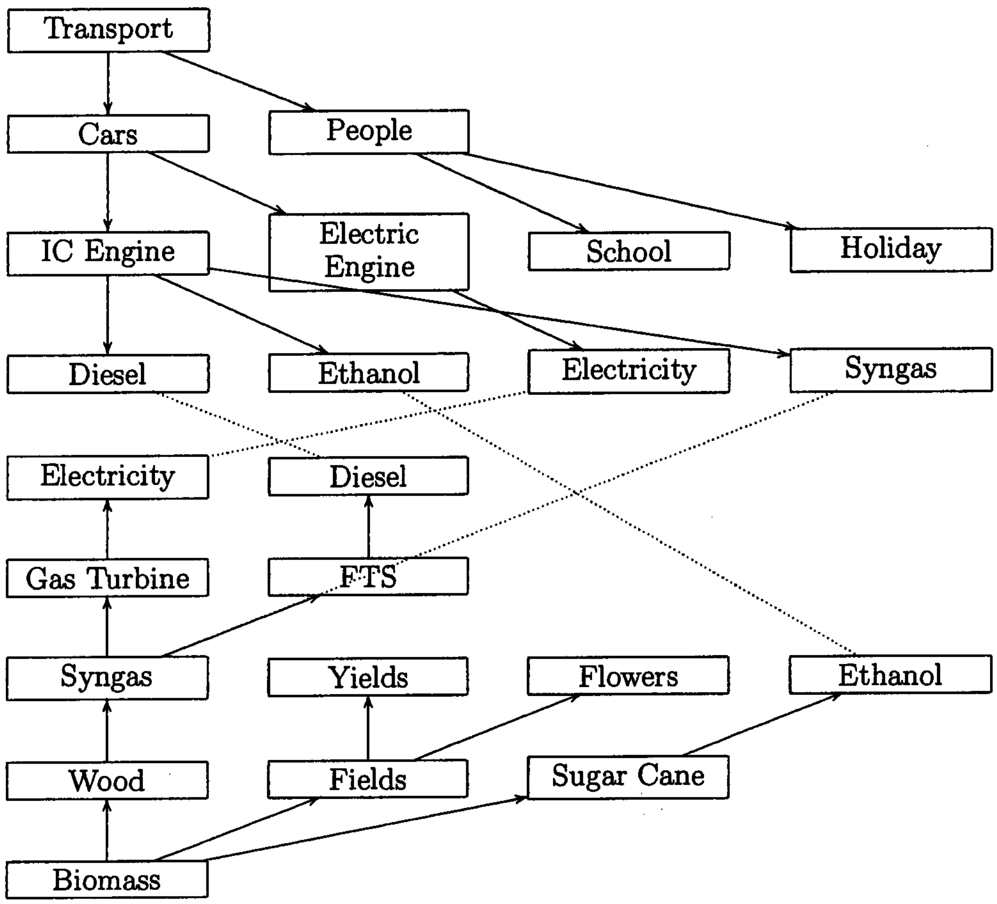


Figure 8.3: Example Option Tree Matching - Transport/Biomass

8.2.3 Processing and Display of Results

One of the main challenges of the creative option generation application is to provide the user with a set of valuable information that he can easily integrate into his multiple-criteria decision problem. In order to achieve this goal, the data that has been retrieved during the option tree generation phase (see Section 8.2.1), and matched during the option tree matching phase (see Section 8.2.2), needs to be processed in such a way that the most relevant data is screened out. This is achieved in three distinct steps. Firstly, as set of parameters needs to be calculated for each result chain, so that a qualitative information regarding the data is obtained. Secondly, the result chains must be ranked according to their quality, integrating a set of weighting values defined according to user-specific priorities. Thirdly, the ranked result chains must be provided to the user in an accessible and understandable manner. This is achieved via the display of a selection of highest ranking result chains in a tabular and graphical form. These three steps will be discussed in detail in the following Sections.

8.2.3.1 Parameter Definition

A set of four parameters has been defined in order to rank the result chains created during the option tree matching phase. The parameters are chain length, keyword importance, website importance, and pattern similarity. In this Section, these four parameters will be explained in terms of significance and calculation.

In Table 8.1, a theoretical example has been developed, which will be utilised for the calculation of the defined parameters based on the proposed equations. The example given in Table 8.1 does not represent an original output of the proposed model and software tool.

The parameter 'Chain Length' represents the number of keywords within a result chain. It is hypothesised that the longer the result chain, the higher the chances to obtain a meaningful connection between the keywords of the result chain. The value for parameter 'Chain Length' (CL) is calculated according to the following formula:

$$CL_i = l(C_{t1,i}) + (l(C_{t2,i}) - 1) \quad (8.1)$$

Where $l(C_{t1,i})$ is the number of keywords in the part of the result chain stemming from the first combination of option trees (*energy demand*), and $l(C_{t2,i})$ the number of keywords in the part of the result chain stemming from the second combination of option trees (*energy supply*). $l(C_{t2,i})$ is subtracted by 1 in order to avoid double accounting for the matching keyword.

As given by the example in Table 8.1, the value for parameter CL is calculated based on the values given in the column 'Position', which gives the value 5 for $l(C_{t1,i})$, and 4 for $l(C_{t2,i} - 1)$. Their sum thus amounts to 9.

	Tree Combo	Position	Keyword #	Website #	Type	Pattern Pos
Wood	t2	1	25	48	EC	1
↓						
Gasification	t2	2	11	8	TT	2
↓						
Syngas	t2	3	33	3	EC	3
↓						
FTS	t2	4	65	22	TT	4
↓						
Liquid fuel	t2/t1	5	11/13	2/1	EC	5
↓						
President	t1	6	17	18	-	0
↓						
IC Engine	t1	7	17	16	TT	1
↓						
Mechanical Energy	t1	8	38	34	EC	2
↓						
Transport	t1	9	6	2	TT	3

Table 8.1: Example Parameter Calculation

The parameter 'Keyword Importance' represents the number of repetitions of a specific keyword within the totality of keywords of the considered option trees. It is hypothesised that the higher the number of repetitions of a keyword, the higher its importance - and thus significance - in a specific search context.

The value for parameter 'Keyword Importance' (KI) is calculated according to the following formula:

$$KI_i = \left[\left(\sum_{j=0}^{l(C_{t1,i})} n(k_{ij}, t1)\right) - l(C_{t1,i})\right] + \left[\left(\sum_{j=0}^{l(C_{t2,i})} n(k_{ij}, t2)\right) - l(C_{t2,i})\right] \quad (8.2)$$

The formula for calculating the parameter KI for result chain i basically consists of two terms, corresponding to the part of the result chain stemming from the first combination of option trees (*energy demand*), and the part of the result chain stemming from the second combination of option trees (*energy supply*). In the left term of the formula, the number of occurrences n of each keyword k_{ij} in the first combination of option trees $t1$ is summed up over j, eventually being subtracted by the number of keywords in the chain $l(C_{t1,i})$ in order to restrict the accounting to the recurring keywords only. In the right hand term, calculations are identical to the calculations in the left hand term, using this time values from the second combination of option trees $t2$.

As given by Table 8.1, the value for parameter KI is calculated based on the values given in the column 'Keyword #', which gives for the first term $(25+11+33+65+11)-5 = 140$, and for the second term $(13+17+17+38+6)-5 = 86$, which gives a total value $KI_i = 226$.

In analogy to the parameter 'Keyword Importance', the parameter 'Website Importance' represents the number of repetitions of a specific URL within the totality of URLs of the considered option trees. It is hypothesised that the higher the number of repetitions of an URL, the higher its importance - and thus significance - in a specific search context.

The value for parameter 'Website Importance' (WI) is calculated according to the following formula:

$$WI_i = \left[\left(\sum_{j=0}^{l(C_{t1,i})} n(w_{ij}, t1)\right) - l(C_{t1,i})\right] + \left[\left(\sum_{j=0}^{l(C_{t2,i})} n(w_{ij}, t2)\right) - l(C_{t2,i})\right] \quad (8.3)$$

The formula for calculating the parameter WI is similar to the formula used for calculating the parameter KI (see equation 8.2), except that the number of occurrences n of each website w_{ij} is summed up over j.

As given by the example in Table 8.1, the value for parameter WI is calculated based on the values given in the column 'Website #', which gives for the first term $(48+8+3+22+2)-5 = 78$, and for the second term $(1+18+16+34+2)-5 = 66$, which gives a total value $WI_i = 144$.

The parameter 'Pattern Similarity' represents the similarity of a result chain to an ideal pattern of keywords of alternating types 'Energy Carrier' (EC) and 'Transformation Technology' (TT) (EC-TT-EC-TT-EC-TT-etc.). The background is that in reality, an energy conversion pathway from resource to end-user demand consists of this two alternating elements. It is hypothesised that the closer the result chain to that ideal pattern, the higher its importance and significance in the specific search context.

The value for parameter 'Pattern Similarity' (PS) is calculated according to the following formula:

$$PS_i = \sum_{j=1}^{n} \left(\frac{(l(p_j) \cdot ((CL_i + 1) - j)}{CL_i} \right) \tag{8.4}$$

This parameter has been developed in order to express quantitatively how close the pattern of keyword types of a result chain i is to an ideal pattern of keyword types, consisting of an infinite alternation of energy carriers and transformation technologies. In order to do so, the length l of each pattern fragment p_j must be identified within the result chain i. This term is multiplied by a term allocating a weight to a pattern fragment p_j according to its position j in the list of pattern fragments sorted by length. This term is calculated by subtracting the position j of a pattern fragment from the total chain length CL_i added by 1. This result is normalised by dividing it by total chain length CL_i.

As given by the example in Table 8.1, the type of each keyword has been given by column 'Keyword Type', 'EC' standing for 'Energy Carrier', 'TT' standing for 'Transformation Technology', and '-' standing for none of the previous two. The two chain chunks are now considered as a whole, eliminating one entry for the matching keyword 'liquid fuel', giving a total length $CL_i = 9$. Two pattern fragments can be identified ($j = 2$), the first one starting at position 1, being 5 positions long ($l(p_1) = 5$), and the second pattern starting at position 7, being 3 positions long ($l(p_2) = 3$). Furthermore, the first fragment is also the longest pattern fragment, positioning it at number 1 before the second pattern fragment. By replacing these values in equation 8.4, one gets the following calculation:

$$PS_i \quad = \quad \frac{5 \cdot ((9+1)-1)}{9} + \frac{3 \cdot ((9+1)-2)}{9} \quad = \quad 5 \, + \, 2.67 \quad = \quad 7.67$$

Note that the importance of the parameter Pattern Similarity is twofold, as it firstly accounts for the types of keywords as such, and secondly allocates more value to result chains the closer they are to an ideal pattern.

8.2.3.2 Ranking of Results

In order to rank the results of a tree matching exercise, one must first calculate the four parameter values as given in Section 8.2.3.1 for each chain of results. Thereafter, the parameter values for each chain are weighted according to user defined settings. The user will define for each parameter its sorting order, ascending or descending, and a weight in percentage. The sum of the weights of all four parameters must be equal to 100%.

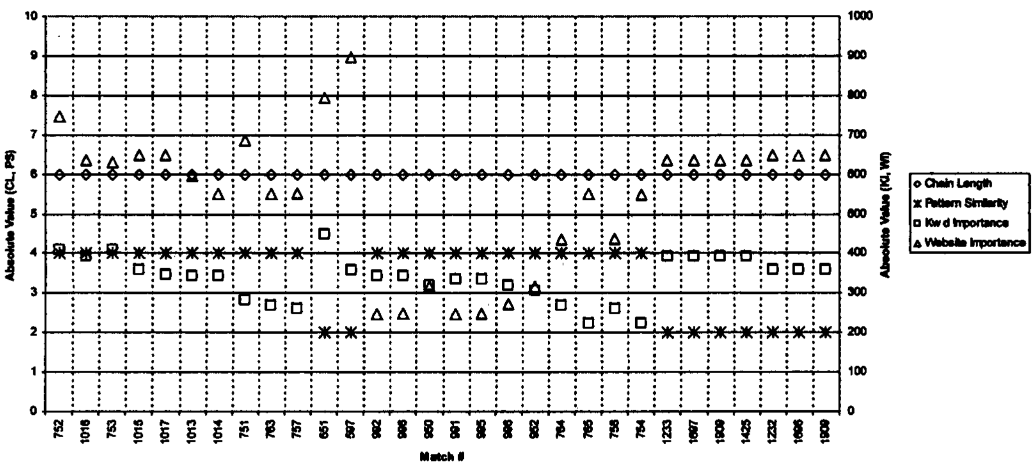


Figure 8.4: Absolute Parameter Values - R2.1 Top 30

In order to illustrate the calculations made for the ranking of results, an example has been chosen based on a random option tree matching exercise performed with the proposed model and software tool. This example will only by utilised throughout this particular section for illustrative purposes, and is not related to the quality of information work carried out in later Sections of this Chapter.

For the proposed example, it can be seen in Figure 8.4 that the absolute values for all four parameters are displayed for the top 30 results of the obtained 2,089 ranking results of a random option tree matching exercise.

The absolute values for the parameters 'Chain Length' and 'Pattern Similarity' are given on the scale of the left y-axis, where as the absolute values for the parameters 'Keyword Importance' and 'Website Importance' are given on the scale of the right y-axis. It can be observed that the order of magnitude for the values of 'Keyword Importance' and 'Website Importance', varying between 200 and 900, is a factor 100 bigger than the order of magnitude of 'Chain Length' and 'Pattern Similarity', varying between 2 and 6.

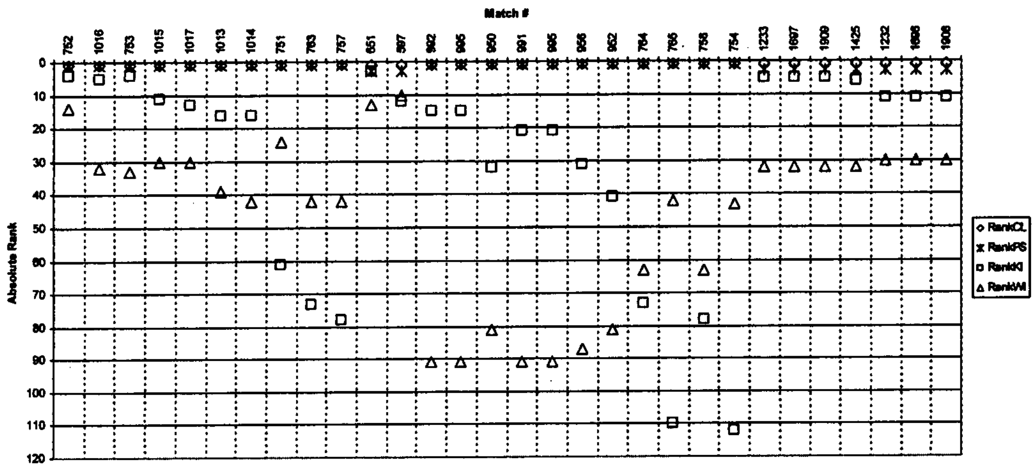


Figure 8.5: Absolute Parameter Ranking - R2.1 Top 30

In order to make the values for the different parameters comparable, two steps are necessary, namely an absolute and a relative ranking of the parameter values for each result chain. As can be observed in Figure 8.5, the absolute rank for each parameter of a result chain is calculated relatively to the values for the same parameter for the other result chains. For instance for result chain number 950, the absolute rank for 'Chain Length' and 'Pattern Similarity' is 1, whereas the absolute rank for 'Keyword Importance' and 'Website Importance' is 32 and 81 respectively. This means that e.g. the value for parameter 'Website Importance' has been ranked on position 81 when compared to the values for parameter 'Website Importance' from the other result chains. It must be noted that the number of ranking positions for each parameter can differ, as it is possible that several result chains were allocated the same value for one parameter. It is therefore necessary to perform a relative ranking for each parameter according to the following formula:

$$p_{i,rel} = \frac{p_{i,abs,max} - p_{i,abs}}{p_{i,abs,max}} \quad (8.5)$$

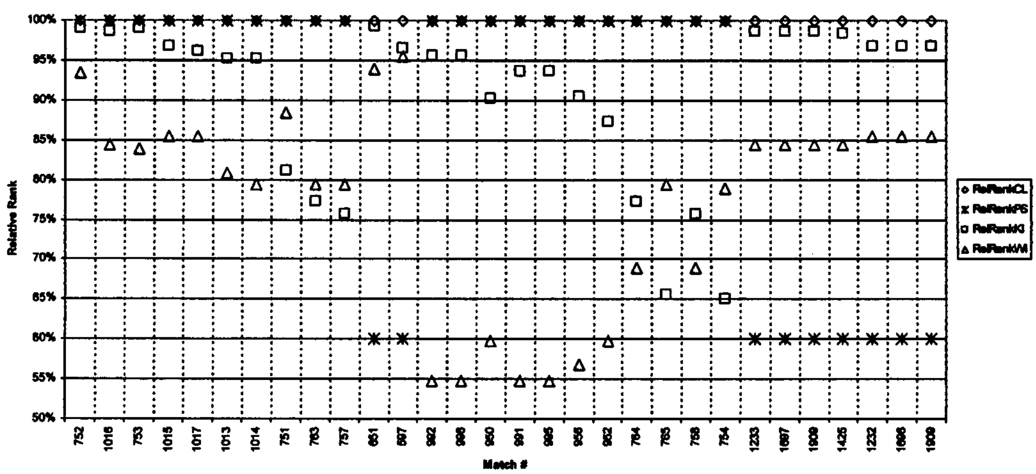


Figure 8.6: Relative Parameter Ranking - R2.1 Top 30

$p_{i,abs,max}$ is the maximum absolute ranking position for the specific parameter for result chain i, and $p_{i,abs}$ is the ranking position for a specific parameter for result chain i.

As can be seen in Figure 8.6, the relative rankings for the top 30 results of a matching exercise have been displayed. For instance, absolute position 1 harnessed 100%, whereas the lower the position, the lower the percentage value. In the case of result number 950, the value for the relative position of parameter 'Keyword Importance' has been calculated based on its absolute position (32), and the lowest position for parameter 'Keyword Importance' for all the result chains (317), which must by definition be smaller or equal to the total number of results (2,089). By inserting these values into equation 8.5, the following result is obtained for the relative ranking of parameter 'Keyword Importance':

$$p_{i,rel} = \frac{317 - 32}{317} = 0.89 \approx 90\%$$

By including the settings made for the sorting order and the weighting factor in %, the final weight for each result chain is obtained by summing-up the 4 parameter weights. In fact, the sorting order is taken into account by substracting the relative parameter position from 100% in case of a descending sorting order; in case of an ascending sorting order, the relative parameter position remains unchanged. The weighting factor is taken into account by multiplying the relative parameter position by it. As depicted by Figure 8.7, the four parameter weights have been added for each result chain, delivering sums ranging between 0.8 - 1.0 for the top 30 results. There is relatively little variance for the parameters 'Chain Length' and 'Pattern Similarity', whereas the parameters 'Keyword Importance' and 'Website Importance' do vary significantly. The sorting order for the parameters have all been set to ascending, and all the weighting factors have been set to 25%, giving a sum of 100%.

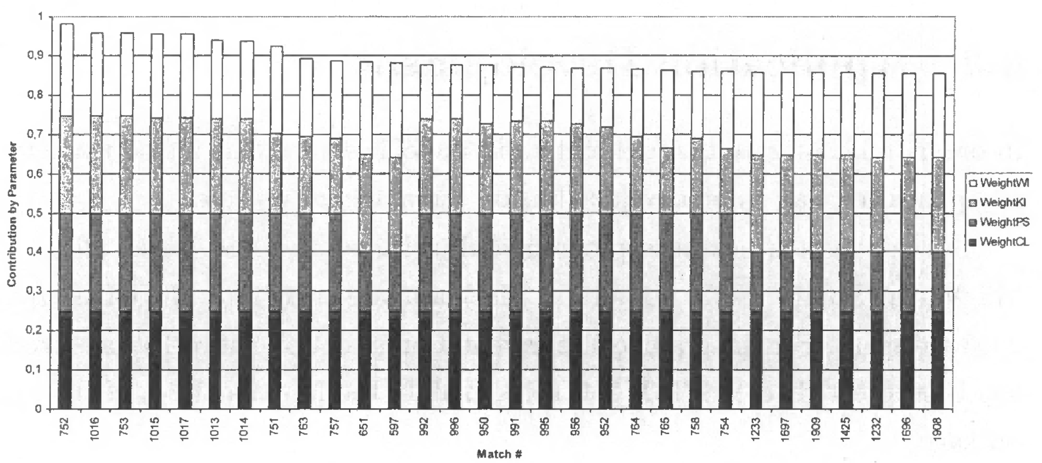


Figure 8.7: Parameter Contributions - R2.1 Top 30

For result chain 950, we obtain a contribution of 22.5% (0.225) for the parameter Keyword Importance by multiplying the relative parameter ranking of 90% by a weighting factor of 25%.

8.2.3.3 Display of Results

Results are displayed either in form of a list or in form of a graph.

The purpose of displaying the highest ranking result chains in form of a list is to provide the user with a set of *separate* transformation pathways including all calculated parameter values, ranking and sorting orders, as well as all intermediate values. In this form, data is easily exportable and can be used for goals such as statistical evaluation.

The purpose to provide the user with a graphical representation of the highest ranking information (e.g. top 10 results) is to give a *concise* and *connected* picture of obtained result chains in form of a box-and-arrow flowdiagram. This form of result representation contains less information than the list form for the sake of clarity.

Eventually, it is up to the users of the application to choose which type of result display is most appropriate to their needs.

8.3 Application Development

In order to investigate the feasibility and the efficiency of the introduced model, an application had to be developed using the model at its core.

The application has been programmed in Microsoft (MS) Visual Basic on a MS Visual Studio .NET platform. The database used is a MS Office Access 2003 database. For the graphical representation of option networks[1], an interface has been created to MiKTeX 2.4, using mainly the functionalities of the `xypic` package.

The option generation application has been designed in a typical three-tier

[1]An option network consists of the matching and combination of option trees

manner[1] as shown in Figure 8.8, consisting of the database layer, the business layer, and the user interface layer.

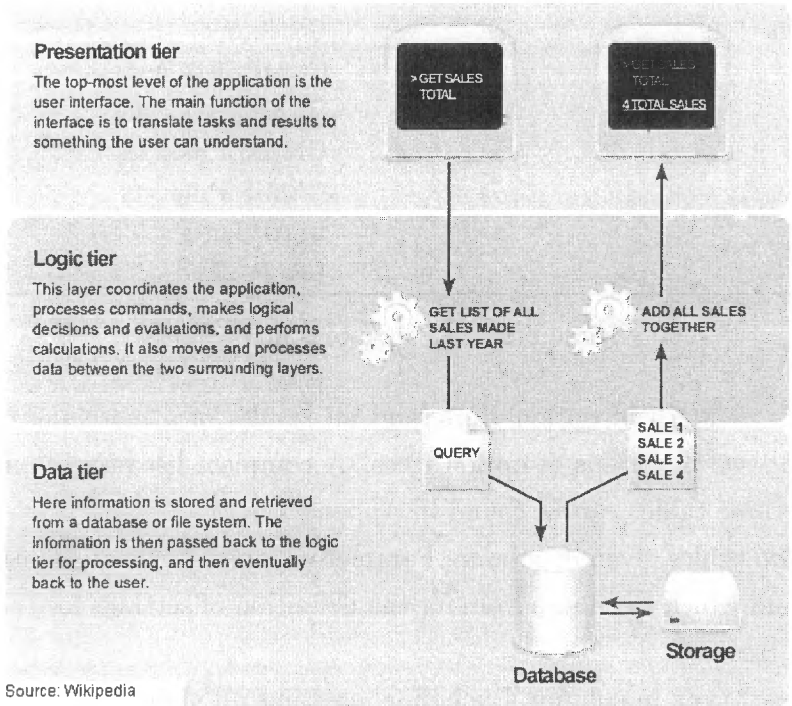


Figure 8.8: Overview of a Three-Tier Application

These three tiers will be briefly discussed in the following Sections.

8.3.1 Design of the Data Tier

The data tier consists of a database, designed as a MS Office Access 2003-database. It contains a total number of 17 tables, as represented in Table 8.2.

The main tables of the database (see column 'Main') are `tblOptionTrees`, `tblConnectors`, and `tblResults`, containing respectively all information regarding option trees and their related parameter settings, all connectors generated

[1] Wikipedia (2006d) says: *"In SAP computing, Three-tier is a client-server architecture in which the user interface, functional process logic ("business rules"), data storage and data access are developed and maintained as independent modules, most often on separate platforms. The term "three-tier" or "three-layer", as well as the concept of multitier architectures, seems to have originated within Rational Software."*

Main	Parameter	Excluding	Comparative I	Comparative II
tblOptionTrees	tblCountry	tblNegatives	Co2db_gen	tblGeneral_FUEL
tblConnectors	tblLanguage		Co2db_inp	tblGeneral_TECH
tblResults			Co2db_out	
			COMPEED_Fuels	
			COMPEED_Tech	
			GEMIS_Processes	
			GEMIS_Products	
			LEAP_Fuels	
			LEAP_TED	

Table 8.2: List of Tables in Database

during the creation of option trees, and all results of a matching exercise performed for two selections of option trees. A complete list of table fields defined for these three tables can be found in Appendix J.

The two tables given in column 'Parameter' contain lists of countries and languages from which to choose from for the definition of settings for the generation of option trees.

`tblNegatives` in column 'Excluding' contains all alphanumerical expressions to be rejected during the generation of an option tree.

In column 'Comparative I' are cited all tables that have been provided by external institutions[1] serving the purpose of defining the types of retrieved keywords by comparing them to the data on transformation technologies and energy carriers contained in them.

The column 'Comparative II' contains the two tables where user-defined transformation technologies and energy carriers are stored.

For the purpose of performance enhancement, indices have been created for the different tables combining the most used table fields. This allows to accelerate data retrieval from the business layer. Furthermore, the MS Data Access Object (DAO)-object used for accessing data in the database can be optimised by choosing adequate parameter settings according to the usage of the data in the application (e.g. generation of read-only recordsets).

[1]By courtesy of IIASA, Austria (CO2DB); EnergiAnalyse, Denmark (COMPEED XL); Öko-Institut, Germany (GEMIS); and SEI-Boston, USA (LEAP).

8.3.2 Design of the Logic Tier

The Logic Tier is the application tier which lies between the Presentation Tier and the Data Tier, and contains all logical procedures necessary either to process inputs from the Presentation Tier and to store them in the Data Tier, or to retrieve and process data from the Data Tier in order to deliver it to the Presentation Tier.

In the case of the option generation application, the Logic Tier basically contains three different procedures in analogy to the model developed under Section 8.2, namely the option tree generation procedure, the option tree matching procedure, and the results processing and display procedure. The three procedures are discussed in detail in Appendix K.

8.3.3 Design of the Presentation Tier

The purpose of the Presentation Tier is to render the interaction between the application and the user as easy as possible. For the creative option generation application, a User Interface (UI) has been developed based on a conventional MS Windows-type UI, in order to keep a relatively large degree of intuition regarding the handling of user dialogues.

In the following Sections, only three key windows of the application will briefly be introduced. A detailed presentation and explanation of all windows and their functionalities is given in Appendix L.

The form 'Tree View' as depicted in 8.9 displays the results of an option tree generation exercise in form of a tree similar to a MS Explorer file tree, allowing to expand and collapse single nodes of the tree.[1] A meaningful functionality of the tree view is the manual rework of the option tree. By right-clicking on a keyword, it is possible to define the type of the keyword as energy carrier, transformation technology or other, or to delete a specific keyword including all subsequent nodes. It is also possible to open a website by clicking on an URL in the option tree.

[1]The top two command buttons on the right hand side of the form allow to expand and collapse all nodes of the tree at once.

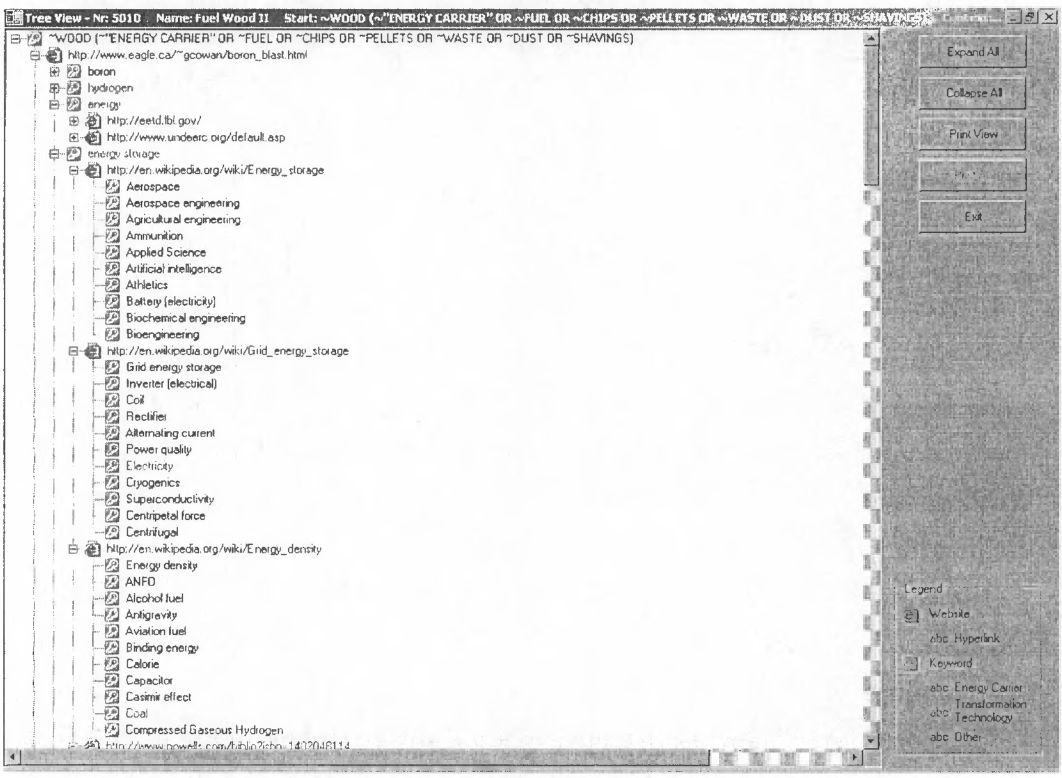


Figure 8.9: Example of a Tree View

In the form 'Evaluation' as given in Figure 8.10, the results of the option tree matching exercise are displayed in the form of result chains, alternating the keywords and corresponding URLs. Moreover, results regarding the calculation of the different parameters, as well as intermediate results regarding the weighting and ranking of the different chains are given.[1]

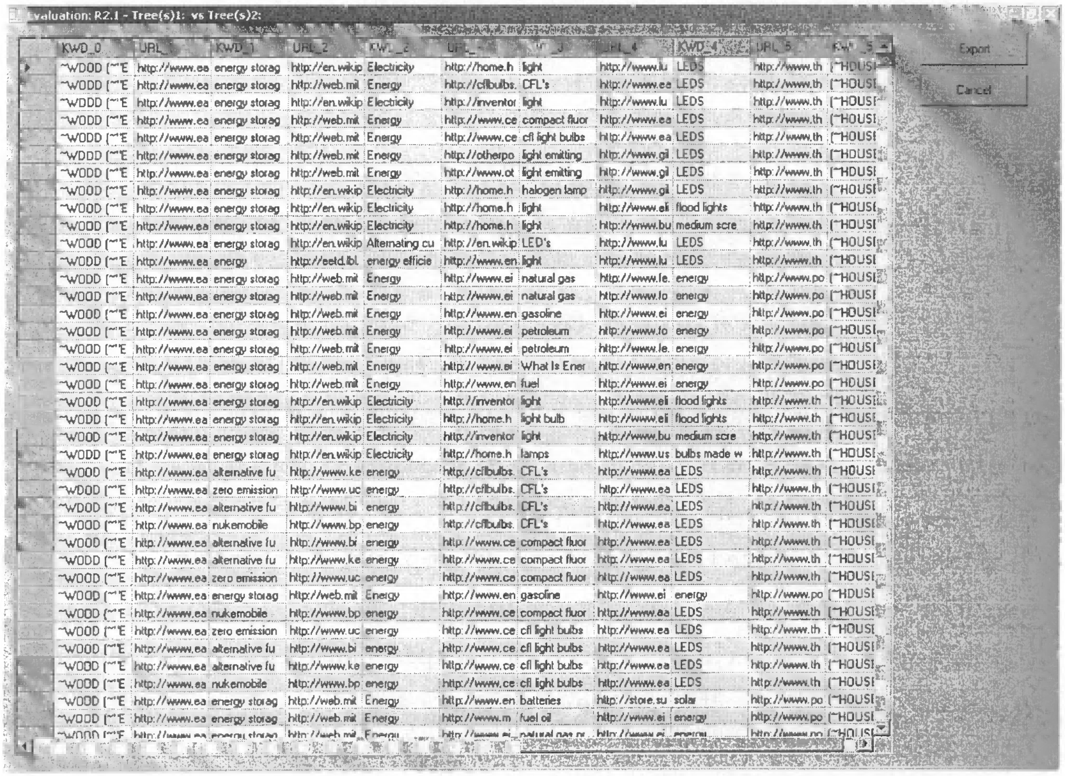


Figure 8.10: Example of an Evaluation - List of Results

The graphical representation of the results happens in the form of a box-and-arrows network, and a list of corresponding URLs (see Figure 8.11). On top and at the bottom of the network, the starting points of the tree matching exercise are displayed. All subsequent keywords are connected via arrows. All connected URLs of a keyword are displayed as a number in the respective keyword box. This number helps to find the connected URL in the list of URLs. Matching keywords

[1]The user has the option to export these data to an MS Excel spreadsheet, offering the opportunity to generate flexible user defined graphs based on the generated data.

in both trees have been connected with dotted lines. The goal of this graphical representation is to give the user an overview of the top 10 results chains of an option tree matching exercise. To display more than 10 results would render the graphical representation unclear and confusing.

8.4 Validation of Model and Software Application

In order to validate the model developed in Section 8.2, and the software application developed in Section 8.3, an approach consisting of two steps has been chosen.

Firstly, a series of exploratory experiments will be run with the software application in order to proof the chosen concept. The outcome of this step is a series of parameter settings which proved to generate the most meaningful results for specific experiments, and which promises furthermore to deliver the same quality of results for new and different experiments.

After having adjusted and fine-tuned the application according to the insights won from the exploratory experimentation and the proof of concept, the verification run consists in carrying out a new experiment using a calibrated series of parameter settings. If the obtained results are of the expected quality, the application and its model have been successfully validated.

It shall be noted that, due to i) the limited timeframe available for this Section of the thesis, ii) the intensity of the software application in terms of internet and database transactions, and iii) the instability of the Google SOAP Search API, a rather small set of experiments can only be run.

8.4.1 Exploratory Experimentation and Proof of Concept

The purpose of the exploratory experimentation phase is to find out which combination of parameter settings delivers the best quality of results. For this purpose, a series of experiments is designed, including findings from Chapter 7. The experiments developed will be run. Subsequently, the obtained results will be

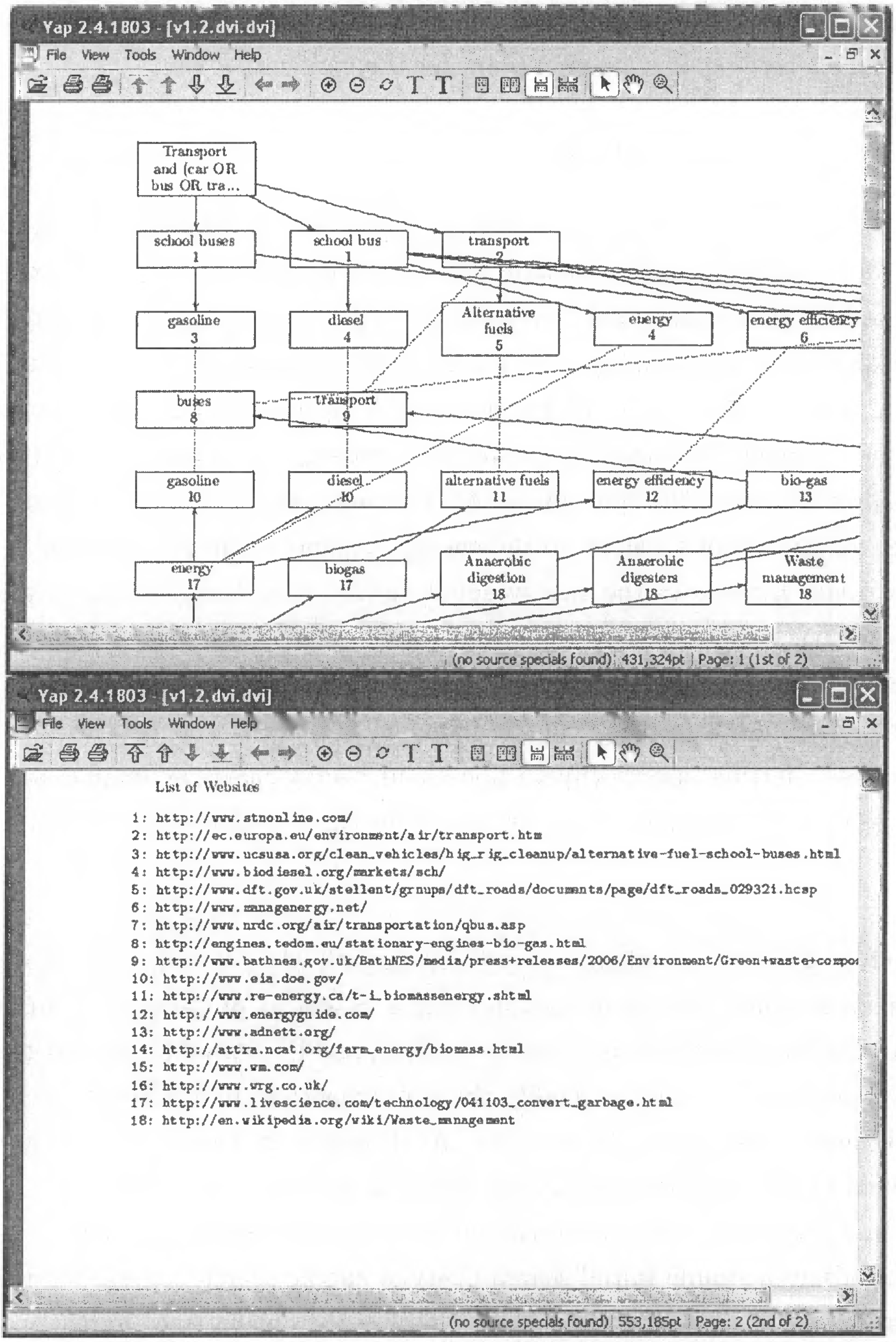


Figure 8.11: Graphical Representation of Option Network and List of Related websites

analysed and interpreted, so that eventually, the application can be adjusted and fine-tuned, serving as a starting point for the verification run.

8.4.1.1 Experimental Design

As can be seen in Table 8.3, a total number of 20 experiments have been designed in order to calibrate the creative option generation application. Each experiment has been given a unique number (column 'Nr'), the first digit of which qualifying an experiment as belonging to a specific series (see column 'Nr' and 'Series').

A series is defined by a specific research topic, as can be seen in column 'Name', namely fuel wood, paper waste, cooking, water heating, and lighting. The first two research topics belong to the energy supply group, whereas the last three research topics belong to the energy demand group (see column 'Group'). The research areas in the energy supply group have been chosen according to the findings of the MFA of wood and paper in Cape Town (see Table 7.1); the research areas of the energy demand group have been chosen according to household energy needs as they can be found in developed and developing country settings, referring specifically to household energy needs as emphasised in the Kuyasa CDM low-income housing project in Khayelitsha, Cape Town[1].

Option Tree Generation A scenario is defined by a specific number of parameter settings. As can be seen in column 'Scenario' of Table 8.3, four different scenarios have been defined, namely A, B, C, and D. Note that the last two digits of the experiment number qualify the experiments as four different scenarios as well, namely '00', '10', '20', and '30'. As displayed in Table 8.4, each scenario is defined by the combination of eight different parameter settings.

In scenario A, it has been chosen to restrict the search as little as possible by choosing a simple initial search query, a simple search context, and allowing websites and keywords to be repeated within the option tree. Furthermore, two intermediate values have been chosen for the number of websites as well as for

[1]See Austin (2004a), 2004b; Cousins & Mahote (2003); Morris & Austin (2005); Winkler & Thorne (2002).

Nr	Series	Group	Scenario	Name
5000	5	Energy Supply	A	Fuel Wood I
5010	5	Energy Supply	B	Fuel Wood II
5020	5	Energy Supply	C	Fuel Wood III
5030	5	Energy Supply	D	Fuel Wood IV
6000	6	Energy Supply	A	Paper Waste I
6010	6	Energy Supply	B	Paper Waste II
6020	6	Energy Supply	C	Paper Waste III
6030	6	Energy Supply	D	Paper Waste IV
7000	7	Energy Demand	A	Cooking I
7010	7	Energy Demand	B	Cooking II
7020	7	Energy Demand	C	Cooking III
7030	7	Energy Demand	D	Cooking IV
8000	8	Energy Demand	A	Water Heating I
8010	8	Energy Demand	B	Water Heating II
8020	8	Energy Demand	C	Water Heating III
8030	8	Energy Demand	D	Water Heating IV
9000	9	Energy Demand	A	Lighting I
9010	9	Energy Demand	B	Lighting II
9020	9	Energy Demand	C	Lighting III
9030	9	Energy Demand	D	Lighting IV

Table 8.3: Experimental Design - Exploratory Experimentation

the number of iteration levels. Finally, it has been chosen to go for a maximum number of keywords, promising a large yield of keywords per website retrieved.

In scenario B, it has been chosen to restrict the search as much as possible by opting for a specific initial search query and a specific search context. This time, a maximum number of websites has been chosen, whereas intermediate values have been chosen for the parameters 'Nr of Keywords' and 'Iteration Level'. The boolean parameters have remained unchanged in order to leave scenario B comparable to scenario A regarding these parameters.

In scenario C and D, it was the aim to choose extreme parameter settings for the number of websites and the number of keywords in order to find out which

Nr	Initial Search Query	Search Context	URLs	KWDs	Iteration Level	URL Repetition	KWD Repetition	KWDs in quotes
A	simple	simple	5	25	3	yes	yes	no
B	specific	specific	10	15	3	yes	yes	no
C	simple	simple	1	25	5	no	no	yes
D	simple	simple	10	1	5	no	no	yes

Table 8.4: Scenario Definition - Exploratory Experimentation

combination of settings would yield the maximum number of connectors. For scenario C, the number of websites has been set to 1, whereas the number of keywords has been set to 25. In scenario D, the number of websites has been set to 10, while setting the number of websites to 1. The remaining parameter settings are similar for both the scenarios, opting for a simple initial search query as well as a simple search context. Website and keyword repetition is not allowed, and search keywords will be set in quotes.

Option Tree Matching and Result Ranking As can be seen in Table 8.5, four families of matching experiments have been created, namely R1 to R4. For each family, the option trees from the energy supply series 5 and 6 are matched to the option trees from the energy demand series 7, 8 and 9. The difference between the families are the scenarios from which the option trees are stemming. For family R1, all option trees stem from scenario A (last two digits of option trees = '00'). For family R2, all option trees stem from scenario B (last two digits of option trees = '10'). In similar fashion, the parallelism also applies to the last two families.

For each experiment family, one option tree matching exercise is being performed, combined to the calculation of the parameters 'Chain Length', 'Pattern Similarity', 'Keyword Importance', and 'Website Importance' for each obtained result chain.

Furthermore, three different combinations of parameter settings have been developed for the subsequent ranking of result chains, as can be seen in Table 8.6. The first combination has been defined in a balanced manner, where all

	Tree Selection 1	Tree Selection 2
R1	5000;6000;7000;	8000;9000;
R2	5010;6010;7010;	8010;9010;
R3	5020;6020;7020;	8020;9020;
R4	5030;6030;7030;	8030;9030;

Table 8.5: Experiment Design: Option Tree Matching - Exploratory Experimentation

parameter sorting orders are ascending, and all parameter weighting factors are equal to 25%. As can be ssen in the second combination, the most weight has been put on the 'Pattern Similarity', with 60% and an ascending sorting order, leaving the 'Keyword Importance' and the 'Website Importance' to play a smaller role with a weight of 10% each and an ascending sorting order. By giving the 'Chain Length' a weight of 20% and a descending sorting order, it was aimed to give a bigger importance to shorter result chains. In the third combination of parameter settings, it was aimed to give the most weight to the longest result chains (60%), which are at the same time wished to be as distant from an ideal pattern as possible (20% weight, descending sorting order). It was hypothesised that this combination of parameter settings might yield an unconventional set of results.

Combo	CL_s	CL_w	KI_s	KI_w	WI_s	WI_w	PS_s	PS_w
1	Asc	25%	Asc	25%	Asc	25%	Asc	25%
2	Desc	20%	Asc	10%	Asc	10%	Asc	60%
3	Asc	60%	Desc	10%	Desc	10%	Desc	20%

Table 8.6: Parameter Setting Combinations: Result Chain Ranking - Exploratory Experimentation

By combining the four experiment families as defined in Table 8.5 with the three different parameter setting combinations, a total number of 12 matching exercises have been defined.

8.4.1.2 Running of Experiments

The 20 exploratory experiments for the option tree generation have been run from the 19^{th} of June 2006 until the 14^{th} of August 2006[1] on a desktop Personal Computer (PC) with following specifications:

- Central Processing Unit (CPU): Intel Celeron D, 2.40 GHz
- Random Access Memory (RAM): 504 MB
- System: MS Windows XP Version 2002, Service Pack 2

The 12 exploratory experiments have been run from the 18^{th} of September 2006 until the 5^{th} of October 2006 on the same machine.[2]

8.4.1.3 Analysis and Interpretation of Results

In the following Section, the results of the option tree generation and matching exercises will be analysed. The option tree generation exercises will mainly be analysed regarding their performance, e.g. the quantitative output, as the results produced at this stage are not easily analysed regarding their quality, viz. their meaningfulness.

The option tree matching and ranking exercises will rather be analysed regarding the quality of results produced, as this is the ultimate goal of the application, and of first priority to the user of the application.

Performance Analysis - Option Tree Generation As can be seen in Figure 8.12, the 20 experiments that have been carried out have been sorted according

[1]Note that during this period, a series of power cuts, some of them during several hours, happened due to infrastructural failures of the national power grid in the Province of the Western Cape, causing the need to restart some of the experiments.

[2]It was tested to run the application on a PC with 4.00 GHz CPU, 1,024 MB RAM, and a Windows XP 16-bit version, but no overall performance increase of the application was measured. The reason therefore is the intensity of the application in terms of web and database transactions, which are not primarily affected by the machine's calculational power. See also Section 8.5.3.

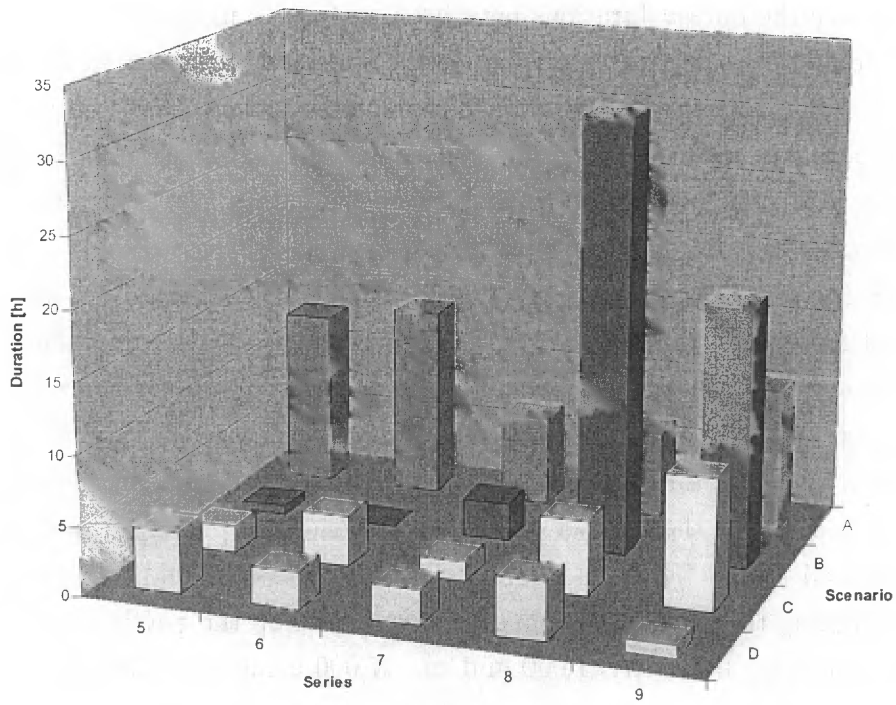


Figure 8.12: Experiment Duration by Series and Scenario - Exploratory Experimentation

to their allocated series on the x-axis, and to their allocated scenario on the y-axis. The experiment duration in hours has been noted on the z-axis. As has been defined in Section 8.4.2.1, the scenario can be recognised at the last two digits of the experiment number as well. This means that the experiment with the x-y-coordinates $5B$ corresponds to experiment number '5010'.

The experiment durations vary between <1h to approx. 30h, letting appear that the highest durations have been achieved for the experiments in scenario B, whereas the lowest durations have been performed in scenario D. As it is not possible at this stage to state whether the series, viz. the search topic, and/or the scenario, viz. the combination of parameter settings, have an influence on the experiment duration, a two-factor Analysis of Variance (ANOVA) (see e.g. Devore, 2000) has been performed based on these data (see Appendix M for full set of results).

For the series, a test value F of 0.97 has been calculated, being smaller than the calculated critical F-value of 3.26. For the scenarios, a test value F of 1.39 has been calculated, being smaller than the critical F-value of 3.49. The interpretation of these results leads to the statement that neither the series nor the scenarios have got a meaningful influence on the experiment duration.

In Figure 8.13, the number of connectors generated per experiment have been represented sorted by series and scenario on the x-axis and the y-axis respectively, noting the number of connectors generated on the z-axis. The number of connectors vary between <1,000 and ca. 27,000 connectors, letting appear that the highest number of connectors has been generated for scenario A, followed by scenario B. The smallest number of connectors has been produced for the experiments in scenario D. Interestingly, it should be noted that in scenario B, for series 7, 8 and 9, a relatively high number of connectors has been generated, with ca. 5,000, 7,000 and 17,000 connectors respectively. The experiments in series 7, 8 and 9 belong to the group of energy demands, whereas series 5 and 6 belong to the group of energy supplies.

By performing a two-factor-ANOVA for the data given in Figure 8.13, one obtains a test value F for the series of 0.46 with a critical F-value of 3.26. For the scenarios, a test value F of 14.55 is calculated, being significantly bigger than the critical F-value of 3.49. These results support the statement that the series does not have a significant influence on the number of connectors generated, whereas the scenario, viz. the combination of parameter settings, does (see Appendix M for full set of results).

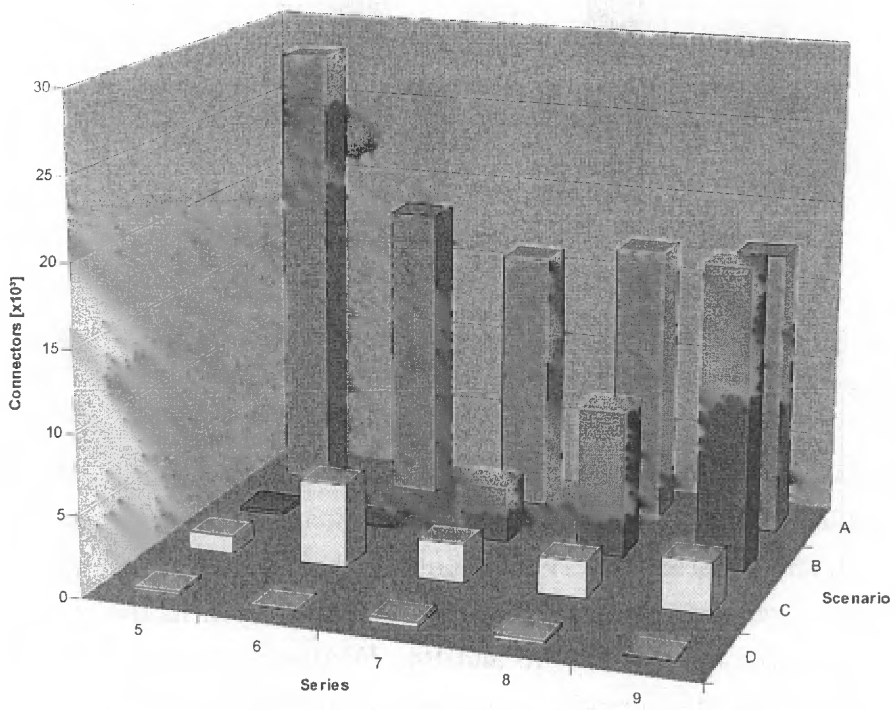


Figure 8.13: Number of Connectors per Experiment by Series and Scenario - Exploratory Experimentation

Quantitative and Qualitative Analysis - Option Tree Matching and Result Ranking As can be seen in Figure 8.14, a success rate can be calculated for each family of option trees for which a matching exercise has been performed. The success rate equals the number of matching results divided by the initial number of connectors (stemming the selected option trees). As can be seen for the families R1, R3, and R4, the success rates are situated above 100%, with R3 taking the lead with 345%, followed by R1 and R4. Family R2 has the smallest

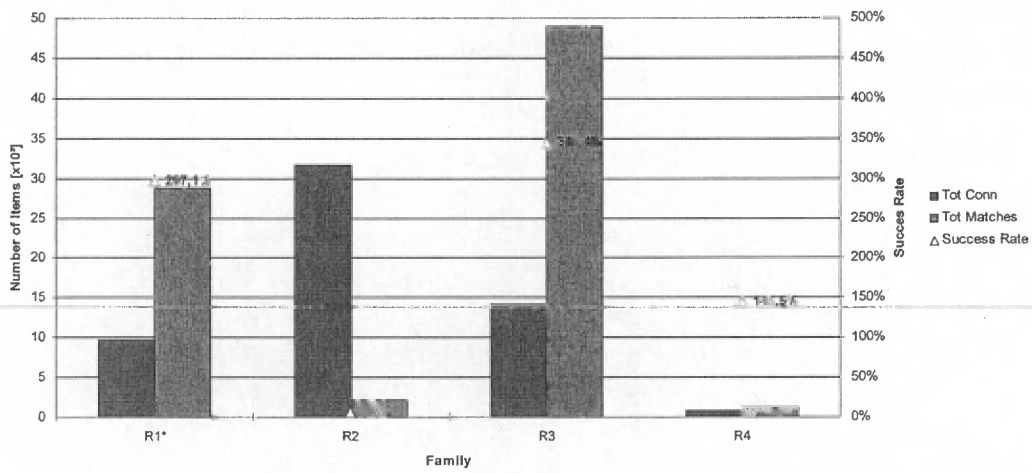


Figure 8.14: Performance Analysis: Option Tree Matching by Family - Exploratory Experimentation

succes rate with 6.6%. Bearing in mind that the matching exercise for family R2 consists in comparing all connectors from option trees generated under scenario B, viz. a specific search query and context, the data representation shows that there are fiewer matches with the same matching word in the family R2 than there are in the families R1, R3 and R4. Furthermore, this explanation would also explain why the number of matches for the three families last mentioned is higher than the initial number of connectors, as a matching word occuring e.g. three times in energy demand option trees, and three times in energy supply options trees would lead to a total amount of nine matches.

Furthermore, it should be noted that for the matching exercise for family R1, only connectors up to the 2^{nd} iteration level were considered, as the matching of the totality of the connectors would have generated a number of matches $> 10^6$.[1]

After the results provided by the matching exercises were ranked according to different parameter settings as defined by Table 8.6, a total of 12 option networks were generated.[2] The obtained results in the option networks were analysed

[1]It would not have been possible to calculate related parameter values for this amount of matches within a realistic time frame, as the extrapolated duration for these calculations would have exceeded 30 days.

[2]All generated networks are represented in Appendix N, including respectively a list of

regarding their quality. For that purpose, a technical scoring scale was developed, allowing it to report numerically the quality of information contained in an option network. In order to achieve this goal, three groups have been defined into which all the keywords of an option network are classified. The first group is the low quality group, being defined as the group of keywords that make no sense at all in the context they are positioned. The second group is the medium quality group, being defined as the group of keywords being of a general nature and making sense in the context they are found. The third group is the high quality group, being defined as the group of keywords of a specific nature and making sense in their context. In a first step, all keywords are sorted according to these three groups. The second step consists in calculating a total score for an option network by multiplying the number of elements of the first group by -5, the number of members of the second group by 0, and the number of members of the third group by 10. By doing so for all 12 option networks, one obtains the results as represented in Figure 8.15.

The highest scores have been obtained by the exercises of family R2, parameter combinations 1, 2 and 3 (R2.1, R2.2 and R2.3), with scores ranging between 50-100. The exercises scoring the lowest are exercises R3.3 and R4.3, scoring respectively -120 and -5 points. Even though a first ANOVA stated that neither the family nor the combination of parameter settings has an impact on the quality of the option networks, it is stated by a second one that the family does have an impact on the quality when the lowest score (-120) is set to 0.

The interpretation of these results leads to the statements that the highest quality of option networks is achieved by matching option trees stemming from scenario B, whiz. having a specific search query and a specific search context. Within family 2, the highest scoring exercise is the one belonging to the parameter combination 2, viz. an emphasis on the parameter 'Pattern Similarity'. Furthermore, it can be stated that the lowest scores for exercises R3.3 and R4.3 is related to the parameter combination 2 - emphasising longer result chains and being as distant as possible from an ideal pattern -, yielding nonsensical results.

related websites.

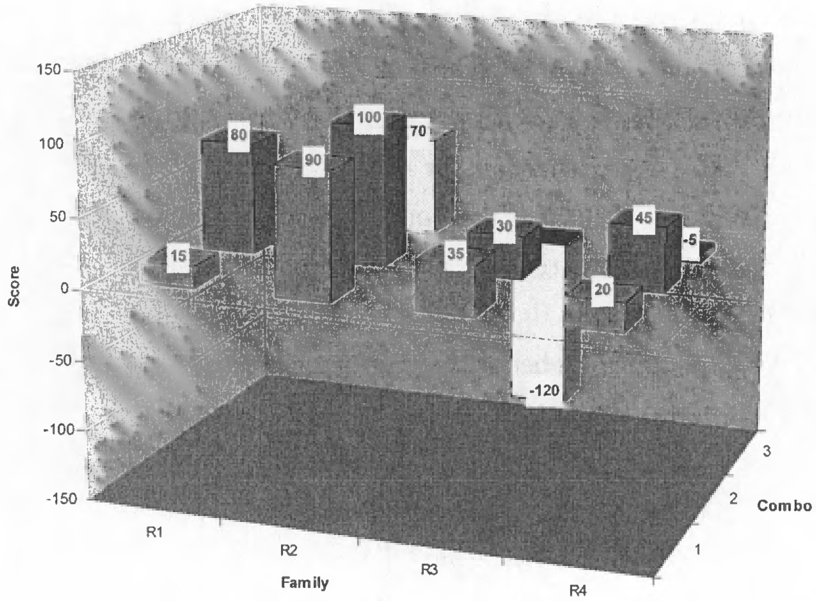


Figure 8.15: Quality of Information in Option Networks by Family and Parameter Combination - Exploratory Experimentation

8.4.1.4 Adjustments, Extensions and Fine Tuning

Following-up on the insights acquired by analysing the results of 20 experiments carried out in order to explore the potentials of the software application, a couple of adjustments, extensions and fine tunings had to be done regarding the application functionalities as well as the programming.

Regarding the functionalities of the application, the categorisation of retrieved keywords from the WWW according to entries in a set of comparative tables had to be enhanced. Therefore, comparative procedures where extended regarding the usage of `like`-operators and wildcards (e.g.'%'). The exclusion of senseless entries was improved by creating a table containing unwanted terms (e.g. "the", "and", "or"), and by adjusting the exclusion procedure (e.g. no numbers, no spaces, no single letters). Furthermore, the option generation procedure was extanded to the parameters 'Language' and 'Country', allowing the user to restrict his option tree generation geographically. A filter was created, allowing the refinement of obtained results. Eventually, the Google SOAP Search API was fine-tuned by adjusting two of its parameters: websites stemming from the same host were restrcited to two in order to enhance the diversity of results, and pages containing adult-content were excluded.

A couple of programmatical interventions were made in order to enhance application and database performance. Firstly, parameters were adjusted for the creation of dataset objects via the MS Visual Basic DAO according to the purpose of the data in the application. Furthermore, the amount of data retrieved per transaction was reduced to a minimum by defining specific Sequenced Query Language (SQL)-statements. Eventually, indices were created in the database tables for the most used table fields.[1]

[1] It had also been investigated how much sorting algorithms used especially for the results processing procedure affected the application performance. Considered alternatives were e.g. the Bubble Sort algorithm. Eventually, it was found out that the time spent on sorting was of minor importance compared to the time spent on database transactions.

8.4.2 Verification

The aim of this Section is to substantiate two logical expectations in order to verify the model that has been developed in Section 8.2, and the software application developed in Section 8.3:

1. From a technical perspective, it is expected that the score for the information quality contained in the option networks generated during the verification phase will be higher than the scores obtained for the option trees generated during the exploratory experimentation phase.

2. From a practically sensible perspective, it is expected that the option networks generated during the verification phase will include stimulants for the design of creative renewable energy conversion pathways, previously unknown to energy planners in Southern urban contexts.

8.4.2.1 Experimental Design and Parameter Calibration

Based on the insights won during the exploratory experimentation phase, it was suggested for the verification run to design an independent series of experiments based on the urban end-user service 'Transportation' and the renewable inner-city resource 'Organic Waste'. The experimental design includes four option trees and two distinct scenarios for the phase of option tree generation. Moreover, it includes two matching families and one combination of settings for the parameter calibration for the phase of option tree matching and result ranking.

Option Tree Generation It appears from the qualitative analysis of the results of the option tree matching and ranking, that the results from family 2 are the most meaningful, corresponding to the matching of option trees from scenario B. Therefore it is suggested to set the parameters for the initial search query and the search context to 'specific' as done for the option tree generation under scenario B.

Regarding the parameter settings of the option tree generation, the following combination of settings appears to give the output with the highest quality of results:

- Emanating out of the performance analysis, the parameters 'Nr of Websites' and 'Nr of keywords' should be set as in scenario A, namely to 5 and 25. The iteration level should remain at 5 in order to leave an open range. For the experiments, an iteration level greater than 4 has not been achieved.

- From the qualitative analysis of matching results, one should not allow the repetition of keywords in order to support a wide variety of different keywords and URLs.

Nr	Series	Group	Scenario	Name
1000	1	Energy Demand	E	Transport I
1010	1	Energy Demand	F	Transport II
2000	2	Energy Supply	E	Organic Waste I
2010	2	Energy Supply	F	Organic Waste II

Table 8.7: Experimental Design - Verification

Nr	Initial Search Query	Search Context	URLs	KWDs	Iteration Level	URL Repetition	KWD Repetition	KWDs in quotes	Language	Country
E	specific	specific	5	25	5	no	no	yes	all	all
F	specific	specific	5	25	5	no	no	yes	English	South Africa

Table 8.8: Scenario Definition - Verification

Option Tree Matching and Result Ranking For the phase of option tree matching and result ranking, it is suggested to create two matching families as described in Table 8.9. In family V1, the option trees from scenario E are compared, namely 1000 and 2000. Similarly in family V2, the option trees from scenario F are compared, namely 1010 and 2010.

The qualitative analysis of the phase of Option Tree Matching and Result Ranking for the exploratory experimentation phase has shown that the most meaningful results are obtained for parameter combinations 1 and 2 (see Table 8.6).

Family	Tree Selection 1	Tree Selection 2
V1	1000;	2000;
V2	1010;	2010;

Table 8.9: Experimental Design: Option Tree Matching - Verification

Furthermore, emphasising that the parameters for the ranking of the matching results should support a great variety of keywords and URLs as well, it is suggested to allocate a descending sorting order for the parameters 'Website Importance' and 'Keyword Importance'. Moreover, it is proposed to allocate the parameter 'Pattern Similarity' the highest weighting factor and an ascending sorting order, as it accounts for the type of the keywords, as well as the similarity to an optimal result chain pattern. Subsequently, the value of the parameter 'Chain Length' should be as high as possible, as it appears that the longer the result chain, the more interesting are the results.[1] The proposed weighting and sorting factors for the four parameters for the ranking of the option tree matching results are presented in Table 8.10.

Combo	CL_s	CL_w	KI_s	KI_w	WI_s	WI_w	PS_s	PS_w
4	Asc	20%	Desc	20%	Desc	20%	Asc	40%

Table 8.10: Parameter Setting Combinations: Result Chain Ranking - Verification

8.4.2.2 Running of Experiments

Four option trees where generated during the period from the 29.12.2006 until the 10.01.2007 on the same machine as used for the exploratory experimentation phase (see Section 8.4.1.2).

This period lies during the break of the festive season, thus the University network was relatively unstressed. Furthermore, error messages delivered by the

[1] Note that this could change once iteration levels higher than 5 for the option tree generation are being achieved. It is believed that a result chain exceeding a certain length would become less important.

[h]	E - Unrestricted	F - Restricted
1 - Transport	5.9	24.0
2 - Organic Waste	83.8	9.3

Table 8.11: Experiment Duration by Series and Scenario - Verification

[items]	E - Unrestricted	F - Restricted
1 - Transport	4,900	7,000
2 - Organic Waste	48,100	10,200

Table 8.12: Connectors per Experiment by Series and Scenario - Verification

Google SOAP Search API decreased markedly during that period of time, although no quantitative measurements were taken for supporting that statement.

8.4.2.3 Analysis and Interpretation of Results

Performance Analysis - Option Tree Generation As can be seen in Table 8.11, the duration of each experiment has been represented according to the previously defined series and scenarios. The longest duration has been recorded for experiment 2000 (Series 2, Scenario E), amounting to approx. 85h. The experiment with the shortest duration is experiment 1000 (Series 1, Scenario E), running for <10h. Furthermore, the two remaining experiments ran for not longer than approx. 25h.

Similarly for Table 8.12, the experiment producing the most connectors is experiment 2000 (Series 2, Scenario E), generating almost 50,000 connectors. The experiment with the lowest connector yield is experiment 1000 (Series 1, Scenario E), generating only approx. 7,000 connectors.

When comparing these two figures, they let appear that there is a parallelism between the duration of the experiments and the number of connectors generated. Note that due to the instabilities of the Google SOAP Search API experienced during the exploratory experimentation phase of the application, a number of generated connectors >1,000 per experiment has been set in order for the experiment to be considered for the evaluation. Each experiment was repeated until this minimum requirement was met. Experiment 2000 seems to be an exception, and must have been generated during a period of stability due to a very low general activity regarding the Google SOAP Search API. The number of experimental data generated is too small for carrying out an ANOVA as it was the case for the exploratory experimentation phase.

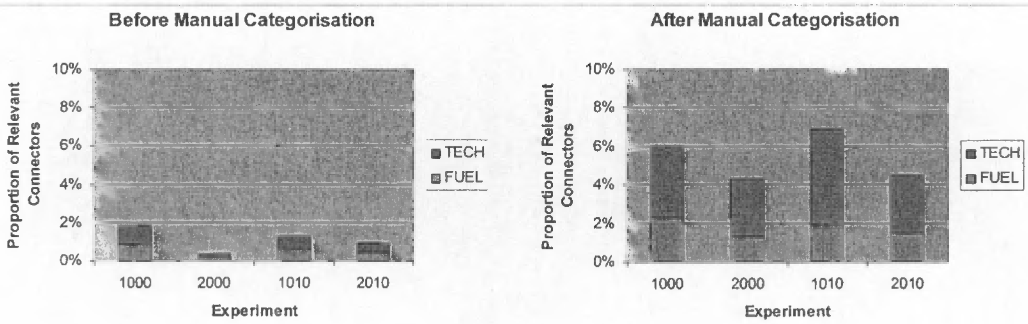


Figure 8.16: Relevant Connectors per Experiment - Verification

Keyword Categorisation During the generation of option trees, when creating a connector based on a newly retrieved keyword, it is automatically compared to the entries in the comparative Database (DB) tables (see Section 8.3.1), and is categorised as energy carrier ('FUEL'[1]), conversion technology ('TECH'[2]), or none.[3] Furthermore, in case the automatic keyword categorisation is estimated as being not sufficient, the user has the option to manually rework the keyword categorisation (see Figure 8.9).

As can be seen in the left graph of Figure 8.16, approx. 2% of the keywords in experiment 1000 have been categorised as either a conversion technology or an energy carrier. In experiment 2000, less than 1% of all connectors have been categorised as relevant for further analysis. A slightly higher share of conversion

[1]also 'EC' for Energy Carrier

[2]also 'TT' for Transformation Technology

[3]The number of entries in the comparative tables does not represent the number of terms of the English language referring to energy conversion technologies and energy carriers. Each English term can be represented by several entries, including small variations of the term, as well as singular and plural forms

technologies than energy carriers can be observed throughout the four experiments.

This analysis lets appear that the entries in the comparative DB tables are useful for the automatic categorisation of keyword types, but a manual rework is necessary for increasing the proportion of relevant connectors.

After having carried out a manual categorisation of the keyword types of the connectors, the number of relevant connectors per experiment has increased on average by approx. 4%. The experiment with the highest share of relevant connectors is experiment 1010 with approx. 7%, followed by experiment 1000 with 6%. The two remaining experiments have slightly over 4% of relevant connectors each.

A number of tables form the basis of the comparative functionalities of the application (see column 'Comparative I' - Table 8.2), containing approx. 13,000 entries. The two remaining tables (see column 'Comparative II' - Table 8.2) have been allocated a self learning purpose. Each time that a keyword is manually categorised as either energy carrier or conversion technology, it is compared to the existing entries in the comparative tables. If the newly defined keyword is not contained in the comparative tables, it is added to one of the self learning tables.

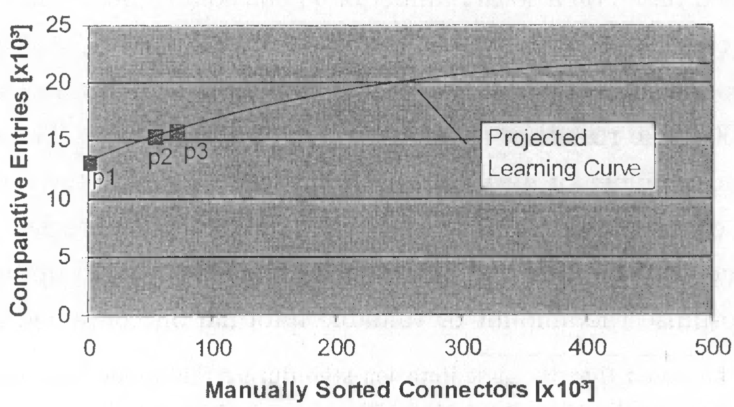


Figure 8.17: Keyword Categorisation: Learning Curve for Comparative Entries - Verification

As can be seen in Figure 8.17, it is projected that the number of entries in the comparative tables will increase in an inversely exponential manner over the number of manually categorised connectors, which will be referred to as a learning curve. Whilst the number of manually categorised connectors will continue to increase, the number of comparative entries will start to plateau, as a decreasing number of unknown keywords will be manually categorised. Data point $p1$ represents a number of approx. 13,000 entries at the point in time where no connector had been categorised manually yet. After having manually categorised a combined number of approx. 55,000 connectors for experiments 1000 and 2000 (family V1), a number of 2,000 new entries where added to the comparative tables (data point $p2$). After the subsequent manual categorisation of a combined number of 17,500 connectors for experiments 1010 and 2010 (family V2), a further 500 new entries were added (data point $p3$). The latter two points confirmed the projected curve so far, although a larger number of results are needed in order to form a representative data basis.

Quantitative and Qualitative Analysis: Option Tree Matching and Result Ranking - Verification Two option networks were generated, denominated family V1 and V2. As can be seen in Figure 8.18, approx. 2,500 matches were obtained based on a total number of 55,000 connectors for family V1, resulting in a success rate of 4.2%. In the case of family V2, approx. 3,000 matches were obtained from a smaller (country-specific) amount of total connectors, namely approx. 17,500. The resulting success rate amounts to 17.1%. These results show that a higher number of initial connectors does not guarantee a higher number of relevant connectors and/or a higher yield of connector matches.[1]

Subsequently, the filter option has been applied for both option networks in order to optimise the amount of valuable information contained in them.[2] For

[1] It shall be noted that the first iteration step during the option tree generation phase is crucial regarding the directions towards which the option tree will develop, and the number of relevant connectors that will be created. The interruption of the option tree generation process is therefore suggested after the first iteration level, at which point in time the user should manually delete the connectors that are not of relevance within the specific search context.

[2] see Figure L.8

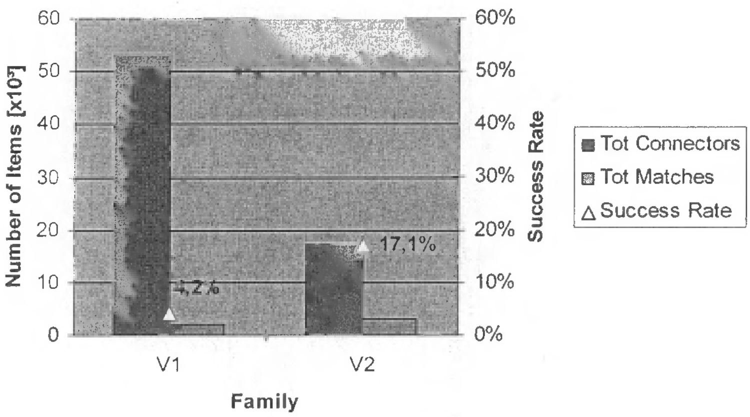


Figure 8.18: Performance Analysis: Option Tree Matching by Family - Verification

option network V1, a filter of 5 exclusive terms[1] has been defined. For option network V2, a filter of 13 exclusive terms[2] had to be defined in order to achieve the highest degree of useful information.

By applying the same rating system as for Figure 8.15, a total score of 250 has been calculated for family V1, whereas family V2 scored 210 points. In both cases, the obtained scores are more than twice as high as the highest score obtained for the exploratory experiments, namely 100. These results verify the initially stated logical expectation of a higher technical score regarding the quality of information contained in option network families V1 and V2.

From a practically sensible point of view, the obtained option networks need to be scrutinised regarding stimulants for the design of creative renewable energy conversion pathways.

In Figure 8.19, the option tree network for the top 10 results of family V1 is represented. The list of corresponding URLs can be found in Appendix N. Furthermore, the top 10 option tree result chains for family V1 have been represented in tabular form in Table 8.13. It can be seen that due to the application

[1] *environment*;*air*;*students*;*answers*;*nuclear*;

[2] *goes*;*air*;*southern africa*;*bryant*;*turning an*;*secretariat*;*adam*;*nuclear*; pebble*;*pbmr*;*missing*;to;and;

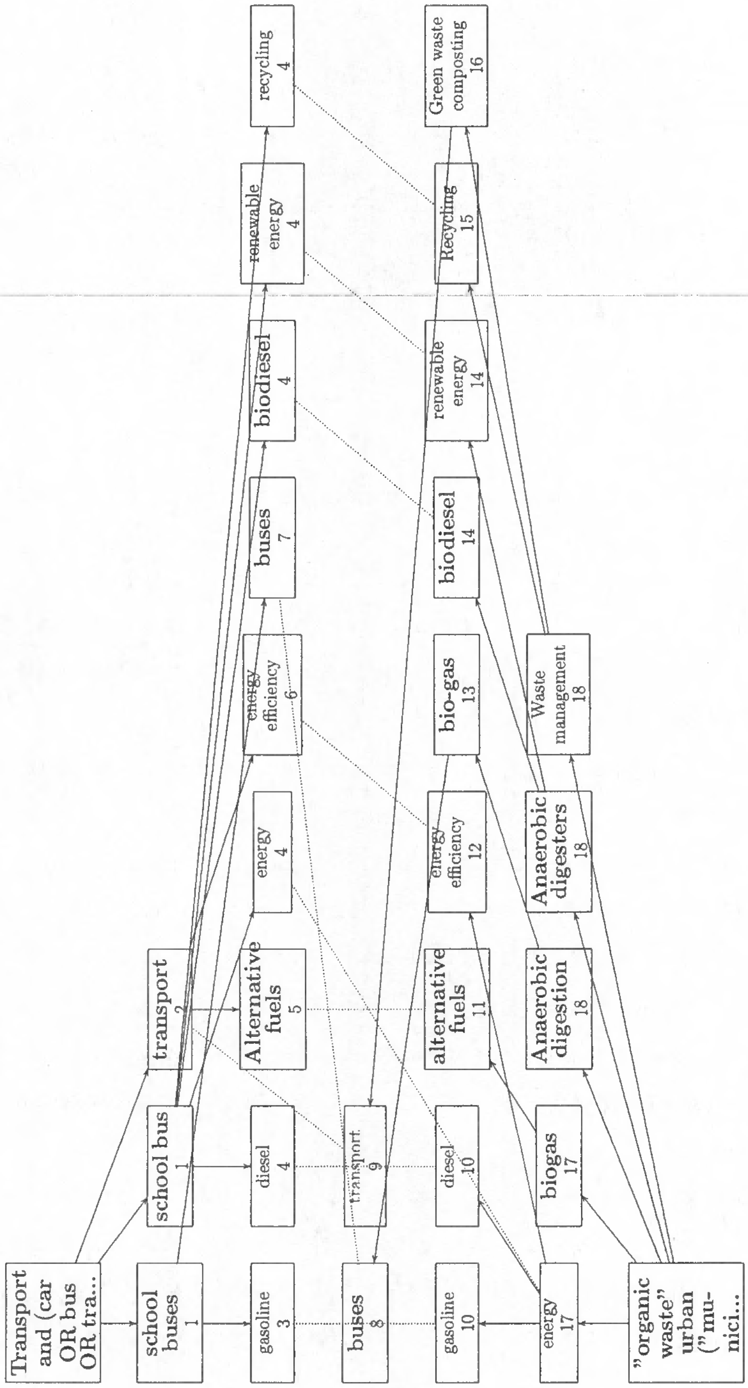


Figure 8.19: Option Tree Network: V1 Top 10 Results - Verification

Rank	Nr	KWD0	URL1	KWD1	URL2	KWD2	URL3	KWD3	URL4	KWD4	URL5	KWD5
25	267	Transport and ...	http://www.stnonline.com/	school buses	http://www.ucsusa.org/clean_vehicles/big_rig_cleanup/alternative-fuel-school-buses.html	gasoline	http://www.eia.doe.gov/	energy	http://www.livescience.com/technology/041103_convert_garbage.html	"organic waste" and ...	-	-
25	211	Transport and ...	http://www.stnonline.com/	school bus	http://www.biodiesel.org/markets/sch/	diesel	http://www.eia.doe.gov/	energy	http://www.livescience.com/technology/041103_convert_garhage.html	"organic waste" and ...	-	-
43	**332**	Transport and ...	http://ec.europa.eu/environment/air/transport.htm	transport	http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_029321.hcsp	Alternative fuels	http://www.re-energy.ca/t-i_biomassenergy.shtml	biogas	http://www.livescience.com/technology/041103_convert_garbage.html	"organic waste" and ...	-	-
45	220	Transport and ...	http://www.stnonline.com/	school bus	http://www.biodiesel.org/markets/scb/	energy	http://www.livescience.com/technology/041103_convert_garbage.html	"organic waste" and ...	-	-	-	-
52	337	Transport and ...	http://ec.europa.eu/environment/air/transport.htm	transport	http://www.managenergy.net/	energy efficiency	http://www.energyguide.com/	energy	http://www.livescience.com/technology/041103_convert_garbage.html	"organic waste" and ...	-	-
52	**277**	Transport and ...	http://www.stnonline.com/	school buses	http://www.nrdc.org/air/transportation/qbus.asp	buses	http://engines.tedom.eu/stationary-engines-bio-gas.html	bio-gas	http://www.adnett.org/	Anaerobic digestion	http://en.wikipedia.org/wiki/Waste_management	"organic waste" and ...
56	**208**	Transport and ...	http://www.stnonline.com/	school bus	http://www.biodiesel.org/markets/sch/	biodiesel	http://attra.ncat.org/farm_energy/biomass.html	Anaerobic digesters	http://en.wikipedia.org/wiki/Waste_management	"organic waste" and ...	-	-
56	221	Transport and ...	http://www.stnonline.com/	school bus	http://www.biodiesel.org/markets/scb/	renewable energy	http://attra.ncat.org/farm_energy/biomass.html	Anaerobic digesters	http://en.wikipedia.org/wiki/Waste_management	"organic waste" and ...	-	-
57	232	Transport and ...	http://www.stnonline.com/	school bus	http://www.biodiesel.org/markets/sch/	recycling	http://www.wm.com/	Waste management	http://en.wikipedia.org/wiki/Waste_management	"organic waste" and ...	-	-
67	111	Transport and ...	http://ec.europa.eu/environment/air/transport.htm	transport	http://www.bathnes.gov.uk/BathNES/media/press+releases/2006/Environment/Green+waste+composting+helps+council+scheme.htm	Green waste composting	http://www.wrg.co.uk/	Waste management	http://en.wikipedia.org/wiki/Waste_managsment	"organic waste" and ...	-	-

Table 8.13: Option Tree Result Chains: V1 Top 10 Results - Verification

of the filter function and the elimination of certain keywords (i.e. result chains), the numeration of the ranks is discontinuous, however increasing.

By scrutinising the option tree network and the tabular representation of the result chains, three chains need to be considered more closely regarding their practical sensibility.

The most sensible pathway is given by the result chain with rank 52, nr 277, and reads as follows in the option network:

> transport → school buses (1) → buses (7/8) → bio-gas (13) → anaerobic digestion (18) → organic waste

The same conversion pathway idea is basically suggested by the result chain with rank 43, nr 332, however including a lower level of detail. It reads as follows in the option network:

> transport → transport (2) → alternative fuels (5/11) → biogas (17) → organic waste

A conversion route containing the renewable energy carrier biodiesel has also been created. However, it is questionable whether biodiesel can be obtained via anaerobic digestion. The pathway is given by the result chain with rank 56, nr 208, and reads as follows in the option network:

> organic waste → anaerobic digesters (18) → biodiesel (14/4) → school bus (1) → transport

Results show that at least one practically sensible renewable energy conversion pathway has been generated in option network V1. It shall be noted that the most practically sensible result chain is ranked 52nd of a total of 180 different ranks for 2,500 result chains. The result chain is situated in the first 30% of the calculated result chain ranks, which basically proves the efficiency of the ranking algorithm, letting appear at the same time the room for its improvement.

It is stressed that the goal of the software application is to provide an energy planner in a Southern urban context with stimulants for the creative generation of energy provision options previously unknown to him. It is believed that the idea of fueling a city's bus fleet with biogas obtained from the anaerobic digestion of organic waste is a novel option for a number of energy planners. However, such a statement is difficult to substantiate, because i) different energy planners have different levels of knowledge, and ii) individuals do not know what is unknown to them.

In the context of Cape Town, the obtained result could be utilised to design the following setup: Methane generated at the City's wastewater treatment works[1] is collected, washed and compressed, and used to fuel the City's public transportation fleet "GoldenArrow"[2]. The diesel engines of the buses will have to be converted to methane fuel, and an infrastructure must be created in order to provide a central point where buses can be fuelled with the compressed and cleaned methane gas. Although the methane generate at the Cape Flats Wastewater works is already utilised as substitute fuel for the diesel boilers, a systematic utilisation of methane obtained at all of the wastewater works in Cape Town equiped with anaerobic digestion units would lead to a massive cut-down on GHG emissions, and meaningful savings in terms of fossil-based transport fuels.

It is therefore stated that, within the constrains of the experimental design, the obtained results demonstrated the potentials of the model and the software application to generate practically sensible stimulants for the design of renewable energy conversion pathways.

It shall be noted that the option network generated with a restriction regarding a specific country and language (V2) contains no practically sensible information (see Appendix N, Figure N.14). Furthermore, it was not established whether the generation of an option network with restrictions regarding country and language delivers keywords and URLs pointing to local technology providers or locally available resources.

[1]See e.g. 3.4.5.2, where 1,200m^3 are generated

[2]See www.gabs.co.za

8.5 Discussion

8.5.1 Principle Outcomes

By means of a two step approach consisting of an exploratory experimentation phase and a verification phase, the potentials of the developed model and the software application to generate practically sensible stimulants for the design of renewable energy conversion pathways have been demonstrated.

It is believed that the results delivered by the software application can be integrated in the development of flowsheet superstructures similar to MARKAL's RES, and can assist Southern energy planners in the MCDM process for the sustainable energisation of the urban poor.

It could be considered to integrate the demonstrated technology in the training of urban energy planners. Furthermore, it is believed that the basic listing and comparison of end-user energy service demands and inner-city energy resources as it is suggested by the software tool can already act as stimulant for the generation of novel energy conversion options.

State-of-the-Art software technology has been used in order to create a powerful option generation tool. By choosing a MS Visual Studio .NET platform for the development of the software application, a good basis has been laid for further development of the application towards an internet application. The integration of the Google SOAP Search API search engine has shown the potential that lays in the creative combination of data accessible in the WWW. The creation of an interface to the MikTeX application has shown to be very useful when it comes to the graphical representation of data.

By learning from the exploratory experimentation phase, and modifying and adjusting the application and parameter settings accordingly, it has been shown that for the verification phase, a combination of a specific search query and search context, a rigorous manual categorisation regarding keyword types, and the utilisation of the end-of-pipe filter functionality, delivered valuable option networks in terms of technical score and practical sensibility.

The utility of the parameters for country and language restriction for the generation of more geographically specific options has not yet been proved.

Based on the exploratory experimentation and verification exercises, a basic set of parameter values has been developed and calibrated, allowing the generation of useful energy option networks. As the parameter settings for the option tree generation and the result ranking are easily modified by the user, it provides a great degree of flexibility when it comes to fine tunning the system for optimal output according to individual user needs.

To display the results in form of a table gives a systematic overview on the calculations necessary for obtaining the final set of results. Furthermore, it makes it easy to export these data for further calculations, e.g. to an MS Excel spreadsheet. The graphical representation of the results gives a neat and clear overview of possible options, easily understandable for a non-scientific audience as well.

Due to the self-learning database for the identification of keyword types, a meaningful by-product has been developed, showing potential for creating a large database of available energy technologies and intermediate and final energy products, especially when it should become accessible to a larger audience, all working on a common set of data.

8.5.2 Weak Spot Analysis

It is known that the definition of keywords on websites has been misused in the past by website owners in order to get high rankings by commonly used search engines (see e.g. HTRG, 2006). This might affect the quality of delivered results by the model, as a logical connection between the keywords on a website might not always be given.

The access and handling of data lies at the core of the option generation application. It is believed that by increasing the amount of accessed and handled data to e.g. a factor 10^3, the quality of delivered results could be improved meaningfully. At the moment of writing, the access to data is limited by the Google API search engine and the proxy server. The amount of data handled is limited by the nature of the software application in connection with the database type.

The Google SOAP search API has been identified as a weak spot in a threefold manner. Firstly, it is at the point of writing limited to 1,000 search queries per day, and 10 provided websites per search query, reducing the access to data tremendously (Google, 2006a). Secondly, the Google API is a β-version, running unstably, regularly causing errors during the search process. At this stage, errors are being handled internally by the software application, allowing a relatively continuous run of option tree generation exercises. Thirdly, the time necessary to retrieve data from the internet via the Google SOAP search API has been identified as the first performance bottleneck in the software application (see Figure 8.20, performance bottleneck PB I). However, that issue must be considered in connection with bandwidth availability, both impacting on the speed of internet transactions. For the purpose of the application, the proxy server of the University of Cape Town (UCT) libraries had been utilised, which allowed relatively fast internet transactions during night hours, as compared to standard UCT internet access during day hours. Therefore, option tree generation exercises were run during night time. However, the performance still laid below broadband internet access.

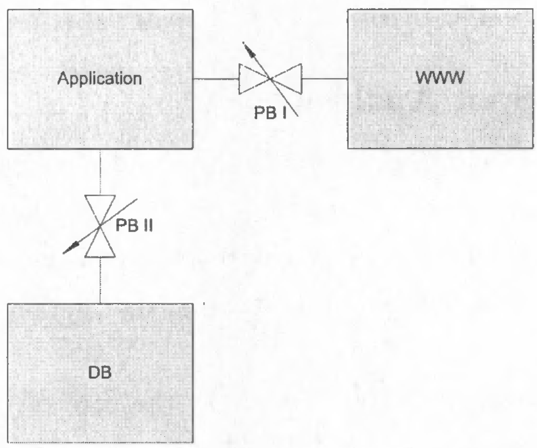


Figure 8.20: Performance Bottlenecks

The velocity of transactions between the business layer and the database layer has been found to be the second performance bottleneck of the application (see Figure 8.20, performance bottleneck PB II). Although playing a negligible role during the option tree generation procedure, it is the main time consumer during the option tree matching procedure and the results processing procedure.

An issue affecting the quality of delivered results is the amount of data in the comparison tables, enabling the definition of keyword types. Although the data provided by external applications such as LEAP form a good basis for the definition of keyword types, it has been identified that the self-learning process by manually defining keyword types in the option trees is of paramount importance. For the running of the exploratory experiments, no systematic manual definition of keyword types was attempted. The time necessary for screening the amount of data contained in the twenty experiments would have extended substantially beyond the time frame set for this thesis. However, a systematic manual sorting of keywords according to type was carried-out for the four experiments of the verification phase.

8.5.3 Outlook and Recommendations

From a model perspective, one could consider to choose another approach regarding the connectivity between keywords in result chains. An option would be to retrieve keywords from websites that are connected via hyperlinks, an approach similar to the one used in the PageRank[1] algorithm. In this case, an iteration step would no longer consist in retrieving a list of keywords from a set of websites obtained by triggering a set of web searches based on a list of previously obtained keywords. An iteration step would then consist in retrieving a list keywords from a set websites that are back-linked to the websites from which stems a list of previously obtained keywords.

For the purpose of performance enhancement of the option generation application, issues respectively affecting the search engine, internet access, and database transactions are considered.

[1]The heart of the Google software is PageRank, a system for ranking web pages developed by Google founders Larry Page and Sergey Brin at Stanford University. The Google website desrcibes the algorithm as follows (Google, 2006b): *"In essence, Google interprets a link from page A to page B as a vote, by page A, for page B. But, Google looks at more than the sheer volume of votes, or links a page receives; it also analyzes the page that casts the vote. Votes cast by pages that are themselves important weigh more heavily and help to make other pages important."*

From the point of view of the search engine provider, it would help to enhance the application performance to get a full version of the Google SOAP search API without restrictions. One might also consider other search engine providers such as Yahoo (Yahoo, 2006), and test their search engine APIs regarding their performance. Moreover, it would be useful to approach such a company for the commercialisation of the tool, as at this point in time, the license agreement allows the usage of the Google API search engine exclusively for non-commercial purposes. Furthermore, it would be very interesting to observe the application performance if one had access to Google's full computational capacity.

A fast internet access via a broadband service provider would accelerate the option tree generation procedure meaningfully.

A further step regarding the enhancement of time of data retrieval would be the setup of a parallel computer structure, enabling the simultaneous data retrieval via a computer cluster. Furthermore, such a cluster could also be used to split up the time consuming procedures of option tree matching and results processing (see Openshaw & Turton, 2000 and El-Rewini & Abd-El-Barr, 2005).

By migrating from an MS Office Access 2003 database to a more performing open-source MySQL[1] database solution, or an industrial scale IBM DB2[2], IBM Informix[3] or Oracle[4] database solution, database transactions could be accelerated. The choice of the database technology for the future large scale realisation of the application is of paramount importance, as the application is database intensive, and database transactions have been identified as a performance bottleneck.

Furthermore, it could be envisaged to convert the programming code from MS Visual Basic .NET to C++ or C# in order to accelerate the application code as such. Note that the performance enhancement here is believed to be not that important, as the application is not process intensive compared to its database activity.

Regarding the quality of the obtained results, one could consider the development of a number of additional parameters used for the ranking of results. By

[1] http://www.mysql.com
[2] http://www-306.ibm.com/software/data/db2/
[3] http://www-306.ibm.com/software/data/informix/
[4] http://www.oracle.com/database/index.html

obtaining the PageRank value for the websites of a result chain, one could calculate an average PageRank value for the chain, delivering a value that could be included in the ranking procedure. Furthermore, more weight could be given to result chains containing renewable energy solutions by introducing an additional keyword type reflecting the keyword's renewable nature. A parameter reflecting the degree of renewability of a result chain could be calculated and integrated to the ranking process as well.

A broader set of comparative data for the definition of keyword types would enhance the quality of delivered results. This goal could be achieved by making the application available to a broad user base, e.g. via the means of a web-based application, using one central database. This database could then be updated by the entire user community. The realisation of this database as a wiki[1], similar to the free encyclopedia Wikipedia[2], could be a technological option.

The release of a smaller version of the application is also imaginable, where the user has access to a database containing already generated option trees for a variety of energy demands and supplies. The user could run matching and ranking exercises based on the existing data, giving him the opportunity to quickly come up with a set of possible options, without having to perform the time-consuming generation of option trees.

At this point in time, the option generation applications draws its data entirely from the WWW. In order to improve the quality of delivered results, one could consider to use additional scientific digital libraries such as ScienceDirect[3]. Migration to these kind of databases should be relatively easy, as they also use indexing systems based on keywords enabling their users to search their contents amongst other things by topic.

[1]A wiki is a type of Web site that allows the visitors themselves to easily add, remove, and otherwise edit and change some available content, sometimes without the need for registration. This ease of interaction and operation makes a wiki an effective tool for collaborative authoring (Wikipedia, 2006e).

[2]According to Wikipedia (2006f), Wikipedia has rapidly grown into the largest reference Web site on the Internet since its creation in 2001. The content of Wikipedia is free, and is written collaboratively by people from all around the world.

[3]ScienceDirect offers more than a quarter of the world's scientific, medical and technical information online, including 2,000 peer-reviewed journals, and hundreds of book series, handbooks and reference works (Elsevier, 2006)

Eventually, it should be noted that the developed model could also be applied to other fields where similar problem statements can be found, e.g. product design, where a variety of input materials and production processes could be deployed for the creation of a single final product, or waste management, where a waste product could be reused as input material for a variety of processes for producing a series of new products.

8.6 Conclusion

In this Chapter, an option generation model has been defined based on the approaches of CPS and data mining. The model was structured into three sections, namely the option tree generation, the matching of obtained option trees, and the processing and display of obtained results.

Option trees are generated based on a previously defined set of parameters, mainly influencing the number of URLs, keywords and iteration steps utilised for the retrieval of information from the WWW via a search engine service.

The matching of option trees consists in comparing the keywords of two or more previously generated option trees, forming keyword chains were the option trees match.

During the processing and display of results, four different values are calculated for each keyword chain, enabling to sort them according to their importance. Finally, a concise option network is displayed, containing all necessary information.

Based on the previously defined model, a software application was developed. The application has been built around a three-tier architecture, consisting of a data tier, a logic tier, and a presentation tier.

The data tier consists of a database and contains 17 tables. The logic tier includes all logical data processing procedures, and has been structured according to the underlying model into the option tree generation procedure, the option tree matching procedure, and the result processing and display procedure. The programming language of the application is MS Visual Basic (VB) .NET, and the database is a MS Access 2003 application.

Subsequently, the defined model and the developed application have been validated during a exploratory experimentation and a verification phase.

For the exploratory experimentation and the verification phase, two series of experiments were developed before the background of sustainable energy planning. For the exploratory experimentation phase, the series of experiments has been developed around the renewable energy resources identified in Chapter 7, and household energy demands for low-income households in Khayelitsha, a township of Cape Town (see Section 3.4.5.2). Twenty different experiments were designed, varying in search topic and parameter settings. After having run the experiments, the results were analysed and interpreted. Thereupon, the application was modified and extended, and parameters were adjusted and fine-tuned.

For the verification phase, an independent series of experiments was developed around energy service needs and resource availability in an urban context that had not yet been investigated in the framework of this thesis, i.e. transportation and organic waste. Four experiments were carried out using an optimised application and a refined set of parameters. In a subsequent analysis and interpretation of obtained results, it was verified by the calculation and comparison of technical scores that the quality of the information contained in the option networks for the verification phase is higher than the one contained in the option networks of the exploratory experimentation phase. Furthermore, it was verified that practically sensible information for stimulating the design of renewable energy conversion pathways can potentially be retrieved from the results obtained for one option network generated during the verification phase.

A final discussion was performed around principle outcomes, a weak spot analysis, as well as an outlook and recommendations. The insights won during the exploratory experimentation and validation phase showed that the generation of option networks must happen based on a specifically defined search topic, a calibrated set of parameters, a vigorous manual categorisation process of keyword types, and a subsequent filtering of obtained results. By doing so, it is possible to create semantically related keyword chains between two different starting points over one or more iteration steps, concisely represented in an option network.

In line with Hypothesis 3, it was furthermore suggested that the results delivered by the software application can be used for the development of renewable energy supply options, and can thus assist Southern energy planners in the MCDM process for the sustainable energisation of the urban poor.

The weak spot analysis revealed that a restricted access to input data is a cause for decreased result quality. Furthermore, two performance bottlenecks in terms of processing speed were identified for the application, namely WWW and database transactions.

In order to tackle the identified weak spots, it was recommended to consider another approach regarding the semantic connectivity of information of the WWW. Furthermore, an altered web search engine - either a full version or another provider -, and a faster internet access (broadband) would help to mine larger amounts of data in a shorter period of time. Finally, the migration to a more performing database solution would increase the speed of database transactions.

Chapter 9

Conclusion and Outlook

9.1 Conclusion

It was the goal of this dissertation i) to develop insights into the renewable energy planning approaches of cities in the developed and the developing world, and ii) to develop and demonstrate novel approaches for assisting renewable energy planners in cities of the global South. Lead by a methodology split into three work phases and seven modules (corresponding to Chapters 2-8), the goal of this dissertation was tackled by substantiating a threefold Hypothesis.

Preliminarily, it was stipulated that energy planning approaches of the North are only transferable to some extent to Southern cities, as they do not implicitly consider typical features of fast-growing cities, only recently started to consider renewable energy alternatives, and are heavily focused on supply-side options.

In Chapter 2, an overview was presented regarding the scientific background, the theoretical basis, and the methods applied for the research undertaken in this dissertation. By providing the background on urban energy planning, the previously stipulated statement was illustrated by means of a short history of energy planning, and a critique of existing energy planning approaches and concepts. It was questioned to which extent existing energy planning approaches are transferable to cities of the South, as they were developed based on insights won from experiences in Northern cities over the last three decades, with a strong environmental element. By following-up on this preliminary statement, it was firstly hypothesised that **the municipal energy planning process in developing cities can have a greater impact on socio-political aspects than in Northern cities, if certain capacities are available or very clear consequences of energy decisions or inactions are given.**

A comparative analysis of two case studies regarding a city in the South (Cape Town - Chapter 3) and a city in the North (Aachen - Chapter 4) was carried-out in Chapter 5. The development of both case studies is based on original research work and interviews. The reason for selecting the case of Cape Town was its position as the leading city regarding sustainable energy planning in Africa. On the other hand, the case of Aachen was selected because of its impressive history regarding renewable energy planning and implementation.

For both cities, the national, historical and geo-political backgrounds were presented and compared. The renewable energy planning process in Aachen was illustrated by means of the planning process of a 30MW wood gasification plant. For Cape Town, four different sustainable energy projects were presented.

Results showed that renewable energy planning emerged in Aachen driven by environmental concern. In turn, Cape Town is preoccupied with energy related challenges tightly linked to socio-economic development issues, but, to some extent, cognisant of global climate change consequences of business-as-usual. Aachen's planning process was qualified as implementation-oriented and efficient, as well as policy driven and rather rigid, especially regarding the cooperation with its private partner. Cape Town's planning process was qualified as strategic and less efficient, i.a. due to lacking human and financial resources, but also improvised and flexible, especially in cooperation with project partners. The insights won helped to substantiate Hypothesis 1.

After having identified the similarities and differences in the urban renewable energy planning approaches of the two case studies, it was aimed in the next phase to develop and demonstrate new approaches for improving the Southern renewable energy planning process. It was stipulated in a second Hypothesis that **by developing a detailed understanding of energy needs, and coupling these to a set of renewable energy options, a meaningful process of social upliftment and economic development is enabled.**

In Chapter 6, the emerging concept of *energisation* was investigated by means of an extensive literature review. Furthermore, the application of the concept of energisation was analysed for three practical South African examples, i.a. through original research work regarding a wood fueled local economy in Khayelitsha, Cape Town's largest township. Based on insights won, a new definition of an extended concept of Sustainable Energisation was proposed.

Thereupon, an economic model was presented for a reframed concept of Sustainable Energisation. Based on the theory of urban ecosystems, a special emphasis was laid on the so-called first and second economy in urban contexts in developing countries. In the next step, within a framework of Multiple-Criteria Decision Making (MCDM), a checklist for the drafting of technical energy supply systems was developed, with the aim of implementing the elements of Sustainable Energisation at each tier of the energy supply chain.

After having developed a deep understanding of energy service demand in cities of the South, it was furthermore aimed at investigating means for the identification of potential urban renewable energy sources. Therefore, the method of MFA was applied to the case of wood-fibre based material in Cape Town in Chapter 7.

As no comprehensive and centralised collection of data on wood fibre based materials in Cape Town existed at the point of writing, data were drawn from existing publications, public databases, telephonic interviews and site visits at companies for the formal sector of Cape Town. Interviews were conducted on site in informal settlements in Cape Town in order to collect data for the informal wood-using sectors. The data collection was conducted over a period of two years.

By focusing on specific biomass streams, it was found that the city possesses a wealth of renewable energy resources within its boundaries, coupled to important linkages between formal and informal activities. It was established that approx. 70% of an inclusively defined renewable energy target of the City of Cape Town could be met via the redirection of wood fibre based material flows within the Cape Metropolitan Area (CMA), and the utilisation of innovative transformation technology. By assisting in the identification of renewable resources for the case of Cape Town, it was demonstrated that the method of MFA is a valuable element in enabling a process of social upliftment and economic development as stipulated in Hypothesis 2.

In the last step, it was claimed that a prerequisite for matching energy needs and renewable energy sources in the most sustainable way is the knowledge of the diversity of possible energy supply options. It was argued that energy planners typically fall back on a poor short list of renewable conversion options that reads: "wind, solar, biomass, hydro". It was thus stipulated in Hypothesis 3 that **the efficient coupling of energy needs with renewable energy options will benefit from the use of computer-aided synthesis of options, informed from the emerging fields of Combinatorial Process Synthesis (CPS), Data Mining, and the Use of Search Engines.**

In Chapter 8, it was demonstrated by means of a model and a software tool that semantically linked keyword chains can be generated based on two distinct starting points, and that this property can potentially be used for the design of novel renewable energy project ideas on a local scale.

The proposed model for creative option generation is structured into the generation of option trees, the matching of option trees, and the processing and display of results. Based on the model, a three-tier software application was developed in MS Visual Basic .NET using an MS Access database, including state-of-the-art web search engine technology (Google Web API).

Based on the wood-fibre based material flows identified for Cape Town in Chapter 7, a series of experiments was designed in order to prove the proposed concept in the exploratory experimentation phase. Next, parameters were calibrated according to insights won during the previous phase. Subsequently, the model and the software tool were tested in the verification phase by means of an independent series of experiments against a technical and a practically sensible goal.

Results showed that from a technical perspective, a higher quality of information was obtain for the verification phase than the exploratory experimentation phase. At least one practically sensible renewable energy conversion pathway has been generated in the verification phase. In line with Hypothesis 3, it was suggested that the results obtained can be used for the development of renewable energy supply options, and can thus assist Southern energy planners in the MCDM process for the sustainable energisation of the urban poor.

Summarily, it can be stated that by carrying out a comparative analysis of two case studies, insights were won regarding the similarities and differences between renewable energy planning approaches in cities of the South and the North, especially in terms of the importance allocated to socio-economic development needs (Hypothesis 1). Subsequently, an understanding of energy service needs was developed by investigating and reframing the concept of energisation, and it was demonstrated by means of a case study that the method of MFA is a valuable tool for the identification of renewable urban energy resources (Hypothesis 2). Finally, it was established by developing a model and a software tool that the coupling of energy needs to a set of renewable energy options in order to enable a process of social upliftment and economic development (see Hypothesis 2) can be informed from the field of Information Technology (IT) (Hypothesis 3).

This dissertation has thus developed deep insights into the field of urban renewable energy planning, and delivered a number of novel approaches which could contribute in their way towards shaping our cities for sustainable development. It is with great optimism that I look into the future, ready to take the challenges that stand ahead of us.

9.2 Outlook

This dissertation has married within its ambit several approaches and methods stemming from different research fields, i.a. energy planning, renewable energy technology, chemical engineering, systems analysis, and information technology, as well as elements from the fields of economics and politics.

Due to its broad spectrum, room for further research has been identified at different levels within this dissertation.

For the case of Cape Town, it would be of interest to follow-up on the development of South Africa's EDI, as well as the new role of Cape Town and other local governments in this changing environment. As the restructuring of the EDI is an ongoing process, it is possible to creatively intervene in the shaping of this new landscape from a local government perspective, assisted by academia, especially regarding a more supportive structure for sustainable energy projects.

Four different sustainable energy projects have been investigated for the case of Cape Town.[1] They all include different planning and cooperation approaches, and can serve as templates for the creative development and implementation of further sustainable energy projects within Cape Town, as well as other cities in South Africa and the developing world. Especially the Kuyasa project has successfully demonstrated that social and environmental issues can be married; in the same line, projects should be identified that link renewable energy options with Sustainable Energisation in urban contexts.

A starting point for the systematic screening of possible projects could be the MFA of wood-fibre based materials in Chapter 7. The latter has also shown that an understanding of renewable energy sources within a city is critical for creating a good basis for future planning. Further research could be undertaken in identifying the amount of renewable energy used within Cape Town - beyond wind-based electricity generated at the Darling Wind Farm -, using the methods of data collection presented, and giving an estimate on how much of Cape Town's renewable energy target has already been achieved. Furthermore, it should be sought out whether future research, especially in Khayelitsha, could be coordinated with ambitions of City departments such as the Air Pollution Control Unit regarding the reduction of local air emissions.

For the case of Aachen, it would be necessary to follow-up on the development of the implementation phase of the presented wood gasification plant. Against the LA21-partnership between Aachen and Cape Town, potential cooperations in both directions regarding the renewable energy sector could be investigated, focusing on differences in planning and implementation approaches, and coupling Aachen's expertise in high-tech renewable energy technology and financing models to socio-economic development issues of special relevance in Cape Town's context.[2] Such cooperations could lead to novel approaches in energy planning

[1] see Section 3.4.5.2

[2] See also Section 5.5 for insights and recommendations emerging from the comparison of both case studies.

for urban contexts in the developing world. Research that could be mutually co-ordinated between both cities is the identification of Renewable Energy options for fuel substitution in their respective industrial sectors, as well as the systematic integration of the waste management sector into the renewable energy planning process.

It has been shown that there is a shortage of financial support and technical skills for the planning and implementation of renewable energy projects in Cape Town.[1] It should be investigated whether Public-Private Partnerships (PPPs) could provide novel business models in terms of financial support from the public sector, and skills from the private sector. Furthermore, it should be clarified whether such an approach would undermine job opportunities in the public sector.

With regards to Southern cities, an investigation of the institutional structures and budgeting procedures at national, provincial and local levels regarding socio-economic and energy issues could reveal insights on the way these are addressed, either separately or concurrently. As it is argued that the former is typically the case, the institutional barriers for the market penetration of renewable energies could be investigated. Moreover, the institutional instruments necessary for enabling a meaningful process of Sustainable Energisation could be identified.

Against the backdrop that Aachen moved away from strategic planning, it should be investigated which type of strategies and guidelines are necessary for steering the renewable energy planning process in a Southern city like Cape Town. Moreover, Cape Town has set itself a series of bold sustainability goals (see Section 3.4.1). Questions that need to be answered are as follows:

- Are Cape Town's goals defined properly, and what is their purpose?
- Are they challenging whilst remaining achievable?
- What tools are needed for implementing them efficiently?
- Is there something that can be learned from Germany and Europe regarding the way they defined their renewable energy targets?

[1]see Section 3.4.5.1

Furthermore, it could be investigated to which extent the concept of Sustainable Energisation can be integrated into the implementation of these sustainability goals.

It was found that the Aachener Modell and the EEG are economically viable in Germany, because overhead costs are burdened to the entire electricity customer base[1]. On the other hand, South Africa introduced a social electricity tariff for the population in need, as not everyone can afford the current price of electricity. An interesting question which emanates from these explanations is as follows: *"Is an environmentally sound energy system only viable in a more egalitarian society?"*

Further points that need to be clarified in order to answer this question are as follows:

- Under which conditions would a system like the EEG be viable in South Africa?
- Is an EEG-type model the way to go for South Africa?
- Would Sustainable Energisation be more viable in South Africa if electricity was more/less expensive?

These issues lead to a more general question: *"Does the developing world need a Northern type environmental movement, or does it already melt social and environmental aspects in a new paradigm?"*

A first step would be to further investigate the concept of Sustainable Energisation[2]. The identification of primary and secondary energy needs by means of case studies would be a good starting point. Secondly, the relationships between the elements in the economic model presented in Section 6.5 should be quantified by means of case studies, and the checklist for Sustainable Energisation should be applied practically to ongoing processes of urban renewable energy planning in order to substantiate its validity (Section 6.6.2.2). Furthermore, parameters for the quantified measurement of the degree of Sustainable Energisation achieved should be developed and applied.

[1] see Section 4.3.3

[2] A number of recommendations have been formulated in Section 6.6.3

Under Section 6.6.3, it has been argued that subsidies distort investment. An interesting research questions is as follows: *"What if Germany's PV-appliances would have been implemented in a sunnier climate, like the one in South Africa, and what would have been the implications in terms of the CDM?"*

Finally, an extensive list of conceptual and technical recommendations was given for the developed web-based option generation model and software tool under Section 8.5.3. The application of the software tool by urban energy planners in the developing world could give insights as to its practical value. Against the background of a shortage of technical skills and financial means in the renewable energy planning sector in the developing world, the software tool could be utilised as supplement or alternative to the cost-intensive training of urban energy planners.

9. CONCLUSION AND OUTLOOK

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Appendix A

Questionnaires for Interviews - City of Cape Town

A. QUESTIONNAIRES FOR INTERVIEWS - CITY OF CAPE TOWN

Questionnaire for Interview Osman Asmal, Director of Environmental Management Department, City of Cape Town, 05.04.2004

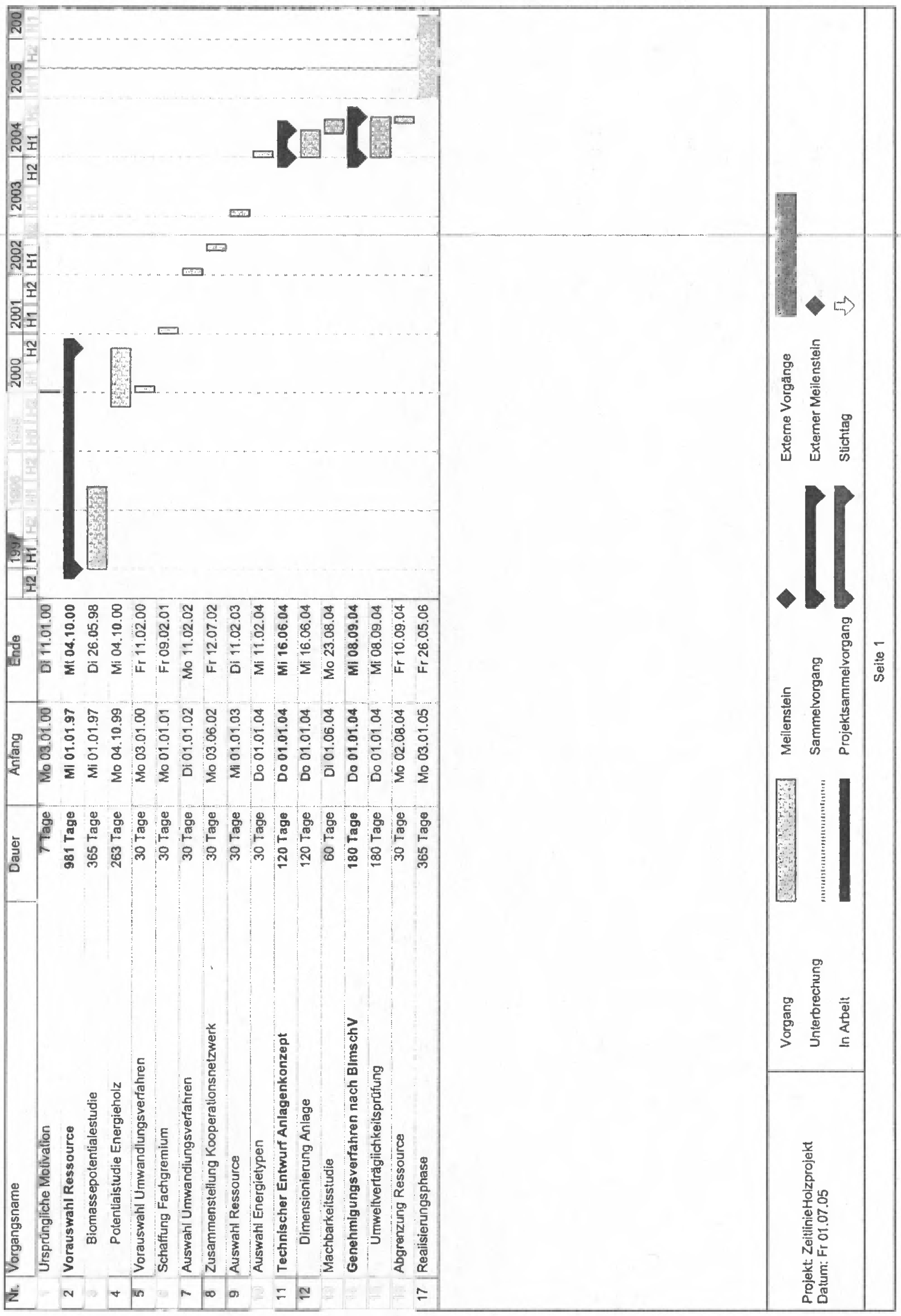
1. Which projects are currently undertaken between Aachen and Cape Town against the background of the LA21-partnership?
2. Would you be interested in the development of a case study sponsored by the Agenda21 bureau?
3. (Presentation of research proposal for dissertation)
4. How does the planning process of the City of Cape Town work?
5. Who is involved? How are you involved in the process?
6. Which approaches are used for the planning process?
7. Are there any specific software tools that are used?
8. How do you generate energy supply options?

Questionnaire for Interview Gordon Munro, Deputy Director of Electricity Services, City of Cape Town, 28.04.2004

1. How are you involved into the energisation process of the City of Cape Town?
2. What is done on the provincial and national level regarding energy planning? Who to speak to?
3. What do you think about the development of a software tool for the assistance in decision making on the local level? Do you see any need? Market?
4. How is Eskom involved into the local energy planning process?
5. What is the fate of the Athlone power station (reference to recent Engineering News article)?

Appendix B

Time Line Wood Gasification Project



Nr.	Vorgangsname	Dauer	Anfang	Ende
1	Ursprüngliche Motivation	7 Tage	Mo 03.01.00	Di 11.01.00
2	**Vorauswahl Ressource**	**981 Tage**	**Mi 01.01.97**	**Mi 04.10.00**
3	Biomassepotentialestudie	365 Tage	Mi 01.01.97	Di 26.05.98
4	Potentialstudie Energieholz	263 Tage	Mo 04.10.99	Mi 04.10.00
5	Vorauswahl Umwandlungsverfahren	30 Tage	Mo 03.01.00	Fr 11.02.00
6	Schaffung Fachgremium	30 Tage	Mo 01.01.01	Fr 09.02.01
7	Auswahl Umwandlungsverfahren	30 Tage	Di 01.01.02	Mo 11.02.02
8	Zusammenstellung Kooperationsnetzwerk	30 Tage	Mo 03.06.02	Fr 12.07.02
9	Auswahl Ressource	30 Tage	Mi 01.01.03	Di 11.02.03
10	Auswahl Energietypen	30 Tage	Do 01.01.04	Mi 11.02.04
11	**Technischer Entwurf Anlagenkonzept**	**120 Tage**	**Do 01.01.04**	**Mi 16.06.04**
12	Dimensionierung Anlage	120 Tage	Do 01.01.04	Mi 16.06.04
13	Machbarkeitsstudie	60 Tage	Di 01.06.04	Mo 23.08.04
14	**Genehmigungsverfahren nach BImschV**	**180 Tage**	**Do 01.01.04**	**Mi 08.09.04**
15	Umweltverträglichkeitsprüfung	180 Tage	Do 01.01.04	Mi 08.09.04
16	Abgrenzung Ressource	30 Tage	Mo 02.08.04	Fr 10.09.04
17	Realisierungsphase	365 Tage	Mo 03.01.05	Fr 26.05.06

Figure B.1: Time Line Wood Gasification Project

Appendix C

Sustainable Energisation: Detailed Discussion of Definition

> *Sustainable Energisation* is the **transitional process (1)** of **progressively (2)** meeting **primary and early secondary energy service needs (3)** of a **poor economic subgroup** (second economy) **(4)** through the delivery of an **enhanced quantity, quality and/or variety (5)** of **accessible and affordable energy services (6)**, enabling the **sustainable development (7)** of the considered subgroup based on **poverty alleviation and economic development (8)**, as well as the **optimisation of the energy service supply network from a life-cycle perspective (9)**.

1. The adjective 'transitional' is used, as the described process focuses on the shift from primary to early secondary energy service needs.

2. The adverb 'progressively' is used in order to emphasise a defined chronological order according to which energy needs have to be met. Although there might be overlaps between primary and secondary energy service needs, it is assumed that generally, primary energy needs will have to be satisfied before secondary energy service needs can be met.

3. The definition of the terms 'primary and early secondary energy service needs' has been given in section 6.4.2.

4. The definition of the target group 'poor economic subgroup (second economy)' is given in section 6.4.1.

5. Sustainable energisation takes place when the quantitiy, quality, and/or variety of energy services delivered are enhanced. This means that at least one of the three elements needs to be enhanced. It is emphasised though that the three elements will never decrease under sustainable energisation. For instance, if the energy carriers fuel wood and cow dung are entirely substituted by the energy carrier electricity, the variety of energy carriers decreases from two to one. However, the variety of energy services delivered (e.g cooking and space heating) will remain equal or even increase (e.g. additional refrigeration).

6. Accessibility and affordability of modern energy carriers have been identified as critical enablers of energisation under section 6.2.2. In analogy, it is assumed that the terms 'accessibility' and 'affordability' can be applied to the energy service as such, as the energy carrier is integral part of the energy service supply network.

7. The term 'sustainable development' has been described in the context of sustainale energisation under section 6.4.3.

8. The terms 'poverty alleviation' and 'economic development' are defined under section 6.4.2.

9. The energy service supply network integrates as such the cradle-to-grave approach to the energy service delivered, as it stretches up to the initial resource. However, the life-cycle perspective emphasises that the optimisation of the energy service supply network must account, next to the cradle-to-grave approach, for impacts on all environmental media, as well as a timely component.

Appendix D

Calculation of Wood Fibre Based Material Streams

M5 - Wood Waste from Sawmills going to Thermal Utilisation Formal

According to an interview with Mr. Louis Silberbauer, manager of Cape Sawmills (Silberbauer, 2005), a total amount of $42,900t/a$ are being thermally utilised on the plant itself. Assuming a moisture content $w = 7\%$[1], this gives a total amount of solid wood fibre of:

$$M5 = 42,900t/a * (1.00 - 0.07) = 39,897t/a \approx 40,000t/a$$

Assuming a lower heating value for South African pine $H_l = 20,420MJ/t$ (CSIR, 1990), the energy content for material stream $M5$ is calculated as follows:

$$M5_e = 42,900t/a * 20,420MJ/t * \frac{1GJ}{1000MJ} = 876,018GJ/a \approx 876,000GJ/a$$

M10 - Construction Wood going from Construction Formal to Disposal

$M10$ is the material stream corresponding to the total amount of construction wood going from construction formal to disposal and can be described as follows:

$$M10 = A + B + \frac{C_1 + C_2}{2} \tag{D.1}$$

[1]based on average moisture content of dried wood (e.g. Wirtgen, 2005)

D. CALCULATION OF WOOD FIBRE BASED MATERIAL STREAMS

The energy content of material stream $M10$ is calculated according to the following equation:

$$M10_e = A_e + B_e + \frac{C_{1,e} + C_{2,e}}{2} \quad \text{(D.2)}$$

According to Jeffares & Green (2004, p.4-6), builder's rubble amounts to $318,392t/a$. Assuming that 5% of the builder's rubble is wood waste[1], and a moisture content $w = 7\%$[2], this gives:

$$A = 318,392t/a * 0.05 * (1.00 - 0.07) = 14,805t/a \quad \text{(D.3)}$$

A corresponds to cell I82 in Excel worksheet 'SummaryTable' (see appendix F).

Accordingly for the energy content, assuming that wood waste is mainly SA pine (*Pinus Patula*):

$$A_e = 318,392t/a * 0.05 * 20,420MJ/t * \frac{1GJ}{1000MJ} = 325,078GJ/a \quad \text{(D.4)}$$

A_e corresponds to cell K82 in Excel worksheet 'SummaryTable' (see appendix F).

According to Jeffares & Green (2004, p.8-34), builder's rubble amounts to $240,000t/a$. Assuming that 5% of the builder's rubble is wood waste[3], and a moisture content $w = 7\%$ (Wirtgen, 2005), this gives:

$$B = 240,000t/a * 0.05 * (1.00 - 0.07) = 11,160t/a \quad \text{(D.5)}$$

B corresponds to cell I84 in Excel worksheet 'SummaryTable' (see appendix F).

Accordingly for the energy content, assuming that wood waste is mainly SA pine (*Pinus Patula*):

$$B_e = 240,000t/a * 0.05 * 20,420MJ/t * \frac{1GJ}{1000MJ} = 245,040GJ/a \quad \text{(D.6)}$$

B_e corresponds to cell K84 in Excel worksheet 'SummaryTable' (see appendix F).

According to Wright-Pierce (1999, p.3-21), total timber waste from the domestic & commercial sector amounts to $33,540t/a$. Assuming a moisture content $w = 7\%$ (Wirtgen, 2005), this gives:

$$C_1 = 33,540t/a * (1.00 - 0.07) = 31,192t/a \quad \text{(D.7)}$$

[1] assumed by author
[2] based on average moisture content of dried wood (e.g. Wirtgen, 2005)
[3] assumed by author

C_1 corresponds to cell I93 in Excel worksheet 'SummaryTable' (see appendix F).

Accordingly for the energy content, assuming that wood waste is mainly SA pine (*Pinus Patula*):

$$C_{1,e} = 33,540t/a * 20,420MJ/t * \frac{1GJ}{1000MJ} = 684,886GJ/a \qquad (D.8)$$

$C_{1,e}$ corresponds to cell K93 in Excel worksheet 'SummaryTable' (see appendix F).

According to Wright-Pierce (1999, p.3-21), total timber waste from the domestic & commercial sector projected for 2030 amounts to $57,720t/a$. Assuming a moisture content $w = 7\%$ (Wirtgen, 2005), this gives:

$$C_2 = 57,720t/a * (1.00 - 0.07) = 53,680t/a \qquad (D.9)$$

C_2 corresponds to cell I95 in Excel worksheet 'SummaryTable' (see appendix F)

Accordingly for the energy content, assuming that wood waste is mainly SA pine (*Pinus Patula*):

$$C_{2,e} = 57,720t/a * 20,420MJ/t * \frac{1GJ}{1000MJ} = 1,178,642.4GJ/a \qquad (D.10)$$

$C_{2,e}$ corresponds to cell K95 in Excel worksheet 'SummaryTable' (see appendix F).

By inserting the results of equations D.3, D.5, D.7 and D.9 in equation D.1, we obtain:

$$M10 = 14,805t/a + 11,160t/a + \frac{31,192t/a + 53,680t/a}{2} = 68,401t/a \approx 68,000t/a$$

By inserting the results of equations D.4, D.6, D.8 and D.10 in equation D.2, we obtain:

$$M10_e = 325,078GJ/a + 245,040GJ/a + \frac{684,886GJ/a + 1,178,642GJ/a}{2}$$
$$= 1,501,882t/a \approx 1,502,000t/a$$

M15 - Construction Wood going from Construction Informal to Thermal Utilisation Informal

$M15$ is the material stream corresponding to the total amount of construction wood going from construction informal to thermal utilisation informal and can be described as follows:

$$M15 = q_{shv} * n_{shv} * w \tag{D.11}$$

$M15$ corresponds to cell I54 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F) and subsequently cell P9 in tab 'Meat Vendors' (see figure F.6).

The amount of wood planks used per sheep head vendor can be calculated according to the following formula:

$$q_{shv} = w_b * n_b \tag{D.12}$$

It has been calculated based on Qase (2000, p.45-50), and interviews 1 & 3 (see figure G.4), that the weight of a bunch of wood planks is approx. $10kg$, therefore, we state that:

$$w_b = \frac{10kg}{unit_b}$$

Furthermore, it has been calculated based on the same sources that the amount of units (bunches) of wood planks used per day and sheep head vendor are approx. 6. Therefore:

$$n_b = \frac{6units_b}{d * unit_{shv}}$$

By inserting w_b and n_b into equation D.12 and converting it to the unit t/a, we obtain the following:

$$q_{shv} = \frac{10kg}{unit_b} * \frac{6units_b}{d * unit_{shv}} * \frac{365d}{a} * \frac{1t}{1000kg} = \frac{22.03t}{a * unit_{shv}}$$

The number of cheap head vendors in the study area can be calculated according to the following formula:

$$n_{shv} = N_{ihh} * n_{com} * s_{shv} \tag{D.13}$$

StatsSA (2001) gives a number of 142,983 informal households in Cape Town. Therefore we state:

$$N_{ihh} = 142,983 units_{ihh}$$

Furthermore, it has been assumed by the author based on cite visits and expert advise from Fikiswa Mahote of the Non-Governmental Organisation (NGO) DAG (Mahote, 2005) that there is a commerce for each 20 households in the study area. Therefore we state that:

$$n_{com} = \frac{0.05 units_{com}}{unit_{ihh}}$$

Eventually, it has been assumed by the author based on cite visits and expert advise from Fikiswa Mahote (Mahote, 2005) that every 4th commerce is a sheep vendor. Therefore, the market share of sheep head vendors can be expressed as follows:

$$s_{shv} = \frac{0.25 units_{shv}}{unit_{com}}$$

By inserting n_{ihh}, n_{com} and s_{shv} into equation D.13, we obtain the following value:

$$n_{shv} = 142,983 units_{ihh} * \frac{0.05 units_{com}}{unit_{ihh}} * \frac{0.25 units_{shv}}{unit_{com}} = 1787.29 units_{shv}$$

By inserting the results of equation D.12 and D.13 into equation D.11, and assuming a moisture content of w=7% (Wirtgen, 2005), we obtain following result:

$$M15 = \frac{22.03t}{a * unit_{shv}} * 1787.29 units_{shv} * (1.00 - 0.07) = 36,617.82t/a \approx 37,000t/a$$

Accordingly, the energy content for material stream $M15$ is calculated as follows, assuming that the waste wood (wood planks) utilised are mainly SA pine (*Pinus Patula*)[1]:

$$M15_e = \frac{22.03t}{a * unit_{shv}} * 1787.29 units_{shv} * 20,420MJ/t * \frac{1GJ}{1000MJ}$$
$$= 804,017MJ/a \approx 804,000MJ/a$$

M16 - Construction Wood going from Construction Informal to Disposal

$M16$ is the material stream corresponding to the total amount of construction wood going from construction informal to disposal. $M16$ corresponds to cell I90 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

[1]assumed by author

According to Wright-Pierce (1999, p.3-21), domestic & commercial wood waste from low-income areas amounts to $10,860.25t/a$. Assuming a moisture content $w = 7\%$ (Wirtgen, 2005), we can state that:

$$M16 = 10,860.25t/a * (1.00 - 0.07) = 10,100.03t/a \approx 10,000t/a$$

Accordingly, the energy content for material stream $M16$ is calculated as follows, assuming that the majority of domestic & commercial wood waste is SA pine (*Pinus Patula*)[1]:

$$M16_e = 10,860.25t/a * 20,420GJ/a * \frac{1GJ}{1000MJ} = 221,766GJ/a \approx 222,000GJ/a$$

M19 - Fuel Wood going from Fuel Wood Traders Formal to Thermal Utilisation Formal

$M19$ is the material stream corresponding to the total amount of fuel wood going from fuel wood traders formal to thermal utilisation formal and can be expressed according to the following formula:

$$M19 = A - B \tag{D.14}$$

The energy content of the material stream is calculated as follows:

$$M19_e = A_e - B_e \tag{D.15}$$

According to Azorin (1992), an amount of $49,000t/a$ of fuel wood is being imported into Cape Town. Assuming a moisture content of $w = 7\%$ (Wirtgen, 2005), we can state that:

$$A = 49,000t/a * (1.00 - 0.07) = 45,570t/a$$

A corresponds to cell I45 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

Accordingly, assuming that the fuel wood is mostly Black Wattle (*Acacia Mearnsii*)[2] and thus the lower heating value $H_l = 17,000MJ/t$ (CSIR, 1990), we can state that:

$$A_e = 49,000t/a * 17,000MJ/t * \frac{1GJ}{1000MJ} = 833,000GJ/a$$

[1]assumed by author

[2]assumed by author

A_e corresponds to cell K45 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to Azorin (1992), a total amount of $13,000t/a$ of fuel wood is imported in order to produce $12,400t/a$ of charcoal. It is further assumed based on the same source that 20% of this amount is being processed in Cape Town. Assuming a moisture content of $w = 7\%$ (Wirtgen, 2005), we can state that:

$$B = 13,100t/a * 0.20 * (1.00 - 0.07) = 2,620t/a$$

B corresponds to cell I47 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

Accordingly, assuming that the fuel wood is mostly Black Wattle (*Acacia Mearnsii*)[1] and thus the lower heating value $H_l = 17,000MJ/t$ (CSIR, 1990), we can state that:

$$B_e = 13,100t/a * 0.20 * 17,000MJ/t * \frac{1GJ}{1000MJ} = 44,540GJ/a$$

B_e corresponds to cell K47 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

By replacing the results for A and B in equation D.14, we can state that

$$M19 = 45,570t/a - 2,620t/a = 43,133.40t/a \approx 43,000t/a$$

By replacing the results for A_e and B_e in equation D.15, we can state that

$$M19_e = 833,000t/a - 44,540GJ/a = 788,460t/a \approx 788,000t/a$$

M23 - Charcoal going from Charcoal Traders Formal to Thermal Utilisation Formal

$M23$ is the material stream corresponding to the total amount of charcoal going from charcoal traders formal to thermal utilisation formal and can be expressed according to the following formula:

$$M23 = A + B \tag{D.16}$$

[1] assumed by author

Accordingly, the energy content is calculated as follows:

$$M23_e = A_e + B_e \tag{D.17}$$

According to Azorin (1992), the charcoal market generates an annual trade of $12,400t/a$. With a share of 20% being produced locally, we know that 80% of the charcoal is being imported. Assuming furthermore a moisture content of $w = 7\%$ (Wirtgen, 2005), we can state that:

$$A = 12,400t/a * 0.80 * (1.00 - 0.045) = 9,473.6t/a$$

A corresponds to cell I48 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

Accordingly, the energy content is calculated as follows, assuming a lower heating value for charcoal $H_l = 17,000MJ/t$ (CSIR, 1990):

$$A_e = 12,400t/a * 0.80 * 29,500MJ/t * \frac{1GJ}{1000MJ} = 292,640GJ/a$$

A_e corresponds to cell K48 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to Azorin (1992), 20% of the charcoal is being produced locally. Assuming a moisture content of $w = 7\%$ (Wirtgen, 2005), we can state that:

$$B = 12,400t/a * 0.20 * (1.00 - 0.045) = 2,368.4t/a$$

B corresponds to cell I49 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

Accordingly, the energy content is calculated as follows, assuming a lower heating value for charcoal $H_l = 17,000MJ/t$ (CSIR, 1990):

$$B_e = 12,400t/a * 0.20 * 29,500MJ/t * \frac{1GJ}{1000MJ} = 73,160GJ/a$$

B_e corresponds to cell K48 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

By replacing the results for A and B in equation D.16, we can state that

$$M23 = 9,473.6t/a + 2,368.4t/a = 11,842t/a \approx 12,000t/a$$

By replacing the results for A_e and B_e in equation D.17, we can state that

$$M23_e = 292,640GJ/a + 73,160GJ/a = 365,800GJ/a \approx 366,000GJ/a$$

M26 - Fuel Wood from Fuel Wood Traders Informal to Thermal Utilisation Informal

$M26$ is the material stream corresponding to the total amount of fuel wood going from wood traders informal to thermal utilisation informal and can be described as follows:

$$M26 = A + B \tag{D.18}$$

$M26$ corresponds to cell I53 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

The energy content of the material stream is calculated as follows:

$$M26_e = A_e + B_e \tag{D.19}$$

$M26_e$ corresponds to cell K53 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix).

A corresponds to the total amount of fuel wood utilised by meat vendors and can be described with the following equation:

$$A = q_{mv} * n_{mv} * w \tag{D.20}$$

A corresponds to cell P5 in Excel worksheet 'SummaryTable', tab 'Meat Vendors' (see figure F.6).

The amount of fuel wood used per meat vendor can be calculated according to the following formula:

$$q_{mv} = w_{bfw} * n_{bfw,mv} \tag{D.21}$$

It has been calculated based on Qase (2000, p.45-50), and Interview 4 (see figure ??), that the weight of a bunch of fuel wood is approx. $10kg$, therefore, we state that:

$$w_{bfw} = \frac{10kg}{unit_{bfw}}$$

Furthermore, it has been calculated based on the same sources that the amount of units (bunches) of fuel wood used per day and meat vendor is approx. 5. Therefore:

$$n_{bfw,mv} = \frac{5units_{bfw}}{d * unit_{mv}}$$

By inserting w_{bfw} and $n_{bfw,mv}$ into equation D.21 and converting it to the unit t/a, we obtain the following:

$$q_{mv} = \frac{10kg}{unit_{bfw}} * \frac{5units_{bfw}}{d * unit_{mv}} * \frac{365d}{a} * \frac{1t}{1000kg} = \frac{18.25t}{a * unit_{mv}}$$

The number of meat vendors in the study area can be calculated according to the following formula:

$$n_{mv} = N_{ihh} * n_{com} * s_{mv} \tag{D.22}$$

StatsSA (2001) gives a number of 142,983 informal households in Cape Town. Therefore we state:

$$N_{ihh} = 142,983units_{ihh}$$

Furthermore, it has been assumed by the author based on cite visits and expert advise from Fikiswa Mahote (Mahote, 2005) that there is a commerce for each 20 households in the study area. Therefore we state that:

$$n_{com} = \frac{0.05units_{com}}{unit_{ihh}}$$

Eventually, it has been assumed by the author based on cite visits and expert advise from Fikiswa Mahote (Mahote, 2005) that 3 out of 4 commerces is a meat vendor. Therefore, the market share of meat vendors can be expressed as follows:

$$s_{mv} = \frac{0.75units_{mv}}{unit_{com}}$$

By inserting n_{ihh}, n_{com} and s_{mv} into equation D.22, we obtain the following value:

$$n_{smv} = 142,983units_{ihh} * \frac{0.05units_{com}}{unit_{ihh}} * \frac{0.75units_{shv}}{unit_{com}} = 5361.86units_{mv}$$

By inserting the results of equation D.21 and D.22 into equation D.20, and assuming a moisture content of w=7% (Wirtgen, 2005), we obtain following result:

$$A = \frac{18.25t}{a * unit_{mv}} * 5361.86units_{mv} * (1.00 - 0.07) = 91,004.17t/a$$

For the energy content, assuming a lower heating value similar to Black Wattle of $17,000 MJ/t$ (CSIR, 1990), we obtain following result:

$$A_e = \frac{18.25t}{a * unit_{mv}} * 5361.86 units_{mv} * 17,000 MJ/t * \frac{1GJ}{1000MJ} = 1,663,517 GJ/a$$

B corresponds to the total amount of fuel wood utilised by sheep head vendors and can be described with the following equation:

$$B = q_{shv} * n_{shv} * w \tag{D.23}$$

B corresponds to cell P8 in Excel worksheet 'SummaryTable', tab 'Meat Vendors' (see figure).

The amount of fuel wood used per sheep head vendor can be calculated according to the following formula:

$$q_{fw,shv} = w_{bfw} * n_{bfw,shv} \tag{D.24}$$

It has been calculated based on Qase (2000, p.45-50), and interviews 1 & 3 (see appendix G.4), that the weight of a bunch of wood planks is approx. $10kg$, therefore, we state that:

$$w_{bfw} = \frac{10kg}{unit_{bfw}}$$

Furthermore, it has been calculated based on the same sources that the amount of units (bunches) of fuel wood used per day and sheep head vendor are approx. 2.3. Therefore:

$$n_{bfw,shv} = \frac{2.3 units_{bfw}}{d * unit_{shv}}$$

By inserting w_{bfw} and $n_{bfw,shv}$ into equation D.24 and converting it to the unit t/a, we obtain the following:

$$q_{fw,shv} = \frac{10kg}{unit_{bfw}} * \frac{2.32 units_{bfw}}{d * unit_{shv}} * \frac{365d}{a} * \frac{1t}{1000kg} = \frac{8.47t}{a * unit_{shv}}$$

The number of cheap head vendors in the study area can be calculated according to equation D.13.

By inserting the results of equation ?? and D.13 into equation D.23, and assuming a moisture content of w=7% (Wirtgen, 2005), we obtain following result:

$$B = \frac{8.47t}{a * unit_{shv}} * 1787.29units_{shv} * (1.00 - 0.07) = 14,087.66t/a$$

For the energy content, assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) of $17,000MJ/t$ (CSIR, 1990), we obtain following result:

$$B_e = \frac{8.47t}{a * unit_{mv}} * 1787.29units_{mv} * 17,000MJ/t * \frac{1GJ}{1000MJ} = 257,351GJ/a$$

By inserting the results for A and B in equation D.18, we obtain the following result:

$$M26 = 91,004.17t/a + 14,087.66t/a = 105,091.83t/a \approx 105,000t/a$$

By inserting the results for A_e and B_e in equation D.19, we obtain the following result:

$$M26_e = 1,663,517GJ/a + 257,351GJ/a = 1,920,868GJ/a \approx 1,921,000GJ/a$$

M30 - Paper Waste going from Pulp & Paper Manufacturing to Thermal Utilisation Formal

$M30$ is the material stream corresponding to the total amount of paper waste going from Pulp & Paper Manufacturing to Thermal Utilisation Formal. $M30$ corresponds to cell I151 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to an interview with a representative of an anonymous paper factory (see figure I.3), a total amount of paper sludge of $6,900t/a$ is produced with a moisture content $w = 60\%$, which is thermally utilised after drying at a later stage. The amount of total solids in sludge can be expressed as follows:

$$M30 = 6,900t/a * (1.00 - 0.60) = 2,760t/a \approx 3,000t/a$$

The energy content will be calculated as follows, assuming a lower heating value for paper for the wood fibre in sludge $H_l = 14,400MJ/t$ (e.g. Masters, 1998):

$$M30_e = 6,900t/a * (1.00 - 0.60) * 14,400MJ/t * \frac{1GJ}{1000MJ}$$
$$= 39,744MJ/a \approx 40,000MJ/a$$

M32 - Paper Waste going from Pulp & Paper Manufacturing to Disposal

$M32$ is the material stream corresponding to the total amount of paper waste going from Pulp & Paper Manufacturing to disposal. $M32$ corresponds to cell I169 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to the Waste Generation Model of Jeffares & Green (2004), a total amount of paper waste of $154,662t/a$ is sent to landfill with a moisture content $w = 10.2\%$. The amount of total dry wood fibre in the waste stream can be expressed as follows:

$$M32 = 154,662t/a * (1.00 - 0.102) = 138,886.48t/a \approx 139,000t/a$$

The energy content of the waste stream can be expressed as follows, assuming a lower heating value for paper $H_l = 14,400MJ/t$ (Masters, 1998):

$$M32_e = 154,662t/a * 14,400MJ/t * \frac{1GJ}{1000MJ} = 2,227,133GJ/a \approx 2,227,000GJ/a$$

M33 - Sewage Sludge going from Waste Water Treatment to Thermal Utilisation Formal

$M33$ is the material stream corresponding to the total amount of sewage sludge going from waste water treatment to thermal utilisation formal. $M33$ corresponds to cell I226 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to an interview with Toll (2005), a total amount of sewage sludge of $6,74t/d$, or $2,453.36t/a$ are being produced with a moisture content $w = 5\%$ (see Figure 3.6). Furthermore, Jarde *et al.* (2003, p.348) states that the wood fibre content in solids of waste water sludge is approx. 25.5%. The amount of total dry wood fibre in sewage sludge can be expressed as follows:

$$M33 = 2,453.36t/a * (1.00 - 0.05) * 0.255 = 594.33t/a \approx 1,000t/a$$

The energy content of the material stream can be expressed as follows, assuming a lower heating value for the dry wood fibre similar to that of SA pine (*Pinus Patula*) $H_l = 20,420MJ/t$ (CSIR, 1990):

$$M33_e = 2,453.36t/a * (1.00 - 0.05) * 0.255 * 20,420MJ/t * \frac{1GJ}{1000MJ} = 12,136GJ/a \approx 12,000GJ/a$$

M34 - Sewage Sludge going from Wastewater Treatment to Disposal

$M34$ is the material stream corresponding to the total amount of sewage sludge going from waste water treatment to disposal. $M34$ corresponds to cell `I207` in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to Jeffares & Green (2004, table 7.8), the total amount of sewage sludge disposed is $53,000t/a$. Given is a moisture content of 80% according to ?. Furthermore, Jarde *et al.* (2003, p.348), states that the wood fibre content in solids of waste water sludge is approx. 25.5%. The amount of total dry wood fibre in sewage sludge can be expressed as follows:

$$M34 = 53,000t/a * (1.00 - 0.80) * 0.255 = 2,703t/a \approx 3,000t/a$$

The energy content of the material stream can be expressed as follows, assuming a lower heating value for the wood fibre similar to that of SA pine (*Pinus Patula*) $H_l = 20,420MJ/t$ (CSIR, 1990):

$$M34_e = 53,000t/a * (1.00 - 0.80) * 0.255 * 20,420MJ/t * \frac{1GJ}{1000MJ} = 55,195GJ/a \approx 55,000GJ/a$$

M36 - Methane going from Wastewater Treatment to Thermal Utilisation Formal

$M36$ is the material stream corresponding to the total amount of methane going from waste water treatment to thermal utilisation formal. $M36$ corresponds to cell `I237` in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F) and subsequently cell `TOT_CH4_USE` in tab 'Wastewater'(see figure F.16).

According to an interview with ?, the total amount of gas produced at the Cape Flats Wastewater Works is $12,000m^3/d$, corresponding to $10,512,000m^3/a$. It is assumed that the density of methane is $\delta_{CH_4} = 0.722kg/m^3$ (Wikipedia, 2006b), and that the average methane content of the gas is $C_{CH_4} = 0.55\%$ (?). Furthermore, assuming that there is 25.5% of wood fibre in the solids of the sewage sludge (Jarde *et al.*, 2003), the total amount of methane in function of the wood fibre can be expressed as follows:

$$M36 = 10,512,000m^3/a * 0.722kg/m^3 * 0.55 * 0.255 * 1t/1000kg = 1064.45t/a \approx 1,000t/a$$

The energy content of the material stream can be expressed as follows, assuming a lower heating value for methane $H_l = 50,000MJ/t$ (e.g. Wikipedia, 2006b):

$$M36_e = 10,512,000m^3/a * 0.722kg/m^3 * 0.55 * 0.255 * 1t/1000kg$$
$$* 50,000MJ/t * \frac{1GJ}{1000MJ} = 53,222GJ/a \approx 53,000GJ/a$$

M37 - Methane going from Wastewater Treatment to Atmosphere

$M37$ is the material stream corresponding to the total amount of methane going from waste water treatment to the atmosphere. $M37$ corresponds to cell I236 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F) and subsequently cell TOT_CH4_REL in tab 'Wastewater' (see figure F.16).

Based on the amount of methane recovered for thermal utilisation at Cape Flats Wastewater Works (see section ??, the amount of methane released to the atmosphere will be calculated for the wastewater treatment schemes at Athlone, Simon's Town and Kraaifontein according to their respective capacity, as their design all include anaerobic digesters without thermal recovery of the gas.

According to CCT (2001), the capacity for Athlone, Simon's Town and Kraaifontein are respectively $C_{AL} = 105Ml/d$, $C_{ST} = 5Ml/d$ and $C_{KF} = 17Ml/d$. Note that Cape Flat's capacity is $C_{CF} = 160Ml/d$.

The amount of methane released to the atmosphere in function of the wood fibre can thus be calculated as follows:

$$M37 = 1064.45t/a * \frac{d}{160Ml} * (\frac{105Ml}{d} + \frac{5Ml}{d} + \frac{17Ml}{d}) = 844.91t/a \approx 1,000t/a$$

The amount of energy bound in this material stream is expressed as follows, assuming a lower heating value for methane $H_l = 50,000MJ/t$ (e.g. Wikipedia, 2006b):

$$M37_e = 1064.45t/a * \frac{d}{160Ml} * (\frac{105Ml}{d} + \frac{5Ml}{d} + \frac{17Ml}{d})$$
$$* 50,000MJ/t * \frac{1GJ}{1000MJ} = 42,245GJ/a \approx 42,000GJ/a$$

M38 - Biomass from Parks & Gardens to Composting Facilities

D. CALCULATION OF WOOD FIBRE BASED MATERIAL STREAMS

$M38$ is the material stream corresponding to the total amount of biomass going from parks & gardens to composting facilities and can be expressed as the average of the values A and B according to the following formula:

$$M38 = \frac{A + B}{2} \quad (D.25)$$

The energy content of the material stream is calculated as follows:

$$M38_e = \frac{A_e + B_e}{2} \quad (D.26)$$

According to Jeffares & Green (2004), a total amount of $30,000t/a$ of green waste goes to composting facilities. Assuming a share of 50% of woody material in the green waste stream[1], and a moisture content $w = 50\%$[2], the amount of wood fibre in green waste can be calculetd as follows:

$$A = 30,000t/a * 0.50 * (1.00 - 0.50) = 7,500t/a$$

A corresponds to cell I124 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Compost Plants' (see figure F.15).

The energy content is calculated assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000MJ/t$ (CSIR, 1990):

$$A_e = 30,000t/a * 0.50 * 17,000MJ/t * \frac{1GJ}{1000MJ} = 255,000GJ/a$$

A_e corresponds to cell K124 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

According to Wright-Pierce (1999), a total amount of $40,950t/a$ of green waste goes to composting facilities. Assuming a share of 80% of green waste in the total amount, a share of 50% of woody material in the green waste stream, and a moisture content $w = 80\%$ (Jeffares & Green, 2004, section 7.5.2), the amount of wood fibre in green waste can be calculetd as follows:

$$B = 40,950t/a * 0.50 * 0.80 * (1.00 - 0.50) = 8,190t/a$$

[1]assumed by author
[2]assumed by author

B corresponds to cell I128 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Compost Plants' (see figure F.15).

The energy content is calculated assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000MJ/t$ (CSIR, 1990):

$$B_e = 40,950t/a * 0.50 * 0.80 * 17,000MJ/t * \frac{1GJ}{1000MJ} = 278,460GJ/a$$

B_e corresponds to cell K128 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F).

By replacing the results for A and B in equation D.25, we can state that:

$$M38 = \frac{7,500t/a + 8,190t/a}{2} = 7,845t/a \approx 8,000t/a$$

By replacing the results for A_e and B_e in equation D.26, we can state that:

$$M38_e = \frac{255,000GJ/a + 278,460GJ/a}{2} = 266,730GJ/a \approx 267,000GJ/a$$

M39 - Biomass from Parks & Gardens going to Disposal

$M39$ is the material stream corresponding to the total amount of biomass going from parks & gardens to disposal and can be expressed according to the following formula:

$$M39 = \frac{C + (D + E + F)}{2} - \frac{A + B}{2} \qquad (D.27)$$

The energy content of the material stream is calculated according to the following equation:

$$M39_e = \frac{C_e + (D_e + E_e + F_e)}{2} - \frac{A_e + B_e}{2} \qquad (D.28)$$

According to Jeffares & Green (2004), a total amount of $114,196t/a$ of green waste is generated in Cape Town consisting of top-up of waste bins, compost plants and drop-off facilities. Assuming a share of 50% of woody material in the green waste stream[1], and a moisture content $w = 50\%$[2], the amount of wood fibre in green waste can be calculetd as follows:

$$C = 114,196t/a * 0.50 * (1.00 - 0.50) = 28,549t/a$$

[1] assumed by author

[2] assumed by author

C corresponds to cell I105 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

Accordingly, the energy content for the material stream can be described as follows, assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000MJ/t$ (CSIR, 1990):

$$C_e = 114,196t/a * 0.50 * 17,000MJ/t * \frac{1GJ}{1000MJ} = 970,666GJ/a$$

C_e corresponds to cell K105 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

According to Wright-Pierce (1999), the amount of industrial garden refuse/building rubble is null, so that we can state:

$$D = 0t/a$$

D corresponds to cell I113 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

Accordingly, the energy content for the material stream can be described as follows, assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000MJ/t$ (CSIR, 1990):

$$D_e = 0GJ/a$$

C_e corresponds to cell K113 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

According to Wright-Pierce (1999), the amount of commercial garden refuse/building rubble is $25,500t/a$, so that we can state, assuming a share of green waste of 50%[1], a share of 50% woody material in the green waste[2] and a moisture content $w = 50\%$ (e.g. Kluttig *et al.*, 1998), that:

$$E = 25,500t/a * 0.50 * 0.50 * (1.00 - 0.50) = 6,375t/a$$

[1] assumed by author

[2] assumed by author

E corresponds to cell I115 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

Accordingly, the energy content for the material stream can be described as follows, assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000 MJ/t$ (CSIR, 1990):

$$E_e = 25,500t/a * 0.50 * 0.50 * 17,000MJ/t * \frac{1GJ}{1000MJ} = 108,375GJ/a$$

E_e corresponds to cell K115 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

According to Wright-Pierce (1999, table 3.10 and Appendix D), the amount of green waste from the low-income , middle-income and high-income sectors are $5,211.18t/a$, $46,455.55t/a$ and $163,968.61t/a$ respectively. Assuming an average share of 5% woody material in the green waste[1] and a moisture content $w = 50\%$ (Kluttig *et al.*, 1998), we can state that:

$$F = (5,211.18t/a + 46,455.55t/a + 163,968.61t/a) * 0.05 * (1.00 - 0.50) = 5,390.88t/a$$

F corresponds to cell I120 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

Accordingly, the energy content for the material stream can be described as follows, assuming a lower heating value similar to Black Wattle (*Acacia Mearnsii*) $H_l = 17,000MJ/t$ (CSIR, 1990):

$$F_e = (5,211.18t/a + 46,455.55t/a + 163,968.61t/a) * 0.05 \\ * 17,000MJ/t * \frac{1GJ}{1000MJ} = 183,290GJ/a$$

F_e corresponds to cell K120 in Excel worksheet 'SummaryTable', tab 'Summary' (see appendix F). Calculations have been made in tab 'Green Waste' (see figure F.14).

[1] assumed by author

By replacing the results for C, D, E and F in equation D.27, acknowledging that the term $\frac{A+B}{2}$ is equal to the amount calculated for $M38$ in section ??, we can state that:

$$M39 = \frac{28,549t/a + (0t/a + 3,187t/a + 5,390.88t/a)}{2} - 7,845t/a$$
$$= 10,718.70t/a \approx 11,000t/a$$

By replacing the results for C_e, D_e, E_e and F_e in equation D.28, acknowledging that the term $\frac{A_e+B_e}{2}$ is equal to the amount calculated for $M38_e$ in section ??, we can state that:

$$M39_e = \frac{970,666GJ/a + (0GJ/a + 108,375GJ/a + 183,290GJ/a)}{2} - 267,000GJ/a$$
$$= 364,165GJ/a \approx 364,000GJ/a$$

S17 - Stock of Construction Wood bound in Informal Constructions

$S17$ corresponding to the total amount of construction wood bound in informal constructions such as shacks and is calculated by multiplying the average weight per shack by the number of informal households.

$$S17 = N_{ihh} * w_s * w \tag{D.29}$$

The number of informal households is given by StatsSA (2001) and is $N_{ihh} = 142,933units_{ihh}$. The average weight of a shack w_s is calculated in the construction wood model (see appendix H), which has been developed based on Boaden (e.g. 1985).

As can be seen in tab 'results', the weight of each wooden material (M1-M10, as defined in tab 'material') has been calculated for each unit option where it has been utilised, as given by column 'Option' in tab 'results'. Each material quantity M_i has been calculated according to the following formula:

$$M_i = \sum_{j=1}^{m} M_iOpt_j * s_j * N \tag{D.30}$$

m is the number of construction unit options including material M_i. M_iOpt_j is the weight of material M_i as found in construction unit option Opt_j and is calculated according to the following formula:

$$M_iOpt_j = \delta_i * l_j * h_j * w_j * q_j \tag{D.31}$$

δ_i is the density of material M_i, l_j is the length of material M_i in option Opt_j, h_j is the height of material M_i in option Opt_j, w_j is the width of material M_i in option Opt_j and q_j is the quantity of material M_i in option Opt_j.

Furthermore, in equation D.30, s_j stands for the share of option Opt_j relative to the other options, as described in tab 'general settings'. N stands for the number of informal households in the study area. In this case, $N = N_{ihh}$.

Eventually, total weight W is calculated as follows:

$$W = \sum_{i=1}^{n} M_i \tag{D.32}$$

Accordingly, total energy content E is calculated as follows:

$$E = \sum_{i=1}^{n} M_i * H_{l,i} \tag{D.33}$$

$H_{l,i}$ represents the lower heating value of the material M_i.

The average weight of wood per informal construction (shack) is calculated according to:

$$w_s = \frac{W}{N} \tag{D.34}$$

In this case, with $N = N_{ihh}$, $w_s = 0.92t/unit_{ihh}$. By replacing N_{ihh} and w_s in equation D.29, assuming a moisture content $w = 7\%$, we get the following:

$$S17 = 142,983units_{ihh} * 0.92t/unit_{ihh} * (1.00 - 0.93) = 122,335.92t \approx 123,000t$$

The average energy content per informal construction (shack) is calculated according to:

$$e_s = \frac{E}{N} \tag{D.35}$$

In this case, with $N = N_{ihh}$, $e_s = 18.45GJ/unit_{ihh}$. Similarly for the energy content, we get:

$$S17_e = 142,983units_{ihh} * 18.45GJ/unit_{ihh} = 2,638,036GJ \approx 2,638,000GJ$$

D. CALCULATION OF WOOD FIBRE BASED MATERIAL STREAMS

Appendix E

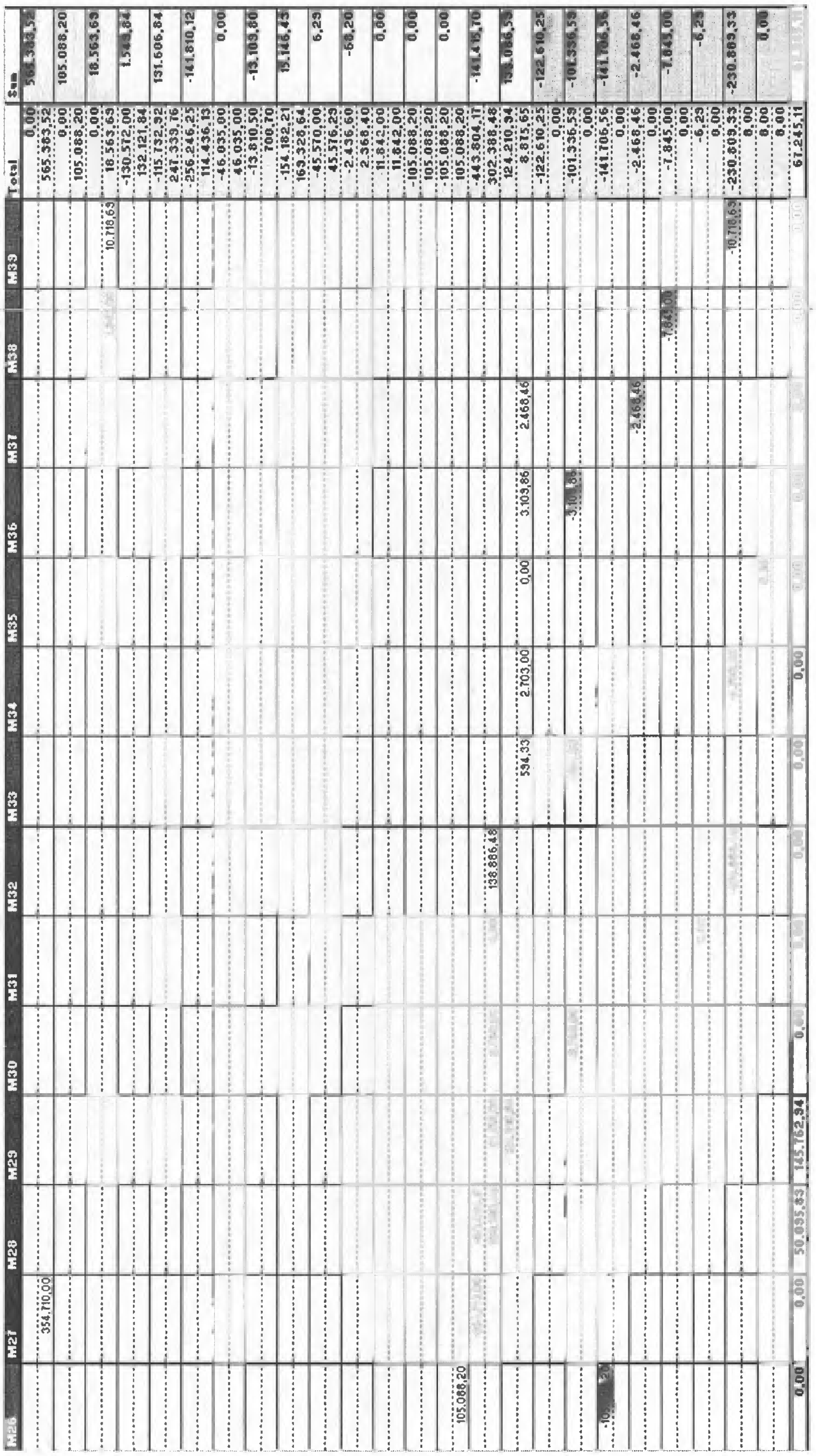
Mass & Energy Balance

			M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
1	Imports	Input											
		Output	90.675,00					64.954,92					
2	Peri-Urban Forests	Input											
		Output											
3	Parks & Gardens	Input											
		Output											
4	Sawmills	Input	-90.675,00		-39.897,00								
		Output		50.778,00	39.897,00	1.549,84	39.897,00						
5	Timber Traders	Input		-50.778,00				-64.954,92					
		Output							224.021,75	23.318,02			
6	Construction Formal	Input							-224.021,75				-32.224,50
		Output									46.035,00	68.401,13	
7	Demolition	Input									-46.035,00		
		Output											32.224,50
8	Second Hand Traders Informal	Input											
		Output											
9	Construction Informal	Input				-1.549,84				-23.318,02			
		Output											
10	Fuel Wood Traders Formal	Input											
		Output											
11	Charcoal Manufacturers Formal	Input											
		Output											
12	Charcoal Traders Formal	Input											
		Output											
13	Fuel Wood Collectors Informal	Input											
		Output											
14	Fuel Wood Traders Informal	Input											
		Output											
15	Pulp & Paper Manufacturing	Input											
		Output											
16	Wastewater Treatment	Input											
		Output											
17	Stock Construction Informal	Input											
		Output											
18	Thermal Utilisation Formal	Input					-39.897,00						
		Output											
19	Thermal Utilisation Informal	Input											
		Output											
20	Athmosphere	Input											
		Output											
21	Composting Facilities	Input											
		Output											
22	Export	Input											
		Output											
23	Disposal	Input										-68.401,13	
		Output											
24	Agriculture	Input											
		Output											
		Total	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure E.1: Mass Balance 1

M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25
					45.570,00					9.473,60			
												105.088,20	
13.810,50													
-13.810,50													
	700,70												
	-129.314,36												
		122.610,25	36.618,36	10.100,03									
					-45.570,00								
						2.436,60	43.133,40	6,29					
						-2.436,60							
									2.368,40				
									-2.368,40	-9.473,60			
											11.842,00		
												-105.088,20	
													105.088,20
													-105.088,20
		-122.610,25											
							-43.133,40				-11.842,00		
			-36.618,36										
								-6,29					
				-10.100,03									
0,00	-128.613,66	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure E.2: Mass Balance 2



M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36	M37	M38	M39	Total	Sum
														0,00	565.383,52
	354.710,00													565.383,52	
														0,00	105.088,20
														105.088,20	
														0,00	18.563,69
												[illegible]	10.718,69	18.563,69	
														-130.572,00	1.549,84
														132.121,84	
														-115.732,92	131.606,84
														247.339,76	
														-256.246,25	-141.810,12
														114.436,13	
														-46.035,00	0,00
														46.035,00	
														-13.810,50	-13.109,80
														700,70	
														-154.182,21	15.146,43
														169.328,64	
														-45.570,00	6,29
														45.576,29	
														-2.436,60	-68,20
														2.368,40	
														11.842,00	0,00
														11.842,00	
														-105.088,20	0,00
														105.088,20	
														-105.088,20	0,00
105.088,20														105.088,20	
	[illegible]	[illegible]												-443.804,17	-141.415,70
		[illegible]	[illegible]	[illegible]	[illegible]	138.886,48								302.388,48	
			[illegible]											124.210,94	133.086,59
							594,33	2.703,00	0,00	3.109,86	2.468,46			8.815,65	
														-122.610,25	-122.610,25
														0,00	
				[illegible]			[illegible]			-3.109,86				-101.336,59	-101.336,59
														0,00	
-105.088,20														-141.706,56	-141.706,56
														0,00	
											-2.468,46			-2.468,46	-2.468,46
														0,00	
												-7.845,00		-7.845,00	-7.845,00
														0,00	
					[illegible]									-6,29	-6,29
														0,00	
						[illegible]		[illegible]					-10.718,69	-230.809,33	-230.809,33
														0,00	
														0,00	0,00
									[illegible]					0,00	
0,00	0,00	50.695,83	145.762,94	0,00	[illegible]	[illegible]	0,00	0,00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.245,11	[illegible]

Figure E.3: Mass Balance 3

			M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
1	Imports	Input											
		Output	1.990.350,00					1.426.214,48					
2	Peri-Urban Forests	Input											
		Output											
3	Parks & Gardens	Input											
		Output											
4	Sawmills	Input	-1.990.350,00		-876.018,00								
		Output		1.114.332,00	876.018,00	34.029,81	876.018,00						
5	Timber Traders	Input		[illegible]				-1.426.214,48					
		Output							4.918.843,09	511.993,47			
6	Construction Formal	Input							-4.918.843,0				-707.553,00
		Output									1.010.790,00	1.501.882,83	
7	Demolition	Input									[illegible]		
		Output											707.553,00
8	Second Hand Traders Informal	Input											
		Output											
9	Construction Informal	Input				-34.029,81				-511.993,47			
		Output											
10	Fuel Wood Traders Formal	Input											
		Output											
11	[illegible]	Input											
		Output											
12	Charcoal Traders Formal	Input											
		Output											
13	Fuel Wood Collectors Informal	Input											
		Output											
14	Fuel Wood Traders Informal	Input											
		Output											
15	Pulp & Paper Manufacturing	Input											
		Output											
16	Wastewater Treatment	Input											
		Output											
17	Stock Construction Informal	Input											
		Output											
18	Thermal Utilisation Formal	Input					-876.018,00						
		Output											
19	Thermal Utilisation Informal	Input											
		Output											
20	Athmosphere	Input											
		Output											
21	Composting Facilities	Input											
		Output											
22	Export	Input											
		Output											
23	Disposal	Input										-1.501.882,83	
		Output											
24	Agriculture	Input											
		Output											
		Total	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure E.4: Energy Balance 1

M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25
					833.000,00					292.640,00			
												1.920.967,03	
303.237,00													
-303.237,00													
	15.385,17												
	-2.839.353,94												
		2.637.719,95	804.028,96	221.766,35									
					-833.000,00								
						44.540,00	788.460,00	106,88					
						-44.540,00							
									73.160,00				
									-73.160,00	-292.640,00			
											365.800,00		
												-1.920.967,03	
													1.920.967,03
													-1.920.967,03
		-2.637.719,95											
							-788.460,00				-365.800,00		
			-804.028,96										
								-106,88					
				221.766,35									
0,00	########	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure E.5: Energy Balance 2

M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36	M37	M38	M39	Total	Sum
														0,00	10.230.804,48
	[illegible]													10.230.804,48	
														0,00	1.920.967,03
														1.920.967,03	
														0,00	631.165,52
												[illegible]	[illegible]	631.165,52	
														-2.866.968,00	34.029,81
														2.900.997,81	
														-2.541.146,48	2.889.690,08
														5.430.836,56	
														-5.626.396,09	-3.113.723,26
														2.512.672,83	
														-1.010.790,00	0,00
														1.010.790,00	
														-303.237,00	-287.851,83
														15.385,17	
														-3.385.377,21	278.138,05
														3.663.515,26	
														-833.000,00	106,88
														833.106,88	
														-44.540,00	28.620,00
														73.160,00	
														-365.800,00	0,00
														365.800,00	
														-1.920.967,03	0,00
														1.920.967,03	
														-1.920.967,03	0,00
1.920.967,03														1.920.967,03	
	[illegible]	[illegible]												-7.116.681,60	-2.272.204,80
		[illegible]	[illegible]	[illegible]	[illegible]	2.227.132,80								4.844.476,80	
			2.536.387,41											2.536.387,41	2.882.634,82
							12.136,15	55.195,26	[illegible]	155.493,24	123.422,74			346.247,41	
														-2.637.719,95	-2.637.719,95
														0,00	
				[illegible]			-12.136,15			-155.493,24				-2.237.651,39	-2.237.651,39
														0,00	
-1.920.967[illegible]														-2.724.995,99	-2.724.995,99
														0,00	
											-123.422,76			-123.422,76	-123.422,76
														0,00	
												[illegible]		-266.730,00	-266.730,00
														0,00	
					0,00									-106,88	-106,88
														0,00	
						[illegible]		-55.195,26					-364.435,52	-4.370.412,76	-4.370.412,76
														0,00	
									0,00					0,00	0,00
														0,00	
0,00	0,00	[illegible]3.318,40	########	0,00	[illegible]	[illegible]	0,00	0,00	[illegible]	[illegible]	0,0[illegible]	0,00	0,00	861.337,05	[illegible]

Figure E.6: Energy Balance 3

E. MASS & ENERGY BALANCE

Appendix F

Summary Table

Summary Table - Case Study Cape Town

Data Sources

APC = Air Pollution Control Database
CTEF = Cape Town Energy Futures
CWM = Construction Wood Model
EFP = Ecological Footprint of Cape Town
FS = Field Study
IWMP = Integrated Waste Management Plan
MTWC = Study on Meat Traders Western Cape
NEC = National Energy Council
SER = State of Energy Report
DT = Diploma Thesis
WESGRO = Western Cape Trade and Investment Promotion Agency
WP = Wright Pierce study

Sector	Sub-Sector	Data Source	Period	User Group	Type	W [%]	Quantity [t/a]	Total Dry Solids [t/a]	Heating Value [MJ/t]	Gross Energy Input [GJ/a]	Energy Used [GJ/a]
Fuel Wood											
	Formal Sector										
		SER (p. 3-1)	2002								
				Domestic							
					Wood	7,0	18.900,00	17.577,00	19.000,00	359.100,00	359.100,00
				Industrial & Commercial							
					Wood	7,0	29.543,00	27.474,99	19.000,00	561.317,00	561.317,00
		SER (p. 5-7)	2002								
				Industrial & Commercial							
					Wood	7,0	3.225,00	2.999,25	19.000,00	61.275,00	61.275,00
					Wood Waste	7,0	26.318,00	24.475,74	19.000,00	500.042,00	500.042,00
		CTEF (p. 13)	2000								
				Industrial							
					Wood	7,0	0,03	0,02	19.000,00	0,50	0,50
		EFP (p. 9, p.12)	1996								
				Domestic							
					Wood	7,0	108.492,00	100.897,56	16.989,27	1.843.200,00	644.400,00
		APC	2005								
				Commercial & Industrial							
					Wood	7,0	1.959,48	1.822,32	19.000,00	37.230,12	37.230,12
					Wood Waste	7,0	26.244,91	24.407,77	19.000,00	498.653,33	498.653,33
		WESGRO	2004								
				Import							
					Wood	7,0	1.060,87	986,61	17.000,00	18.034,82	18.034,82
				Export							
					Wood	7,0	6,29	6,29	17.000,00	106,88	106,88
		NEC	1991								
				Fuel Wood							
					Wood Import	7,0	49.000,00	45.570,00	17.000,00	833.000,00	833.000,00
				Charcoal							
					Wood Import	7,0	2.620,00	2.436,60	17.000,00	44.540,00	44.540,00
					Charcoal Import	4,5	9.920,00	9.473,60	29.500,00	292.640,00	292.640,00
					Charcoal Manufactured CT	4,5	2.480,00	2.368,40	29.500,00	73.160,00	73.160,00
	Informal Sector										
		FS	2005								
				Commercial							
					Wood	7,0	112.998,06	105.088,20	17.000,00	1.920.967,03	1.920.967,03
					Wood Waste	7,0	39.374,58	36.618,36	20.420,00	804.028,96	804.028,96
Structural Wood											
	Construction Sector										
		EFP (p. 9)	1996-1998								
				CT Market							
					Timber Input	7,0	69.844,00	64.954,92	20.420,00	1.426.214,48	1.426.214,48
		FS	2005								
				Sawmills (Cape Sawmills)							
					Timber Input	7,0	97.500,00	90.675,00	20.420,00	1.990.950,00	1.990.950,00

Figure F.1: Summary Table 1

					Timber Output	7,0	54.600,00	50.778,00	20.420,00	1.114.932,00	1.114.932,00
					Timber Recycled	7,0	42.900,00	39.897,00	20.420,00	876.018,00	876.018,00
				Sawmills (General, incl. Cape Sawmills)							
					Timber Formal	7,0	22.885,15	21.283,19	20.420,00	467.314,68	467.314,68
					Timber Informal	7,0	1.666,49	1.549,84	20.420,00	34.029,81	34.029,81
				Traders							
					Timber Formal	7,0	240.883,60	224.021,75	20.420,00	4.918.843,09	4.918.843,09
					Timber Informal	7,0	25.073,14	23.318,02	20.420,00	511.993,47	511.993,47
				Second Hand Market							
					Timber (as in doors, etc.)	7,0	753,44	700,70	20.420,00	15.385,17	15.385,17
				Demolition							
					Timber Formal	7,0	34.650,00	32.224,50	20.420,00	707.553,00	707.553,00
					Timber Informal	7,0	14.850,00	13.810,50	20.420,00	303.237,00	303.237,00
				Wendy Houses/Shacks							
					Timber	7,0	139.047,70	129.314,36	20.420,00	2.839.353,94	2.839.353,94
	Landfill										
		IWMP	2002/2003								
		p. 4-6		Builder's rubble			318.392,00	318.392,00			
					Wood Waste	7,0	15.919,60	14.805,23	20.420,00	325.078,23	325.078,23
		p. 8-34		Builder's rubble			240.000,00	240.000,00			
					Wood Waste	7,0	12.000,00	11.160,00	20.420,00	245.040,00	245.040,00
				Hazardous waste							
		p. 10-58			CCA sludges	90,0	9,00	0,90			
					Timber sludges	90,0	4,00	0,40			
		WP									
		p. 3-21	1998	Domestic & Commercial							
					Wood (LI)	7,0	10.860,25	10.100,03	20.420,00	221.766,35	221.766,35
					Wood (MI)	7,0	0,00		20.420,00	0,00	0,00
					Wood (HI)	7,0	22.679,75	21.092,17	20.420,00	463.120,45	463.120,45
					Timber waste Total	7,0	33.540,00	31.192,20	20.420,00	684.886,80	684.886,80
			2030	Domestic & Commercial							
					Timber waste	7,0	57.720,00	53.679,60	20.420,00	1.178.642,40	1.178.642,40
	Bound in Construction										
		CWM	2005								
				Informal Dwellings							
					Timber	7,0	131.838,96	122.610,25		2.637.719,95	2.637.719,95
Woody Biomass											
	Generation										
		IWMP	2002/2003								
				Green Waste							
					Wood Total	50,0	57.098,00	28.549,00	17.000,00	970.666,00	970.666,00
				Organic Waste							
					Wood (Lo Inc)	50,0	11.269,80	5.634,90	17.000,00	191.586,60	191.586,60
					Wood (Mi Inc)	50,0	4.931,70	2.465,85	17.000,00	83.838,90	83.838,90
					Wood (Hi Inc)	50,0	3.702,25	1.851,13	17.000,00	62.938,25	62.938,25
					Wood Total	50,0	19.903,70	9.951,85	17.000,00	338.362,90	338.362,90
		WP	1998								
		p. 3-10		Green Waste (Industrial)							
					Wood	50,0	0,00	0,00	17.000,00	0,00	0,00
				Green Waste (Commercial)							
					Wood	50,0	6.375,00	3.187,50	17.000,00	108.375,00	108.375,00
				Green Waste (Domestic)							
					Wood (Lo Inc)	50,0	260,56	130,28	17.000,00	4.429,50	4.429,50
					Wood (Mi Inc)	50,0	2.322,78	1.161,39	17.000,00	39.487,22	39.487,22
					Wood (Hi Inc)	50,0	8.198,43	4.099,22	17.000,00	139.373,32	139.373,32
					Wood Total	50,0	10.781,77	5.390,88	17.000,00	183.290,04	183.290,04
	Disposal/Recycling										
		IWMP	2002/2003								
				Compost Plants							
					Wood Input	50,0	15.000,00	7.500,00	17.000,00	255.000,00	255.000,00
					Wood Output	50,0	11.283,75	5.641,88	17.000,00	191.823,75	191.823,75
		WP	1998								
		p. 3-2		Compost Plants							
					Wood Input	50,0	16.380,00	8.190,00	17.000,00	278.460,00	278.460,00
		DT	1998								
				Organic Waste							
					Wood	50,0	18.876,00	9.438,00	17.000,00	320.892,00	320.892,00
Pulp, Paper and Cardboard											
	Paper Sector										
		EFP	1996/1998								

Figure F.2: Summary Table 2

				Input CT market							
					Paper	10,2	335.000,00	354.710,00	14.400,00	5.688.000,00	5.688.000,00
		FS	2005								
				Sappi Cape Craft							
					Paper Input (100% sec fibre)	10,2	68.614,00	61.615,37	14.400,00	988.041,60	988.041,60
					Paper Output	10,2	42.380,00	38.057,24	14.400,00	610.272,00	610.272,00
					Sludge (Compactors)	0,0	2.912,00	2.912,00	14.400,00	41.932,80	41.932,80
					Sludge (Sand)	0,0	130,00	130,00	14.400,00	1.872,00	1.872,00
					Sludge (Centrifuge)	0,0	3.057,60	3.057,60	14.400,00	44.029,44	44.029,44
					Effluents	0,0	20.134,40	20.134,40	14.400,00	289.935,36	289.935,36
				NAMPAK Tissue							
					Paper Input (virg fibre)	10,2	300,00	269,40	14.400,00	4.320,00	4.320,00
					Paper Input (sec fibre)	10,2	30.600,00	27.478,80	14.400,00	440.640,00	440.640,00
					Paper Output	10,2	24.000,00	21.552,00	14.400,00	345.600,00	345.600,00
					Sludge Total	60,0	6.900,00	2.760,00	14.400,00	99.360,00	99.360,00
					Sludge Solids	0,0	2.760,00	2.760,00	14.400,00	39.744,00	39.744,00
				NAMPAK Sacs							
					Paper Input	10,2	3.106,00	2.789,19	14.400,00	44.726,40	44.726,40
					Paper Output	10,2	2.799,00	2.513,50	14.400,00	40.305,60	40.305,60
					Paper Waste Total	10,2	307,00	275,69	14.400,00	4.420,80	4.420,80
					Paper Waste (SMX)	10,2	83,20	74,71	14.400,00	1.198,04	1.198,04
					Paper Waste (CMW)	10,2	148,28	133,16	14.400,00	2.135,25	2.135,25
					Paper Waste (K1)	10,2	39,91	35,84	14.400,00	574,70	574,70
					Paper Waste (K4)	10,2	3.192,80	2.867,13	14.400,00	45.976,32	45.976,32
					Paper Waste (Other)	10,2	19,96	17,92	14.400,00	287,35	287,35
				NAMPAK Redibox							
					Paper Waste	10,2	162,86	146,25	14.400,00	2.345,18	2.345,18
	Waste Generation							0,00			
		IWMP	2002/2003					0,00			
				Waste				0,00			
		(Waste Gen Model)			Paper (LI)	10,2	63.836,00	57.324,73	14.400,00	919.238,48	919.238,48
					Paper (MI)	10,2	57.706,00	51.819,39	14.400,00	830.966,40	830.966,40
					Paper (HI)	10,2	33.120,08	29.741,76	14.400,00	476.928,00	476.928,00
					Paper Total	18,2	154.662,00	138.886,48	14.400,00	2.227.132,80	2.227.132,80
	Waste Disposal/Recycling										
		IWMP	2002/2003								
				Recycling							
					Paper (SAPPI)	10,2	78.000,00	70.044,00	14.400,00	1.123.200,00	1.123.200,00
					Paper (MONDI)	10,2	65.000,00	58.378,80	14.400,00	936.000,00	936.000,00
					Paper (Nampak)	10,2	35.000,00	31.430,00	14.400,00	504.000,00	504.000,80
					Paper (Rest)	10,2	12.000,00	10.776,80	14.400,00	172.800,00	172.800,00
		(Bergman Ingérop)	2002		Paper Total	10,2	190.000,00	178.620,80	14.400,00	2.736.000,00	2.736.000,00
		IWMP	2002/2003	Hazardous Waste							
		p. 10-58			Aqueous Effluent Sludge	90,0	40,00	4,00			
					Laboratory Effluent	90,0	0,10	0,01			
		WP	1998								
				Recycling							
			1998		Paper Total	10,2	120.000,00	107.760,00	14.400,00	1.728.080,00	1.728.000,00
			1998		Paper (Industrial)	10,2	93.600,00	84.052,80	14.400,08	1.347.840,00	1.347.840,00
			2010		Paper (Industrial)	10,2	122.720,00	110.202,56	14.400,08	1.767.168,00	1.767.168,00
			2028		Paper (Industrial)	10,2	139.620,00	125.378,16	14.400,00	2.010.528,00	2.010.528,00
			2030		Paper (Industrial)	10,2	146.120,00	131.215,76	14.400,00	2.104.128,00	2.104.128,00
			1998		Paper (Com & Ind)	10,2	26.780,00	24.048,44	14.400,00	385.632,00	385.632,00
			2810		Paper (Com & Ind)	10,2	69.160,00	62.105,68	14.400,00	995.904,00	995.904,00
			2820		Paper (Com & Ind)	10,2	126.880,00	113.938,24	14.400,00	1.827.072,00	1.827.072,80
			2030		Paper (Com & Ind)	10,2	183.040,00	164.369,92	14.400,00	2.635.776,00	2.635.776,00
Sewage Sludge											
	Generation										
		WP	1998								
		p. 3-3		Wastewater treatment plant sludge		80,0	245.206,00	49.041,20			
					Wood fibre	0,0	12.505,51	12.505,51	20.420,00	255.362,43	255.362,43
		p. 3-14	1997	Wet sludge		80,0	245.208,08	49.840,08	20.420,00	5.006.984,00	5.006.984,00
				Dry sludge		0,0	53.700,08	53.700,08	28.420,00	1.096.554,00	1.096.554,80
					Wood fibre	0,0	2.685,08	2.685,00	20.420,00	54.827,70	54.827,78
		FS	2005								
				Methane Generated							
					Wood fibre	0,0	51.660,00	51.660,00	50.000,08	2.583.000,00	2.583.808,00
	Disposal/Recycling										
		IWMP	2002/2003								
		Table 7.8		Wastewater sludge (Hz W - Disposed)		80,0	53.000,00	10.600,00			
					Wood fibre	0,0	2.703,00	2.703,00	20.420,00	55.195,26	55.195,26

Figure F.3: Summary Table 3

		p. 10-58		Wastewater sludge (Hz W - Disposed)		80,0	130.000,00	26.000,00			
					Wood fibre	0,0	6.630,00	6.630,00	20.420,00	135.384,60	135.384,60
				Water treatment sludge (Hz W - Disposed)		80,0	24.000,00	4.800,00			
					Wood fibre	0,0	1.224,00	1.224,00	20.420,00	24.994,08	24.994,08
		WP	1998								
		p. 3-3		Wastewater treatment sludge (Recycled)		80,0	59.000,00	11.800,00			
					Wood fibre	0,0	3.009,00	3.009,00	20.420,00	61.443,78	61.443,78
		FS	2005								
				Methane Recovered							
					Wood fibre	0,0	28.800,00	28.800,00	50.000,00	1.440.000,00	1.440.000,00
	Treatment										
		FS	2005								
				Cape Flats Wastewater Works							
					Sludge (Total)	80,0	14.560,00	2.912,00			
					Wood fibre	0,0	742,56	742,56	20.420,00	15.163,08	15.163,08
					Cake	80,0	2.912,00	582,40			
					Wood fibre	0,0	148,51	148,51	20.420,00	3.032,62	3.032,62
					Pellets	5,0	2.453,36	2.330,69			
					Wood fibre	0,0	594,33	594,33	20.420,00	12.136,15	12.136,15
					Screenings (Total)	20,0	1.460,00	1.168,00			
					Wood fibre	0,0	297,84	297,84	20.420,00	6.081,89	6.081,89
				All							
					Sludge (Total)	0,0	481.889,29	481.889,29			
					Wood fibre	0,0	122.881,77	122.881,77	20.420,00	2.509.245,72	2.509.245,72
					Screenings (Total)	0,0	5.212,44	5.212,44			
					Wood fibre	0,0	1.329,17	1.329,17	20.420,00	27.141,70	27.141,70
				Methane							
					CH4 produced	25,5	7.487,68	5.578,32	50.000,00	278.916,00	278.916,00
					CH4 Released	25,5	3.313,36	2.468,46	50.000,00	123.422,76	123.422,76
					CH4 Used	25,5	4.174,32	3.109,86	50.000,00	155.493,24	155.493,24

Figure F.4: Summary Table 4

Type	Heating Value [MJ/t]	Density [kg/m³]	Moisture Content Wet [%]	Moisture Content Dry [%]	Wood Fibre in Solids [%]
SA Pine	20.420,00	450	50,00	7,0	
Black Wattle	17.000,00	500	50,00	7,0	
Paper (mixed)	14.400,00			10,2	
Sludge (paper manufacturing)			90,00		55,5
Sludge (General)			90,00		
Wastewater sludge			96,00	80,0	25,5
Sewage sludge pellets	18.000,00			5,0	25,5
Sewage Sludge Screenings	15.000,00	800	80,00	20,0	50,0
Organic waste (mixed food waste)	3.400,00			72,0	
Green waste (mixed green yard waste)	4.300,00			62,0	
Methane	50.000,00	0,722			
Charcoal	29.500,00			4,5	

WESGRO	Gross Geographic Product 2004	
CT share WC	Manufacturing	76,2%
	Wholesale & Retail Trade	79,3%

Yellow Pages		
Name	**YP Name**	**# of Companies**
Sawmills	Sawmills	5
Traders	Timber Merchants	52
Demolition	Demolition Contractors	11

Figure F.5: Constants

	User Group	Type	W [%]	Heating Value [MJ/t]
	Meat Vendor			
		Fuel wood	7,0	17.000,00
	Sheep Head Vendors			
		Fuel wood	7,0	17.000,00
		Planks	7,0	20.420,00

# of bunches [#/d]	Weight [kg/bunch]	Quantity [t/a]	Gross Energy Input [GJ/a]	Market Share [%]	Total Av. Quantity f(Market Share) [t/a]
				75,0	
5,0	10,0	18,25	310,25		13,7
				25,0	
2,3	10,0	8,47	144,04		2,1
6,0	10,0	22,03	449,86		5,5

Total Av. Energy f(Market Share) [GJ/a]	# of Commerces per informal Household	# of informal Households (CT)	Total Quantity [t/a]	Gross Energy Input [GJ/a]
	0,05	142983		
232,69			97.853,99	1.663.517,84
36,01			15.144,07	257.449,19
112,46			39.374,58	804.028,96
381,16			**152.372,64**	**2.724.995,99**

Figure F.6: Meat Vendors

F. SUMMARY TABLE

Table 1: Cape Town (Import and Export) Fuel wood and waste wood		
Year	Total Import	Total Export
1995	260376	9751
1996	410166	66236
1997	1073976	145539
1998	744532	54414
1999	744107	165234
2000	283770	836048
2001	613036	1674
2002	874713	2987
2003	1742078	377856
2004	1060872	6287
It is assumed that main purpose here is overall fuel wood		
It is furthermore assumed that price per t of fuel wood is SAR 1000.-		

Figure F.7: WESGRO

Name	Production [m^3/mo]	Production [t/a]	Sales to WC [%]	Sales CT [t/a]	Formal Market Share [%]
Cape Sawmills	3500	18.900,00	90,0%	12.961,62	100,0
Agrico	250	1.350,00	100,0%	1.028,70	10,0
Stander Houtdienste	225	1.215,00	80,0%	740,66	90,0
Total				**14.730,98**	
Total CT				**24.551,64**	

Formal Market [t/a]	Informal Market [t/a]	Share of CT market [%]
12.961,62	0,00	60,0%
102,87	925,83	
666,60	74,07	
13.731,09	**999,90**	
22.885,15	**1.666,49**	

Figure F.8: Sawmills

Name	Sales [items/w]	weight per item [kg/item]	Sales [t/a]	Share of CT market [%]
Thembinkosi (7)	6	24,15	7,53	1,0
Total			**7,53**	
Total CT			**753,44**	

Figure F.9: Second Hand Market

Name	Sales [items/w]	weight per item [kg/item]	Sales [t/a]	Share of CT market [%]
Lundi (5)	7	922,07	335,63	1,0
Andy (6)	15	922,07	719,21	
Naftali (Wallacedene)	7	922,07	335,63	
Total			**1.390,48**	
Total CT			**139.047,70**	

Figure F.10: Shack Construction

DT			
Name	Amount [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]
Organic Waste (Generated)	377.520,00	5,0	18.876,00
Organic Waste (Disposed)	377.520,00	5,0	18.876,00

Figure F.11: Organic Waste

Name	Sales [m³/mo]	Sales [t/a]	Sales WC [%]	Sales CT [t/a]	Formal Market Share [%]	Formal Market [t/a]	Informal Market [t/a]	Share of CT market [%]
HM Timbers	4000	21.600,00	100,0%	17.128,80	100,0	17.128,80	0,00	15,4%
Great Brak Sawmill	500	2.700,00	100,0%	2.141,10	100,0	2.141,10	0,00	
Woodtraders	2150	11.610,00	90,0%	8.286,06	100,0	8.286,06	0,00	
Jarah Supplies	50	270,00	80,0%	171,29	100,0	171,29	0,00	
Airton Timbers	100	540,00	80,0%	342,58	99,0	339,15	3,43	
Cape Timber & Mouldings cc	3000	16.200,00	100,0%	12.846,60	70,0	8.992,62	3.853,98	
DRC Timber	200	1.080,00	100,0%	856,44	100,0	856,44	0,00	
Timber Turf	30	162,00	100,0%	128,47	100,0	128,47	0,00	
Total				**40.916,42**		**37.059,02**	**3.857,41**	
Total CT				**265.956,74**		**240.883,60**	**25.073,14**	

Figure F.12: Traders

Name	Sales [m³/w]	Density [kg/m³]	Sales WC [%]	Sales [t/a]	Formal Market Share [%]	Formal Market [t/a]	Informal Market [t/a]	Share of CT market [%]	
Ross Demolition	10	450,00	100,0%	4.500,00	70,0	3.150,00	1.350,00	9,1%	
Total				**4.500,00**		**3.150,00**	**1.350,00**		
Total CT				**49.500,00**		**34.650,00**	**14.850,00**		

Figure F.13: Demolition

IWMP

Name	Amount [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]				
Green waste	114.196,00	50,0	57.098,00				
			57.098,00				

WP

Name	Total input [t/a]	Share of Green Waste [%]	Total Green Waste [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]		
Garden Refuse/Building Rubble (Industrial)	0,00	50,0	0,00	50,0	0,00		
Garden Refuse/Building Rubble (Commercial)	25.500,00	50,0	12.750,00	50,0	6.375,00		

Name	Amount [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]			Income Area	Organics share from Total Waste [%]
Garden Waste (LI)	5.211,18	5,0	260,56			High Income	33,35
Garden Waste (MI)	46.455,55	5,0	2.322,78			Middle Income	15,51
Garden Waste (HI)	163.968,61	5,0	8.198,43			Low Income	5,1
Garden Waste (Domestic - Total)	215.635,34	5,0	10.781,77				

Figure F.14: Green Waste

IWMP

Name	Total Green input [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]		
Green Waste to Compost	30.000,00	50,0	15.000,00		

Name	Total output [t/a]	Amount derived from green waste [%]	Total garden waste [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]
Compost (Main)	150.000,00	15,0	22.500,00	50,0	11.250,00
Compost (Small)	450,00	15,0	67,50	50,0	33,75
					11.283,75

WP

Name	Total input [t/a]	Share of Green Waste [%]	Total Green Waste [t/a]	Share of Woody Material [%]	Amount of Woody Material [t/a]
Total Amount to Compost	40.950,00	80,0	32.760,00	50,0	16.380,00

Figure F.15: Compost Plants

Info on methane gas from 20 Waste Water Treatment Plants in CT

SUMMARY OF THE FINDINGS

Plant	Name	Status	Orig. Capacity [Ml/d]	Interviewee	Phone number	Process type	Obtained capacity [Ml/d]	Methane [m³/d]	Sludge Density [kg/m³]	Sludge [t/d]	Water content [%]	Solids [t/d]		Screenings [t/d]	Screenings [t/Ml]
	NORTHERN AREA														
1	Athlone	Done	120,00	Mr J Bruiners	021 6841066	anaerobic-dry sludge	[illegible]	18.900,00	898,18	50,00	80,0	10,[illegible]			
2	Potsdam	Done	32,00	Mr DW Sindle	021 5572226	earobic-wet slud_e	35,[illegible]	--	[illegible]	[illegible]71,85	80,0	14,37			
3	[illegible]	Done	[illegible]	[illegible]	[illegible]	earobic-dry slud_e	0,10	--	662,20	[illegible]	10,0	0,35			
4	Melkbosstrand	Done	2,50	Mr [illegible]	021 5532484	earobic-dry slud_e	2,90	--	662,20	[illegible]	10,0	117,41			
5	Wesfleur	Done	14,00	Mr S van Oerburg	021 5772411	earobic-dry slud_e	10,00	--	662,20	39,25	10,0	35,32			
6	Llandudno	Done	10,50	[illegible]	[illegible]	earobic-dry slud_e	10,50	--	662,20	1,96	10,0	1,77			
7	Oudekraal	Done	0,03	[illegible]	[illegible]	earobic-dry slud_e	0,03	--	662,20	0,12	10,0	0,11			
	SOUTHERN AREA														
8	Cape Flat	Done	200,[illegible]	Mr [illegible]	[illegible]	anaerobic-dry sludge	160,[illegible]	[illegible]	898,18	[illegible]	80,0	2,95		4,00	[illegible]
9	Mitchells Plain	Done	37,50	Mr RG Amos	021 3925116	earobic-wet sludge	32,00	--	969,77	1.2[illegible]	94,5	68,27			
10	WildevoelVlei	Done	14,00	Mr Thom_son	021 7831018	earobic-wet sludge	14,00	--	926,48	[illegible]	86,0	116,74			
11	Simon's Town	Done	5,00	Mr trom_	021 78[illegible]182	anaerobic-dry sludge	5,00	800,00	662,20	11,69	10,0	10,52			
12	Miller's Point	Done	0,[illegible]	[illegible]	[illegible]	anaerobic-dry sludge	0,03	--	662,20	0,12	10,0	0,11			
13	Macassar	not done	34,00	Mr P Lodewyks	021 8572100	earobic-wet sludge	34,00	--	898,18	1.221,53	80,0	244,31			
14	Zandvliet	Done	[illegible]55,[illegible]	[illegible]	[illegible]	[illegible]	55,00	--	662,[illegible]	215,8[illegible]	10,0	194,28			
	EASTERN AREA														
15	Borcherd's Quarry	Done	30,00	Mr Dreyer	[illegible]	earobic-dry sludge	35,00	--	[illegible]	140,00	10,0	[illegible]			
16	Bellville	Done	46,00	Mr [illegible]	[illegible]	earobic-wet sludge	[illegible],00	--	916,[illegible]	[illegible]	84,0	[illegible]			
17	Kraaifontein	Done	7,00	Mr K Bur_er	[illegible]	anaerobic-wet sludge	17,[illegible]	3.060,00	936,3[illegible]	56,18	88,0	[illegible]			
18	Parow	Done	1,2[illegible]	[illegible]	[illegible]	earobic-dry sludge	1,[illegible]	--	662,[illegible]	4,71	10,0	4,24			
19	Scottsdene	Done	4,5[illegible]	Dalie	021 [illegible]	earobic-dry sludge	10,[illegible]	--	650,00	38,53	5,0	36,60			
20	Gordon's Bay	Done	3,50	Mr J Basson	[illegible]	earobic-wet sludge	2,40	--	980,55	[illegible]	96,5	3,43			
Total			606,86				579,16	51.660,00		6.371,02		1.338,58		14,479	
								18.855.900,00 m³/a		2.293.568,71 t/a		481.889,29 t/a		5.212,44 t/a	
								13.613,96 t/a							
							av CH4 Cont	55,0 %							
							m(CH4)	7.487,68 t/a							
	Dry Sludge density	638	kg/m3												
	Density of pellets	650	kg/m3												
Formula u	Density of water	1000	kg/m3				CH4 Rel								
								8.343.900,00 m³/a							
								6.024,30 t/a							
							av CH4 Cont	55,0 %							
							m(CH4)	3.313,36 t/a							
where;															
x_s															
x_w															
p_s							CH4 Use								
p_w	mass fraction of solids							10.512.000,00 m³/a							
	mass fraction of water							7.589,66 t/a							
	density of solids						av CH4 Cont	55,0 %							
	density of water						m(CH4)	4.174,32 t/a							

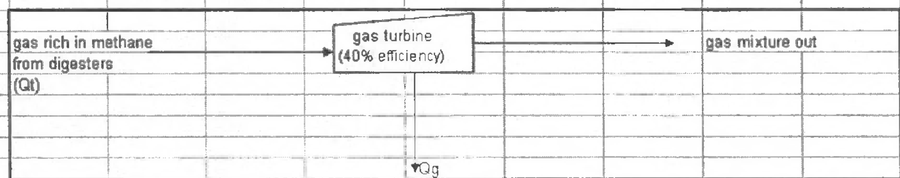
$$\rho\_slurry := \frac{1}{\left(\frac{x\_s}{\rho\_s} + \frac{x\_w}{\rho\_w}\right)}$$

Figure F.16: Wastewater

ELECTRIC ENERGY GENERATION

gas mixture from digesters=	1200	m3/h		
methane fraction=	45	% by vol		
methane inflow (F_{CH4})=	540	m3/h	389,88	kg/h
Methane Gas Properties				
density (ρ)	0,722	kg/m3		
Calorific Value (C.V)	50000	kJ/kg		
Energy Calculations				
Inlet Total Energy (Qt) =	F_{CH4} * ρ * C.V			
=	19494000	kJ/h		
=	19494	MJ/h		
=	5,415	MWh/h		
Energy Generated (Qg) =	η * Qt	...............where η is the turbine efficiency of 40%		
=	2,166	MWh/h		

gas mixture fi	1200	m3/h		
methane fraction=	65	% by vol		
methane inflow (F_{CH4})=	780	m3/h	563,16	kg/h
Methane Gas Properties				
density (ρ)	0,722	kg/m3		
Calorific Valu	50000	kJ/kg		
Energy Calculations				
Inlet Total En	F_{CH4} * ρ * C.V			
	28158000	kJ/h		
	28158	MJ/h		
	7,82166667	MWh/h		
Energy Gene	η * Qt	...............where η is the turbine efficiency of 40%		
	3,12866667	MWh/h		



av. Methane production	6,62	MWh/h
av. Energy generated	2,65	MWh/h

Figure F.17: Methane

F. SUMMARY TABLE

Appendix G

Interviews

Questionnaire

How important is wood in your daily live?

Zibaluleke kangakanani iinkuni kubomi bakho bemihla ngemihla?

Dear Citizen,
Botani Bahlali,

The purpose of this questionnaire is to find out how important wood is in your daily lives.
Iinjongo zalemibuzo kukufuna ukufumana ukuba zibaluleke kangakanani na iinkuni kubomi bakho bemihla le.

It is known that wood is utilised for cooking and heating, and that it plays an important role as construction material in your homes and businesses.
Siyazi ukuba iinkuni niyazisebenzisa ekuphekeni nasekufudumezeni indawo, kwaye ke zidlala indima ebalulekileyo kakhulu njengesixhobo zokwakha nakwishishini.

What the University of Cape Town wants to find out now is how the wood market operates in your community.
Eyona nto esifuna ukuyazi kukuba ingaba olu shishino lwee nkuni lusebenza ekuhlaleni?

The outcome of this research will help to:
Le ngxelo iyakusinceda ukuba si:

- Identify the importance of wood regarding income generation and job creation in your community
- *Kwazi ukuba sichaze ukuba iinkuni zinceda njani ekungeniseni umvuzo nase kwakheni or ekuvuleni amathuba emisebenzi apha ekuhlaleni.*

- Come up with alternatives of using wood, especially regarding recycling options, which will result in additional job creation opportunities
- *Nasekuthini sizame ukuba size nendlela ezizezinye zokuphuculan indlela ekusetyenziswa ngay inkuni, ngakumbi indlela esinokwenza ngayo irecycling enokuthi yenze amathuba emisebenzi awongezelelekileyo.*

- Identify what health impacts the utilisation of wood has, and how negative health impacts can be diminished in order to improve the environment in which you live
- *Singatsho sikwazi ukuphawula sifumanise ukuba zigulo zini na ezithi zibangelwe kukusebenziswa kwenkuni namalahle , kwaye zingayingozi kanjani kwimpilo yethu, kungezwa njani ukuze kuzanywe ukuphucula le meko yokuhlala esiphila kuyo.*

1

Figure G.1: Questionnaire 1

You can help us in achieving these goals by answering the following questions:
Singavuya ukuba ninokusinceda niphendule le mibuzo ingezantsi ukuze sikwazi ukufezekisa iminqweno yethu ngale research:

1. Where is wood collected?

2. What type of wood is collected?[1]

3. Who collects wood?

4. How is wood collected and transported?

5. Who sells wood?

6. What is the price of wood?

7. Who buys wood?[2]

[1] Tree cuttings, branches, planks, panels, poles, doors, windows, frames, boxes, etc.
[2] Private households, restaurants, building contractors, traders, etc.

2

Figure G.2: Questionnaire 2

8. What is wood utilised for?[3]

[3] Energy: cooking, heating, braaing, etc.; Construction: roofs, ceilings, side walls, doors, windows, floors, fences, etc.; Furniture: tables, chairs, cupboards, beds, shelves, etc.

3

Figure G.3: Questionnaire 3

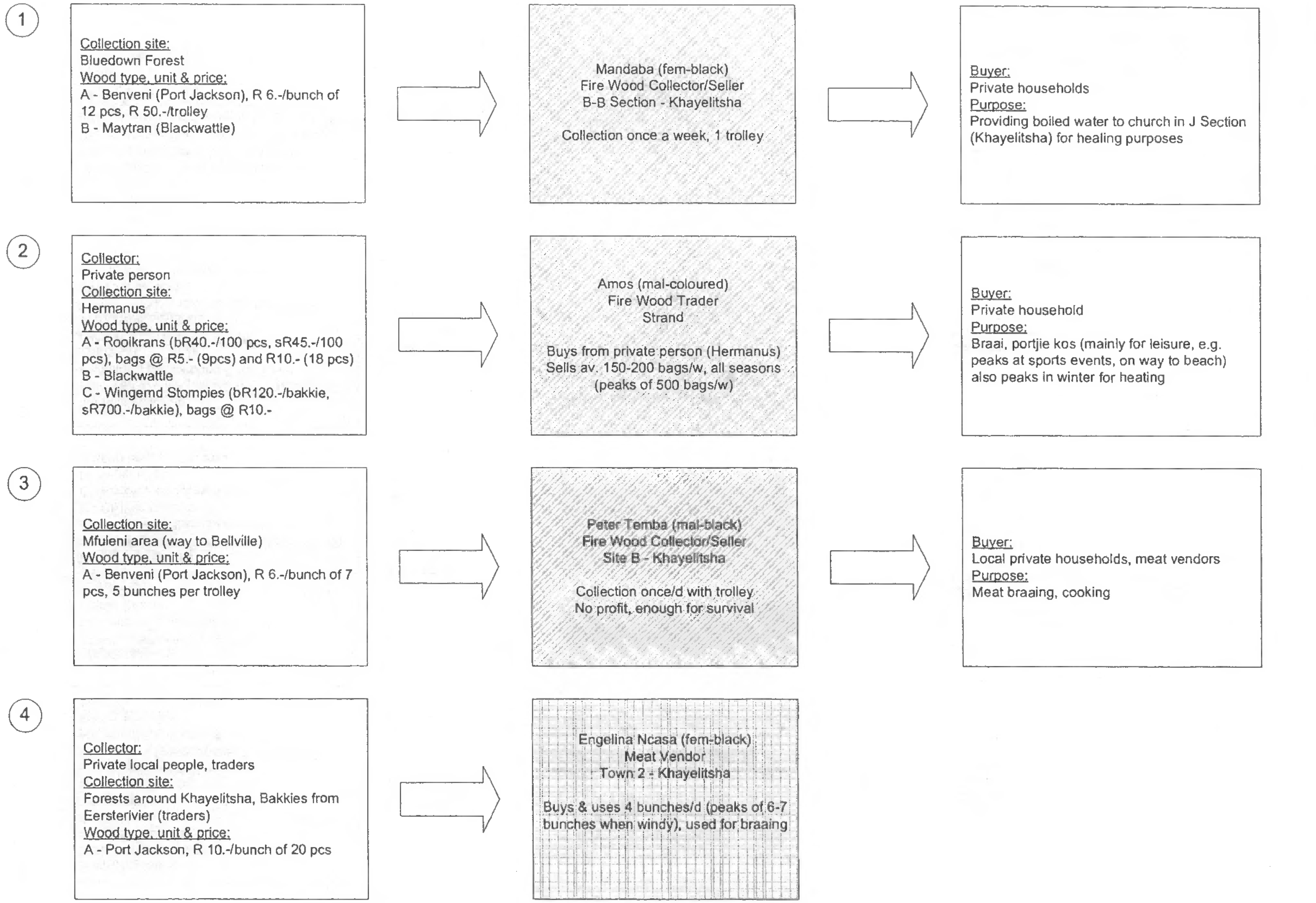


Figure G.4: Interviews 1-4

5

Wood suppliers:
Blackheath (Madala, African Timber)
Somerset Top Timber
Franschoek
Transport:
R150.- per go
Wood type, unit & price:
Rusty pine (19mm, 25mm) 3 m long, ca. R7.-/m, discount on bulk
Price per house:
R 3500,-/house (3m*5m)

→ Lundi Mguli (mal-black)
Shack Construction
New Way - Khayelitsha

Sells 6-7 (business) bungalows/mo (peaks of 9-10/mo), mainly zinc or mainly wood (wood is more expensive)

→ Customers:
Private people and businesses from Khayelitsha, Gugulethu, Langa, Houtbay, Stellenbosch, Fischhoek

6

Wood suppliers:
Blackheath (Agrico, Stander)
Lansdowne (Cape Timbers)
Phillipi (Bossof)
Transport:
own bakkie
Wood type, unit & price:
A - Walls: Pine (102*12*300) , R4.80 (2002), R7.-/m (2005), discount on bulk
B - Ceiling: rhinoboard
C - Roofing: corrugated iron
Price per house:
R 5500,-/house (3m*6m)

→ Andy (mal-coloured)
Wendy House Constructor
Blackheath

Sells 15 wendy houses/mo
(life span 7-8 years)
transport of house on truck ca. R 200.-

→ Customers:
Private people blackheath and surroundings

Wood becomes scarce, wood price rises, shift of clientele to richer people

7

Material suppliers:
Ross Demolotion (Lansdowne, Brackenfell)
Demolition sites around Cape Town
Transport:
own backie, truck hire R 300.-
Wood type, unit & price:
Doors, windows and frames, furniture, R 50.–R 150.-/item
(wood poles from Ross Demolition too expensive (ca. R 18.-/m))

→ Thembinkosi Mpokwana (mal-black)
Second Hand Construction Materials Trader
Khayelitsha

Sells about 6 items/w at R 50.- to R 150.-; total of ca. R 2000.-/mo

→ Customers:
Private people end businesses for house construction

8

She bought it 10 years ago and moved all ready 4 times from site to site with it. Problem with coloured people is that they are too rich for PHP housing program, and too poor for getting a loan from bank for constructing own house.
Price:
R 7000.-/house (1995)

→ Hillary (fem-coloured)
Wendy House Owner
Blackheath

Legend: End-user | Supplier

Evaluation of Survey
Khayelitsha 16.4.05

Figure G.5: Interviews 5-8

Company Name:	Stander Houtdienste
Sawmill/Trader?	sawmill
Tel Number:	021 905 4331
Attendent?	Blackheath
0. Where/How do you get untreated wood?	They have their own plantations all over WC
1. What is quality of wood?	They sell sawn,wetted,untreated SA pine (in planks ; poles & boards)
2. Moisture content (%)?	because they sell wetted timber, it is being said that moisture is 100%
3. Production per month (e.g m3,tons,etc)?	(200-250) m3
4. Who are your customers?	Wendy houses,winding,construction,housing,fencing,etc - **(for an average Wendy House of 3x3m you need 100planks, 3m long)**
5. Are customers province,national,inter. based?	Most (about 80%) goes to WC, and the rest into the nearby areas outside WC like George.
6. Informal Settlement people in the market?	yes! they form 10% of the market.They buy to build houses and to sell in townships!
7. % each major customer contribute on market?	There's a wide range of customers all over the country
8. Selling (market) price per quantity sold (R/m3)?	R1800/m3 (on average)
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts, "**BUT NOT SAWDUST**". Get sold to township people : R60 off cuts/bakkie load
Company Name:	H.M Timbers
Sawmill/Trader?	Agent (only a marketing office in WC), and their sawmill is in EC
Tel Number:	021 945 1444
Location?	
Attendent?	Didi (salesperson at the marketing office in WC)
0. Where/How do you get untreated wood?	They have their own plantations and "4 sawmills" EC and Kwazulu Natal
1. What is quality of wood?	They get timber untreated and kiln dried then (sell it untreated to others; and CCA treat it for others), sell in bulk planks
2. Moisture content (%)?	12%
3. Production per month (e.g m3,tons,etc)?	+/-4000 m3
4. Who are your customers?	traders and merchants (who treat it into their customers specifications)
5. Are customers province,national,inter. based?	the agent only sells to it province, so H.T timber sell all 4000m3 to WC.
6. Informal Settlement people in the market?	none,
7. % each major customer contribute on market?	There's a wide range of customers all over South Africa
8. Selling (market) price per quantity sold (R/m3)?	R1820/m3 (on average)

Figure G.6: Interviews Sawmills 1

9. Any wood waste? Type? How do you treat it?	none (because there's no processing going on except for treatment, only trading)
Company Name:	Cape Sawmills
Sawmill/Trader?	sawmill
Tel Number:	021 808 7440
Location?	
Attendent?	Andrea and (Amos - about the steam production)
0. Where/How do you get untreated wood?	They have their own plantations of timber in WC - at Stellenbosch,Groobe,Tokai
1. What is quality of wood?	They sell both treated and untreated SA Cape pine,but both kiln dried,and in huge bundles of planks (not loose)
	They produce their own steam using 1boiler; they use off cuts and bark as fuel (and they don't take that wood waste amount used into account)
2. Moisture content (%)?	14 - 16 %
3. Production per month (e.g m3,tons,etc)?	+/-3500m3
4. Who are your customers?	traders and merchants
5. Are customers province,national,inter. based?	Most of the timber wood (90%) goes to WC and rest (sawn,value-added,alluminated timber) into EC
6. Informal Settlement people in the market?	none ; because they only sell in huge bundles
7. % each major customer contribute on market?	There's a wide range of customers all over WC and minority in EC
8. Selling (market) price per quantity sold (R/m3)?	R2100/m3 - sawn timber, R4000/m3 - value-added timber; it varies with type: but on average_R2100/m3
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts. Get sold to the contractor on site (called Bite n Board) to make chip boards
Company Name:	Great Brak Sawmill
Sawmill/Trader?	Agent - a marketing office ; (Connecton between Sawmills"suppliers" and customers)
Tel Number:	021 975 2796
Location?	
Attendent?	Sean
0. Where/How do you get untreated wood?	from sawmills situated in WC, EC, Traansval (they directly buy and sell)

Figure G.7: Interviews Sawmills 2

1. What is quality of wood?	Agent buy timber: treated and untreated; dry and wet; and sell it only in bulk planks, "at least 70m3"
2. Moisture content (%)?	dried timber - (12-15%); wetted timber - (90-100%)
3. Production per month (e.g m3,tons,etc)?	they sell to the whole nation, but +/-500m3 goes to WC
4. Who are your customers?	traders and merchants
5. Are customers province,national,inter. based?	they sell to the whole nation, but +/-500m3 goes to WC
6. Informal Settlement people in the market?	none, because the Agent doesn't sell timber in loose planks
7. % each major customer contribute on market?	There's a wide range of customers all over the country
8. Selling (market) price per quantity sold (R/m3)?	depends
9. Any wood waste? Type? How do you treat it?	Off cuts are only in the sawmills (so the agent is not quite sure what they do with it), propably they sell it!
Company Name:	Agrico
Sawmill/Trader?	sawmill
Tel Number:	021 905 1374
Location?	
Attendent?	Mrs Scotts
0. Where/How do you get untreated wood?	They have a small plantation in WC
1. What is quality of wood?	they sell SA pine timber in sawn, rough, untreated and wetted planks, (in bundles and loose sets)
2. Moisture content (%)?	because they sell wetted timber, it is being said that moisture is 100%
3. Production per month (e.g m3,tons,etc)?	+/-250m3
4. Who are your customers?	Wendy Houses who build houses; and Informal Settlement People; **(for an average Wendy House of 3x3m you**
	need 100planks, 3m long-- info obtained from Timber Town cc - 9032181)
5. Are customers province,national,inter. based?	only WC
6. Informal Settlement people in the market?	Yes! I.S.P buy cheap wood called "**strips - wood still with (50mm) bark on**" to make shacks and to sell in townships
7. % each major customer contribute on market?	Maily to Wendy Houses, and rest to I.S.P, etc. (their target market is black and coloured people)
8. Selling (market) price per quantity sold (R/m3)?	Varies with type of wood, size, dimensions, etc.
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts. They sell it to the township people for fire,etc ; where a bakkie load is R80

Figure G.8: Interviews Sawmills 3

Company Name:	Woodtraders
Sawmill/Trader?	trader
Tel Number:	021 905 5073
Location?	
I spoke to?	Chris Gordon
0. Where/How do you get untreated wood?	Suppliers "sawmills" of untreated timber wood from WC,other parts of SA and from overseas (depending on the type of wood they need = see sheet 3 for more details)
1. What is quality of wood?	They get dry untreated "in +/-50 types of" timber and then sell it in bulk and loose planks; (if customers desparetely need treated wood then they treat for them or redirect them to other traders)
2. Moisture content (%)?	12%
3. Production per month (e.g m3,tons,etc)?	2150 m3 ; (but it really depends on the demand, because they order when there's demand in hand)
4. Who are your customers?	shopfitters,carpenters,landscapers,veneer upgraders,home owners,ceiling
5. Are customers province,national,inter. based?	national (but most goes to WC)
6. Informal Settlement people in the market?	none (I.S.P maily order from sawmills)
7. % each major customer contribute on market?	There's a wide range of customers all over South Africa
8. Selling (market) price per quantity sold (R/m3)?	depends on maily on type and "thickness,length,width of a plank".
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts. Get sold to people who need small pieces of wood on discount or otherwise given to I.S.P free of charge for fire. (it helps to clean the yard),
Company Name:	Jarah Supplies
Sawmill/Trader?	trader or Agent
Tel Number:	021 981 6444
Location?	
I spoke to?	Yolandi
0. Where/How do you get untreated wood?	Import timber from Australia and sell it to customers as it is (they directly buy and sell)
1. What is quality of wood?	They get untreated, kiln dried "hard Jarah and Tamaniam Oak" and then trade it in bulk and loose planks
2. Moisture content (%)?	12%

Figure G.9: Interviews Wood Traders 1

3. Production per month (e.g m3,tons,etc)?	+/-50 m3
4. Who are your customers?	wood merchants,capernters,home owners, etc
5. Are customers province,national,inter. based?	national (about 80% goes to WC)
6. Informal Settlement people in the market?	none
7. % each major customer contribute on market?	There's a wide range of customers all over South Africa
8. Selling (market) price per quantity sold (R/m3)?	(R14000-17000)/m3 ; expensive because of it nature,type,purpose and due to transportation costs
9. Any wood waste? Type? How do you treat it?	none (because there's no processing going on, only buying and selling)
Company Name:	Airton Timbers
Sawmill/Trader?	trader
Tel Number:	021 511 2318
Location?	
I spoke to?	
0. Where/How do you get untreated wood?	Suppliers from - Stellebosch, George, EC, North Gauteng
1. What is quality of wood?	they buy dried treated SA pine timber woods and then trade in bulk and loose planks
2. Moisture content (%)?	12-15%
3. Production per month (e.g m3,tons,etc)?	+/-100 m3
4. Who are your customers?	construction and building purposes only
5. Are customers province,national,inter. based?	national ; (most goes to WC; about 80%)
6. Informal Settlement people in the market?	Yes! They form 1%; for houses
7. % each major customer contribute on market?	There's a wide range of customers all over South Africa
8. Selling (market) price per quantity sold (R/m3)?	+/-R2500/m3 (but varies based on strength-due to different purposes)
9. Any wood waste? Type? How do you treat it?	Yes - 2m3 off cuts/day! Get sold because treated timber is not good to be given off to the public for fire. It Illegal.
Company Name:	Cape Timber & Mouldings cc
Sawmill/Trader?	Merchant
Tel Number:	021 691 8948
Location?	

Figure G.10: Interviews Wood Traders 2

I spoke to?	Mr Cock
0. Where/How do you get untreated wood?	from suppliers "sawmills" situated in WC, EC, Traansval
1. What is quality of wood?	they deal with SA pine timber wood (they buy wetted and already dried timber)
2. Moisture content (%)?	From sawmills: the wetted sawn pine timber is 100% moist; the already dried pine timber is 12% moist
3. Production per month (e.g m3,tons,etc)?	+/-100m3/day ; therefore +/-3000m3/month
4. Who are your customers?	housing, fencing, carpenters, etc
5. Are customers province,national,inter. based?	maily in WC
6. Informal Settlement people in the market?	Yes! For housing and maybe fencing; and they form 30% of the market
7. % each major customer contribute on market?	There's a wide range of customers all over WC
8. Selling (market) price per quantity sold (R/m3)?	depends
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts. Get sold to the contractor on site to make chip boards. (waste is about 5% of the input)
Company Name:	DRC Timber
Sawmill/Trader?	trader
Tel Number:	021 982 3880
Location?	
I spoke to?	
0. Where/How do you get untreated wood?	from all over South Africa as SA pine
1. What is quality of wood?	They get most timber treated and still wet-and sell in bulk and loose, and a small % untreated,kiln dried for industrial use-sell only in bulk (all in planks)
2. Moisture content (%)?	From sawmills: the wetted pine timber is 80-100% moist; the already dried pine timber is 12% moist
3. Production per month (e.g m3,tons,etc)?	+/-200m3
4. Who are your customers?	merchants
5. Are customers province,national,inter. based?	only WC
6. Informal Settlement people in the market?	none
7. % each major customer contribute on market?	There's a wide range of customers all over WC
8. Selling (market) price per quantity sold (R/m3)?	depends
9. Any wood waste? Type? How do you treat it?	Yes! Any off cuts get recycled and re-machined to form other forms of material to sell, nothing is thrown away.

Figure G.11: Interviews Wood Traders 3

Company Name:	Timber Turf
Sawmill/Trader?	trader
Tel Number:	021 948 1362
Location?	
I spoke to?	
0. Where/How do you get untreated wood?	from SA and overseas
1. What is quality of wood?	they deal with +/-40 types of timber-incl SA pine,Maranti,oak,etc; they get it untreated,kiln dried and in planks
2. Moisture content (%)?	12%
3. Production per month (e.g m3,tons,etc)?	+/-30m3
4. Who are your customers?	shopfitters,carpenters,landscapers,veneer upgraders,home owners,ceiling,other merchants
5. Are customers province,national,inter. based?	only WC
6. Informal Settlement people in the market?	none
7. % each major customer contribute on market?	There's a wide range of customers all over WC
8. Selling (market) price per quantity sold (R/m3)?	depends on type
9. Any wood waste? Type? How do you treat it?	Yes! Off cuts. Get sold to people who need small pieces of wood on discount

Figure G.12: Interviews Wood Traders 4

Company Name:	Ross Demolition
Demolition/Construction?	Demolition
Tel Number:	021 692 1275 - 2nd hand yard / 021 511 1204 - main offices
Attendent?	Runnel
0. How do you get 2nd hand wood?	After they have demolished wooden structures,they store wood on their
1. What is quality of wood?	Any type of timber wood depending on construction; mainly it SA pine & oregon and untreated wood used in contruction.
2. Moisture content (%)?	As a 2nd hand wood; they get dry appr. 12% moist
3. Production per month (e.g m3,tons,etc)?	Varies, depending on how much wood is coming in after demolition
	(I tried the 2nd time to get a value but still couldn't get any thing
4. Who are your customers?	wide range of public sector & private companies
5. Are customers province,national,inter. based?	WC based customers; mainly municipal and surrounding areas
6. Informal Settlement people in the market?	yes! they form 30% of the market.For shack & roof construction and
7. % each major customer contribute on market?	There's a wide range of customers
8. Selling (market) price per quantity sold (R/m3)?	R5 SA pine/m ; R3 Oregon/m
9. Any wood waste? Type? How do you treat it?	pieces.
Company Name:	TAR Demolition & Excavation
Demolition/Construction?	Demolition & Excavation
Tel Number:	Work: 021 396 2888 / Cell: 0829320565
Attendent?	Abri van Difente (not quite sure of the spelling)
3. Production per month (e.g m3,tons,etc)?	2 houses per month. Whereby the amount of wood attainable could vary
	On average about R8000 worth of wood is obtained from an average
	About 80% of the good wood is used for furniture manufacture, if it's old
	Various types of wood can be achieved, but mainly SA pine, oregon &
	WALLS.Hence it varies from house to house!
Company Name:	BRADIS Construction & Demolition
Demolition or Construction?	both
Tel Number:	021 386 5050
Attendent?	PAUL

Figure G.13: Interviews Construction & Demolition Contractors 1

3. Production per month (e.g m3,tons,etc)?	On average they demolish 1 wooden structure (house) every 6 months.Hence they hardly deal with wooden structures e.g. of an 80% wood built structure, 60% of that can be recovered &

I found 9 companies Yellow Pages on demolition and construction.

1. Skye Demolition & Earthworks (425 4027) - their telephone number could not go through.
2. Speedy Plant hire and Earthmoving Contractors (981 3352) - I could not get hold of them
3. Duncker's Demolition (949 1779) - their number has changed
4. C & H Transport (692 4557) - was not a demolition company but funeral services company
5. W.H.J Transport (551 6283) - They dont work with wooden structures but steel and alloy structures
6. TAR Demolition & Excavation (396 1107) - A guy that I had to speak to (Mr Lewis) was always on business off site
7. L.O Rall Demolition & Scrap Dealers (982 6918) - A person who could help me (Neils) could only speak afrikaans to me
8. BRADIS Construction & Demolition (386 5050) - I could not get hold of them
9. Ross Demolition (692 1275/6) - See the findings above.

Figure G.14: Interviews Construction & Demolition Contractors 2

G. INTERVIEWS

Appendix H

Informal Construction Wood Model

MATERIALS			
Type	Description	Average density at 10% moisture content [kg/m³]	Gross lower calorific value [MJ/kg]
M1	Wattle Poles	500,00	20,00
M2	Wattle Horizontal Battens	500,00	20,00
M3	Packing case material (Plywood)	500,00	20,00
M4	Softboard	500,00	20,00
M5	SA Pine Brandering	450,00	20,42
M6	SA Pine Rafters	450,00	20,42
M7	Hollow core timber door	500,00	20,00
M8	Solid timber door	500,00	20,00
M9	Timber window	500,00	20,00
M10	Ditto	500,00	20,00

Figure H.1: Materials

GENERAL SETTINGS										
1. WALLS			2. ROOF			3. FINISHES			4. DOORS AND WINDO'	
Option	Quantity [%]		Option	Quantity [%]		Option	Quantity [%]		Option	Quantity [%]
W1	50		R1	50		FN1	10		DW1	50
W2	25		R2	25		FN2	15		DW2	50
W3	25		R3	25		FN3	15			100
	100			100		FN4	15			
						FN5	15			
						FN6	15			
						FN7	15			
							100			

Figure H.2: GeneralSettings

AREA DATA				
[illegible]	[illegible]	Informal Households (stock)	Informal Households (input)	Informal Households (output)
A1	Ca, e Metro, olitan Area	142.982	4.000	

Figure H.3: Area Data

CONSTRUCTION UNITS/ELEMENTS							
1. WALLS							
Option	Description	Material ρ(kg/m3)	Length [m]	Height [m]	Width [m]	Quantity	Total weight [kg]
W1	Wattle poles 76mm x 3m	500	3	0,00454	1	42	282
	Wattle horizontal batten,35mm x 3m	500	3	0,00096	1	308	444
W2	Wattle poles 76mm x 3m	500	3	0,00454	1	47	321
	Packing Case Material (Plywood)	500	79	0,018	1		714
2. ROOF							
Option	Description	Material ρ(kg/m3)	Length [m]	Height [m]	Width [m]	Quantity	Total weight [kg]
R 1	Wattle , oles 76mm x 3m	500	3	0,00454	1	15	104
R 2	Wattle poles 76mm x 3m	500	3	0,00454	1	15	104
R 3	Wattle , oles 76mm x 3m	500	3	0,00454	1	15	104
	Packing Case Material (Plywood)	500	47	0,018	1		425
3. FINISHES							
Option	Description	Material ρ(kg/m3)	Length [m]	Height [m]	Width [m]	Quantity	Total weight [kg]
FN7	Softboard fixed to brandering	500	30	0,018	1		267
	SA Pine brandering size 38 x 38mm	450	65	0,038	0,038		42
	SA Pine rafters size,38 x 152mm	450	24	0,038	0,152		62
4. DOORS AND WINDOWS							
Option	Description	Material ρ(kg/m3)	Length [m]	Height [m]	Width [m]	Quantity	Total weight [kg]
DW1	Hollow core timber door	500	2	0,04	0,8		24
	+ frame		3,018	0,018	0,3		
	Solid timber door	500	2	0,04	0,8		40
	+ frame		3,018	0,018	0,3		
DW2	Timber Window	500	0,6	0,018	0,05		1,1
			0,64	0,018	0,05		
	Ditto	500	1	0,018	0,05		2,0
			1,3	0,018	0,05		

Figure H.4: Construction Units

RESULTS					
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M1	W1	Wattle poles	2,019E+07	4,038E+08	
	W2	Wattle poles	1,147E+07	2,295E+08	
	R1	Wattle poles	7,459E+06	1,492E+08	
	R2	Wattle poles	3,730E+06	7,459E+07	
	R3	Wattle poles	3,730E+06	7,459E+07	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M2	W1	Wattle horizontal batten	31777470,01	6,355E+08	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M3	W2	Packing Case Material	25522287	5,104E+08	
	R3	Packing Case Material	1,517E+07	3,035E+08	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M4	FN7	Softboard	5,726E+06	1,145E+08	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M5	FN7	SA pine brandering	9,105E+05	1,859E+07	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M6	FN7	SA pine rafters	1,329E+06	2,713E+07	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M7	DW1	Hollow core timber door	1,726E+06	3,453E+07	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M8	DW1	Solid timber door	2,870E+06	5,741E+07	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M9	DW2	Timber window	7,747E+04	1,549E+06	
Material	**Option**	**Description**	**Weight (kg)**	**Calorific Value (MJ)**	
M10	DW2	Ditto	1,457E+05	2,913E+06	
		TOTAL MASS (kg)	**1,318E+08**	131.838,98	[t]
		CALORIFIC VALUE (MJ)	**2,638E+09**	2.637.719,95	[GJ]
		Average Weight of Shack	0,92	[t]	
		Average Energy Content c	18,45	[GJ]	

Figure H.5: Results

Appendix I

Pulp & Paper Industry

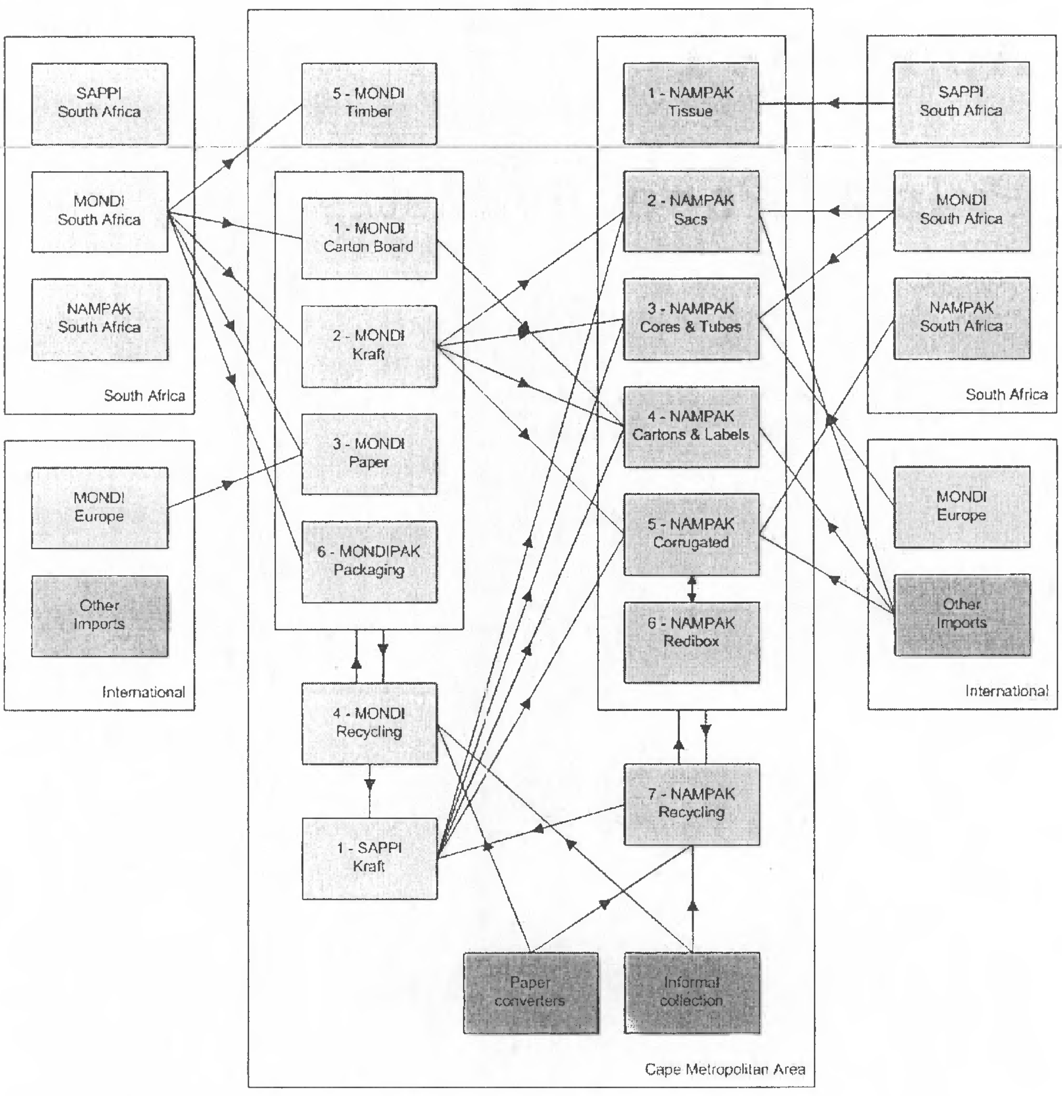


Figure I.1: Pulp & Paper Industry Network

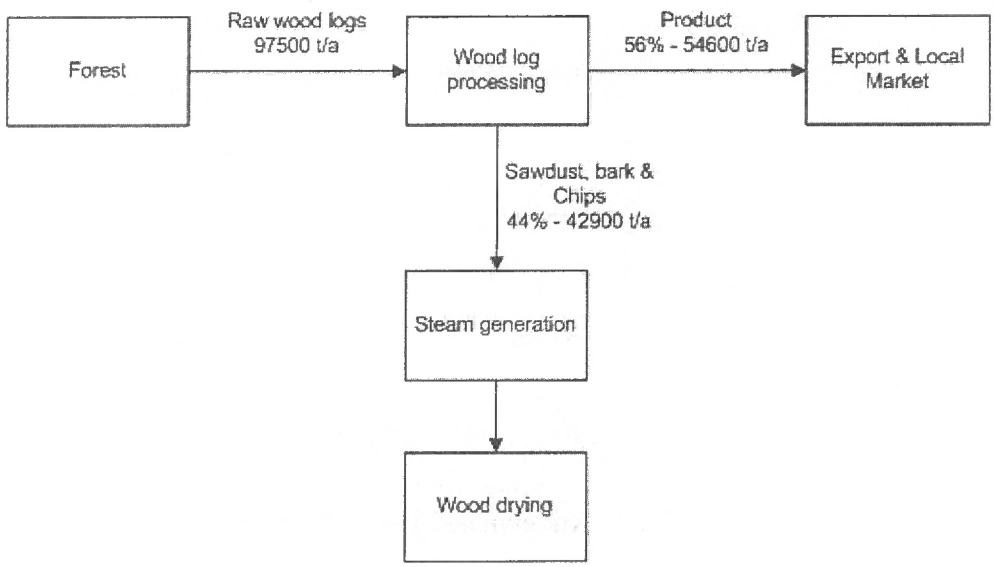


Figure I.2: MONDI Timber - Cape Sawmills

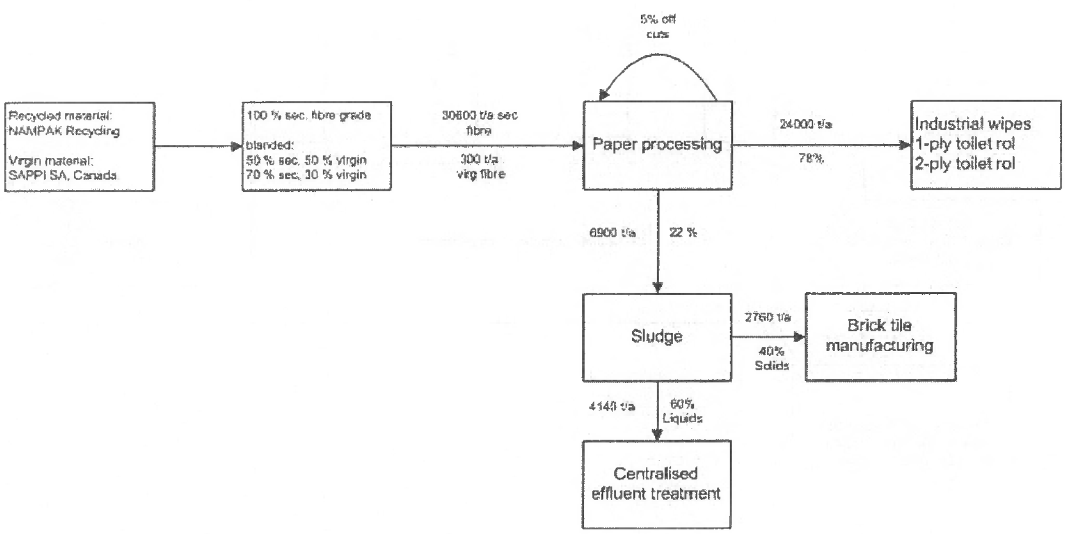


Figure I.3: Anonymised Paper Factory I

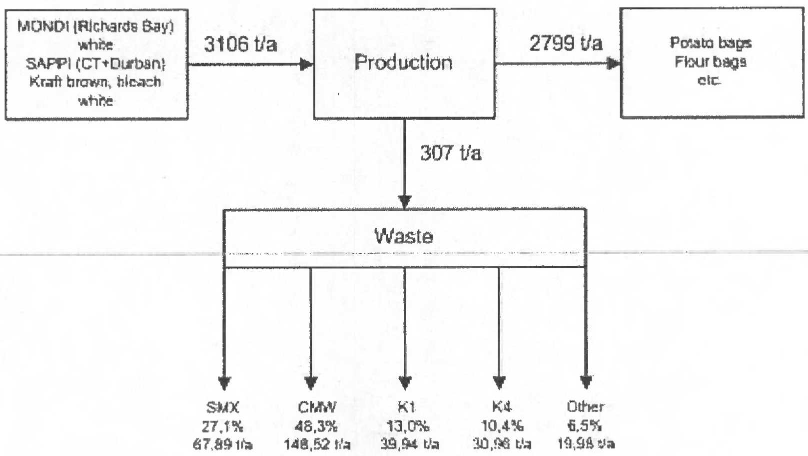


Figure I.4: Anonymised Paper Factory II

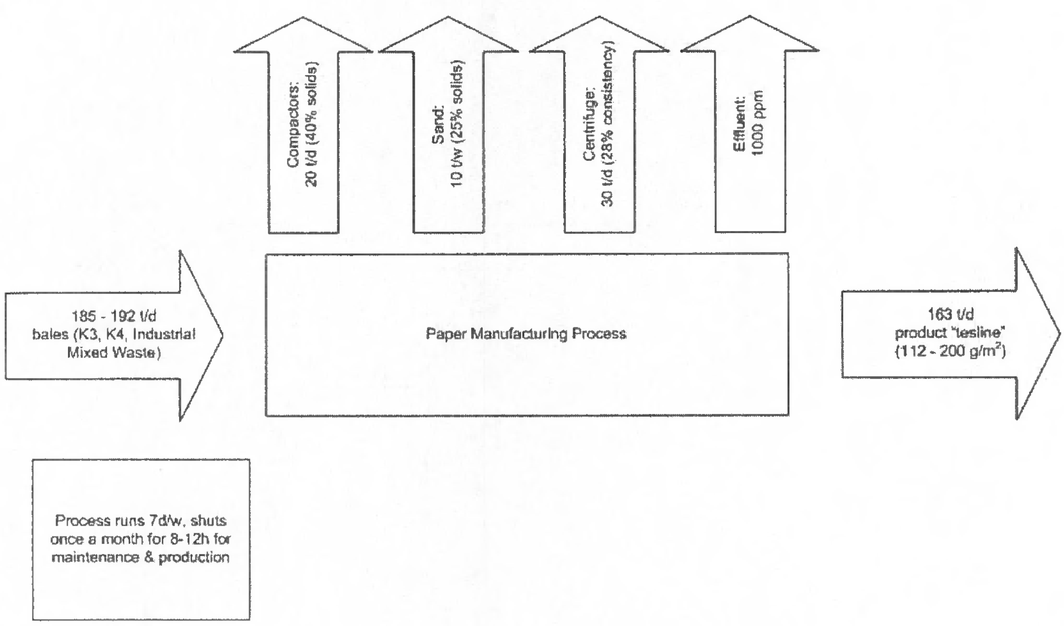


Figure I.5: SAPPI - Montague Gardens

Appendix J

Database Design

Name	Type	Size
ID	Long Integer	4
TreeNr	Long Integer	4
StartKwd	Memo	-
ItLvl	Long Integer	4
URL	Memo	-
URLNr	Long Integer	4
EndKwd	Memo	-
EndKwdNr	Long Integer	4
EndKwdType	Text	4
PrevID	Long Integer	4
Lineage	Text	50
Created	Text	50

Table J.1: Table Option Trees - tblOptionTrees

Name	**Type**	**Size**
OptTreeNr	Long Integer	4
OptTreeName	Text	50
ItLvl	Long Integer	4
URLNr	Long Integer	4
KwdNr	Long Integer	4
SearchQuery	Memo	-
SearchContext	Memo	-
WRep	Yes/No	1
KRep	Yes/No	1
Quotes	Yes/No	1
Comments	Memo	-
Language	Text	50
Country	Text	50
Generated	Yes/No	1
Duration	Text	50
Connectors	Text	50
Created	Date/Time	8
LastModified	Date/Time	8
chkKwd	Yes/No	1
chkGeneral	Yes/No	1
chkCO2DB	Yes/No	1
chkCOMPEED	Yes/No	1
chkGEMIS	Yes/No	1
chkLEAP	Yes/No	1

Table J.2: Table Connectors - tblConnectors

Name	Type	Size
ID	Long Integer	4
Nr	Long Integer	4
Caption	Text	50
MatchPair	Text	50
MatchWord	Memo	-
Lineage1	Text	50
Lineage2	Text	50
CL	Long Integer	4
KI	Single	4
WI	Single	4
PS	Single	4
RankCL	Long Integer	4
RankKI	Long Integer	4
RankWI	Long Integer	4
RankPS	Long Integer	4
WeightCL	Double	8
WeightKI	Double	8
WeightWI	Double	8
WeightPS	Double	8
SumWeight	Double	8
RankSumWeight	Long Integer	4
len1	Long Integer	4
LowPosCL	Long Integer	4
LowPosKI	Long Integer	4
LowPosWI	Long Integer	4
LowPosPS	Long Integer	4

Table J.3: Table Results - tblResults

Appendix K

Design of the Logic Tier

Option tree generation procedure

In figure K.1, a flow diagram depicting the programmatic approach for the generation of option trees is represented. The first step in this procedure is for the user to enter a number of parameters, amongst other things the defined maximum number of websites x, the defined maximum number of keywords y, the defined maximum number of iteration levels z, the initial start keyword $sKWD_0$, and the search context SC. After having initialised the counters i, j, k, l to 0, and having set the number of items α of the list of search results A to 0, the data entered by the user are saved under the name of an option tree, e.g. 5000, in the database table 'Trees' (`tblOptionTrees`).

Subsequently, a list of search results A is retrieved from the WWW via the Google API, defined by the search context SC and the start keyword $sKWD_l$, which in this case is the initial start keyword $sKWD_0$, as the counter l had been initialised to 0. α represents now the number of search results in A. The first website WS_i is retrieved from A, followed by the generation of a list of keywords B which are defined on the website WS_i. After retrieving the first keyword $eKWD_j$ from list B, it is checked in table 'Type' (see column 'Comparative I' and Comparative II' in figure 8.2) in the database for the type of keyword $eKWD_j$. Once this has happened, a connector $CONN$ along with the values for start keyword $sKWD_l$, end keyword $eKWD_j$, counters i, j, k, as well as the type of keyword $typeeKWD_j$ is saved in table 'Connectors' (`tblConnectors`) in the

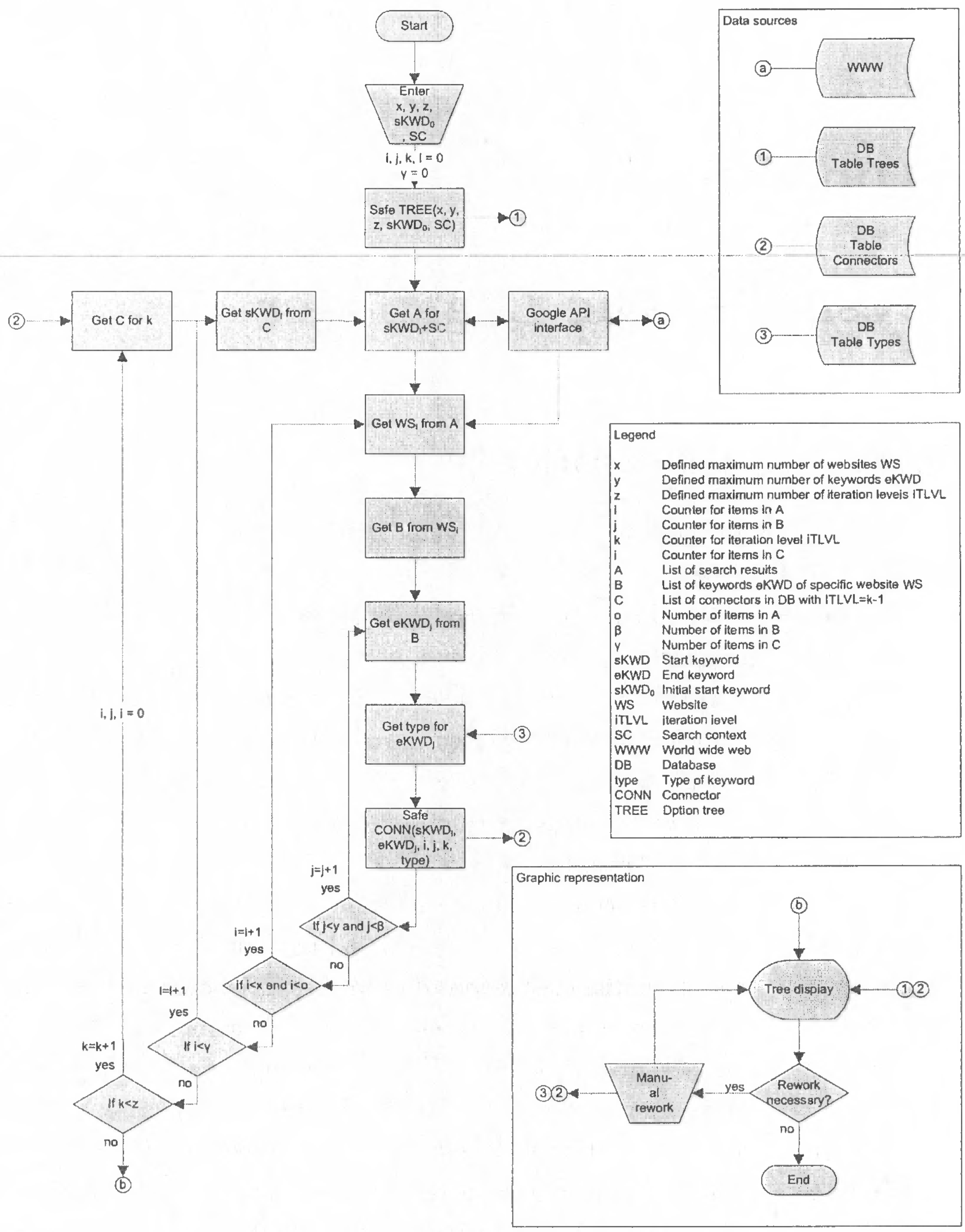


Figure K.1: Option Tree Generation Procedure database. These last three steps will be repeated either for all keywords in B in case the number of keywords β in list B is smaller than the user defined maximum number of keywords y, or for a number of keywords y in case y is smaller than β. Once done, a new website WS_i will be fetched from the list of websites A. This bigger loop will be repeated either for all websites in A in case the number of websites α in A is smaller than the user defined maximum number of websites x, or for a number of websites x in case x is smaller than α. Once this loop has been finished, the application will move to the next iteration level. Exceptionally for the first round, the next loop is skipped, as γ, the number of items of the list of connectors with iteration level equal to $k - 1$, is equal to 0. The condition of the last loop is that the counter for iteration level is smaller than the user defined maximum number of iteration levels z. As long as this condition is given, a new list of connectors C will be fetched from the database, table 'Connectors', with an iteration level equal to k. Subsequently, a new start keyword $sKWD_l$ will be retrieved from list C, which will be used to generate a new list of websites A via the Google API, based on a new start keyword and the search context SC, which will remain constant throughout the option tree generation process. Note that by generating a list of connectors C, the number of items γ in C is no longer equal to 0, which will not allow the application to skip the loop $l < \gamma$ again, as it has been done in the first round. The loop in question will be carried out for each start keyword $sKWD_l$ in C.

Once the condition $k < z$ is no longer true, the application will move to the graphic representation of results. An option tree will be displayed being fed from data stored in table 'Trees' and table 'Connectors'. In case keywords have been allocated the wrong type definitions, or the option tree contains senseless branches, a manual rework interface will allow the user to make the necessary changes, e.g. redefine keyword types and delete branches. Once the tree has been reworked, the option tree generation process is finished. Note that the retrieval of search results via the Google API is one of the bottlenecks regarding the application performance for the generation of option trees. At the point of writing, only a β-version of the Google API was accessible by the public, having limitations regarding the retrieval of websites (max. 10 per search query), and an allowed maximum number of search queries per day and user (max. 1,000) (Google, 2006a). Furthermore, the stableness of the API service was moderate, as the service regularly delivered error message, known to the programmer community using the Google API (e.g. ?). This problem has been stabilised programmatically by inserting error handling loops, retrying failed search queries a number of times, including waiting phases.

Option tree matching procedure

As displayed in figure K.2, the programatic procedure for the option tree matching consists basically of a hierarchy of four loops. The first step in this procedure is to display a set of option trees, out of which the user selects a list of option trees A as *energy demands*, and a list of option trees B as *energy sources*. After having initialised the counters i, j, k, l to 0, an option tree a_i will be fetched from the list of energy demands A. For this option tree, a connector aa_j will be retrieved from table 'Connectors'. The next two steps are similar to the two previous ones, fetching this time an option tree b_k of the list of energy sources B, and subsequently, a connector bb_l from table 'Connectors'. In the next step, it will be checked if the end keyword $eKWD$ of connector aa_i is equal to the end keyword $eKWD$ of connector bb_l. In case this condition is true, the matching pair of connectors aa_i and bb_l will be added as a couple to the table 'Results' of the database. In case the condition is not true, the next connector bb_l will be selected from table 'Connectors' of the database. This loop will be repeated for each connector of b_k, namely $\beta\beta_k$ times. Once finished, the next loop in the hierarchy will be repeated for each option tree b_k of the list of energy sources B, namely β times. The next two loops in the hierarchy are similar to the two previous ones, except that the loops will be repeated for each connector aa_j for option tree a_i, namely $\alpha\alpha_i$ times, and each option tree a_i from the list of energy demands A, namely α times.

In summary, each connector of each option tree in the list of energy demands should have been compared to each connector of each option trees in the list of energy sources, the matching connectors having been added as couples to the table 'Results' of the database. After this procedure has been finished, the

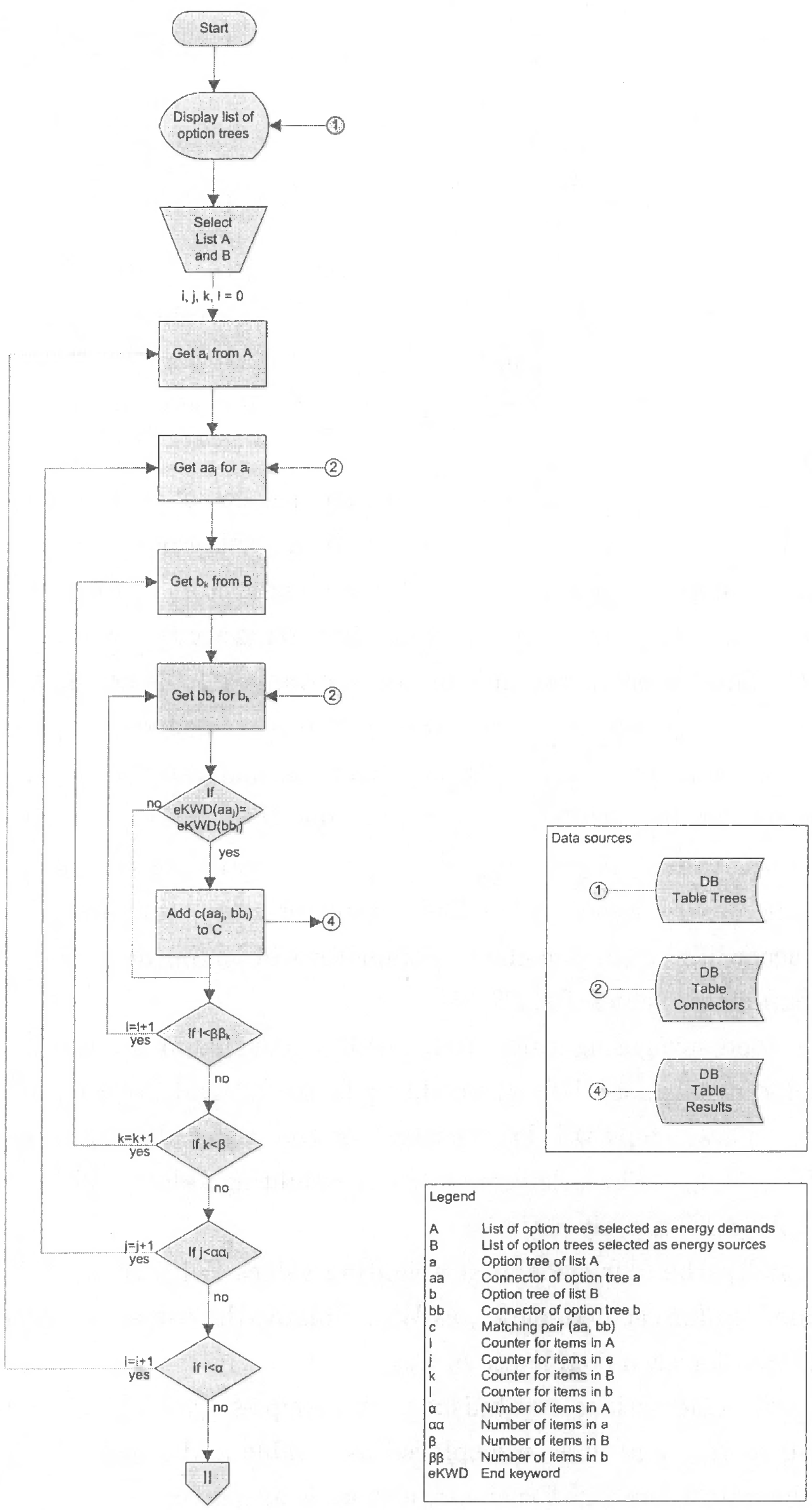


Figure K.2: Option Tree Matching Procedure application will move on to step number II, which is the results processing and display procedure, see figure K.3.

Results processing and display procedure

The purpose of the Results Processing and Display Procedure as given by the flow diagram in figure K.3 is twofold: firstly, to calculate values for four parameters (see section 8.2.3.1) for the results collected in the Option Tree Matching Procedure (see figure K.2), and secondly, to display to the user a clear and concise set of results.

The first step in this procedure is to enter a set of user defined weighting factors $w1, w2, w3, w4$, and a set of user defined sorting orders $s1, s2, s3, s4$.

The next step is to get a list of matching connectors C from table 'Results' in the database. The first couple of matching connectors c_m will be fetched from the list C. Subsequently, the first parameter value $P1_m$ is calculated for couple c_m. This loop is repeated for each couple in the list of couples C, namely γ times. Only once all parameter values $P1$ have been calculated for each couple in C, the rankings $R1$ can be calculated, as the ranking for a couple according to one of its parameter values needs to happen relatively to the correspondent parameter value of the other couples in C. The parameter calculation and the subsequent ranking according to the calculated parameter will be repeated three more times, for the parameter values $P2, P3, P4$.

Once done, weighting value $W1_m$ will be calculated for the ranking value $R1_m$, including the user defined weighting factor $w1$ and the user defined sorting factor $s1$. These steps will be repeated for the calculation of weighting values $W2_m, W3_m, W4_m$. The calculation of the weighting values will be repeated for each couple in C, namely γ times.

Eventually, the four calculated weighting values $W1_m, W2_m, W3_m, W4_m$ will be summed up for each couple c_m as W_m. Finally, the overall ranking values will be calculated for each couple c_m as R_m.

Once the calculations are finished, the couples c_m of list C will be sorted according to R_m, and will be displayed as a table and a graph. The option to export the data to an MS Excel spreadsheet is also given.

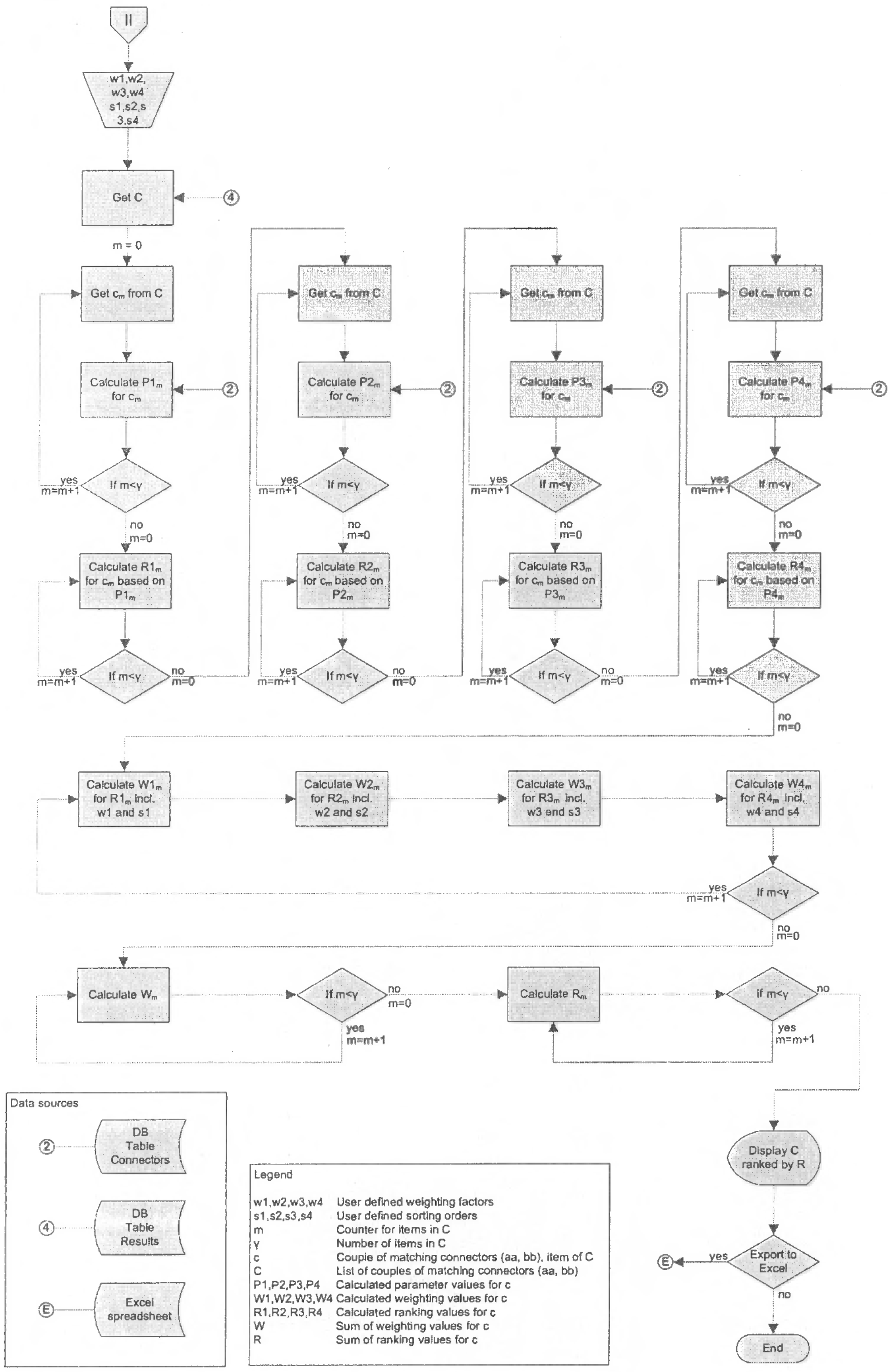


Figure K.3: Results Processing and Display Procedure

Appendix L

Design of the Presentation Tier

Start Window

The first window to be introduced is the Start Window, as depicted in figure L.1. On the top half of the window are two command buttons, giving the user the choice between the two main tasks of the application, namely the Option Tree Management and the Option Tree Matching Management. On the bottom half of the window are five text boxes, allowing the user to define general settings for the application:

- The path of the database
- The path of the log file
- The key code for the Google API
- The host name of the proxy server
- The port number of the proxy server

In case the application is run for the first time, the text boxes will contain default values.

Note that the user needs to open a Google Account and to obtain a license key in order to be able to use the Google SOAP Search API functionalities [1] which lay at the core of the option tree generation process.

[1] `http://code.google.com/apis/soapsearch/`

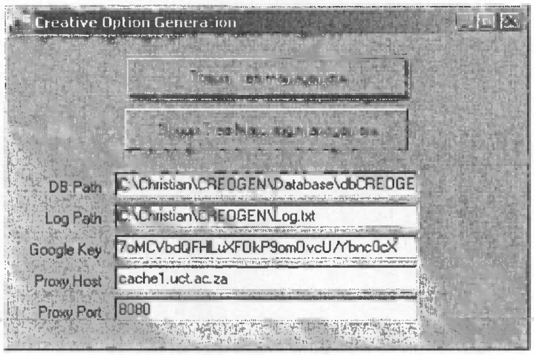


Figure L.1: Start Window

Option Tree Generation

The second window to be introduced is the Option Tree Management window, containing key information and command options for the generation of option trees (see figures L.2 and L.3).

On the left hand side of the window is a list of option trees which allows the user to select a single option tree. On the right of the list, details of the selected option tree will be displayed. In the frame 'caption', the number and the name of the tree will be displayed. On the tabs below, information regarding 'Parameters', 'Validation', 'Comments' and 'Status' will be displayed. Only the information regarding the first two tabs will be explained further below. On the right hand side of the window are two sets of command buttons.

The top three command buttons are related to the manipulation and generation of option trees as such. The top command button will display an option tree in case a tree has already been generated. The second button will generate a new option tree with the specifications made in the form, and the third command button will validate the keywords of an existing option tree by comparing them against the libraries. Note that the validation process happens automatically after the generation of a new option tree.

The bottom four command buttons are related to the editing of information regarding these option trees.

As can be seen in tab 'Parameters' in figure L.2, information regarding the initial search query, the search context, the number of keywords, the number

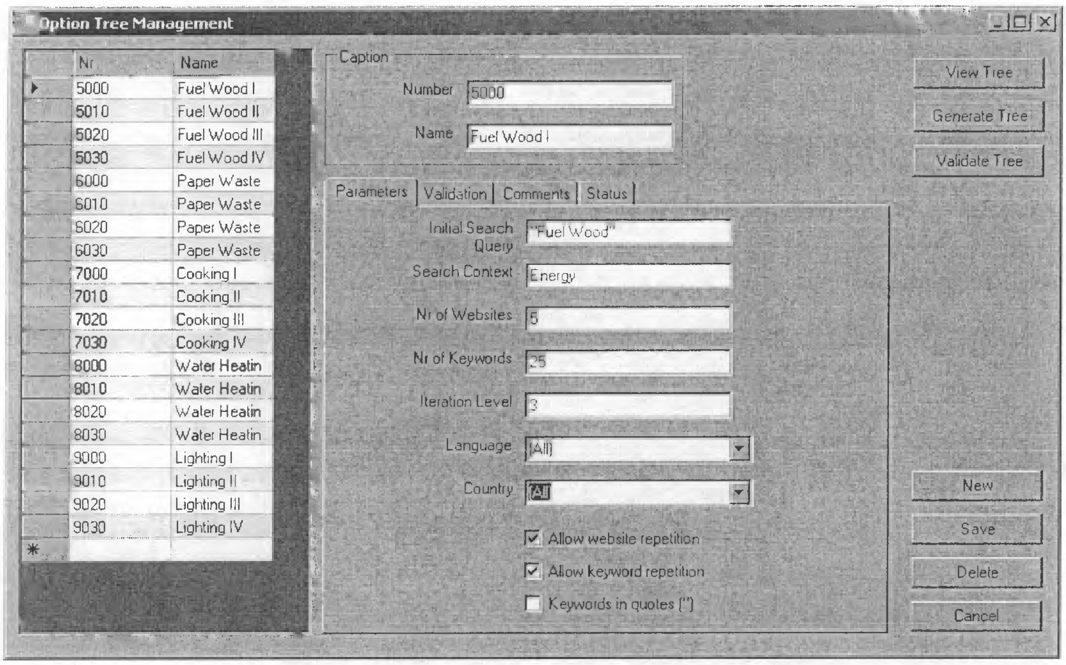


Figure L.2: Option Tree Management - 'Parameters' tab

of websites, the number of iteration levels, the language and the country can be displayed and edited in the corresponding text boxes. Below the text boxes are situated three check boxes, allowing the user to tick options regarding the repetition of keywords, the repetition of websites, and whether or not search keywords shall be marked in quotes.

As can be seen in the tab 'Validation' (see figure L.3), the user has the possibility to choose whether or not the collected keywords shall be compared against a set of comparative tables, containing terms classified as energy carriers and energy transformation technologies, allocating the keywords a certain type. Moreover, the user can decide in an affirmative case against which tables he wishes to compare the collected keywords. A general table contains user defined data; the other tables contain data from energy planning software tools and databases, namely LEAP, Compeed XL, CO2DB, and Gemis (see section 8.3.1).

The form 'Tree View' as depicted in L.4 displays the results of an option tree generation exercise in form of a tree similar to a MS Explorer file tree, allowing

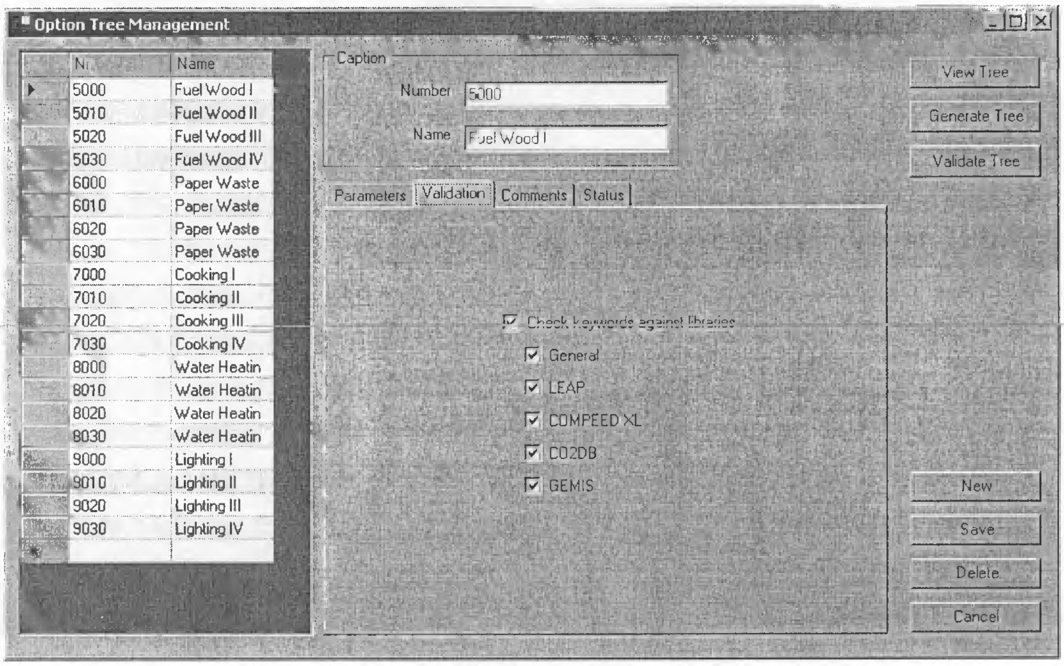


Figure L.3: Option Tree Management - 'Validation' tab

to expand and collapse single nodes of the tree.[1] A meaningful functionality of the tree view is the manual rework of the option tree. By right-clicking on a keyword, it is possible to define the type of the keyword as energy carrier, transformation technology or other, or to delete a specific keyword including all subsequent nodes. It is also possible to open a website by clicking on an URL in the option tree.

Option Tree Matching and Result Processing

In the form 'Option Tree Matching Management', the user defines which option trees shall be matched. In the list on the left hand side of the form, the user will select a number of option trees as *energy demand*, and on the right hand side, the user will define a number of option trees as *energy supply*. The command buttons on the right hand side will allow the user to edit settings regarding the

[1]The top two command buttons on the right hand side of the form allow to expand and collapse all nodes of the tree at once.

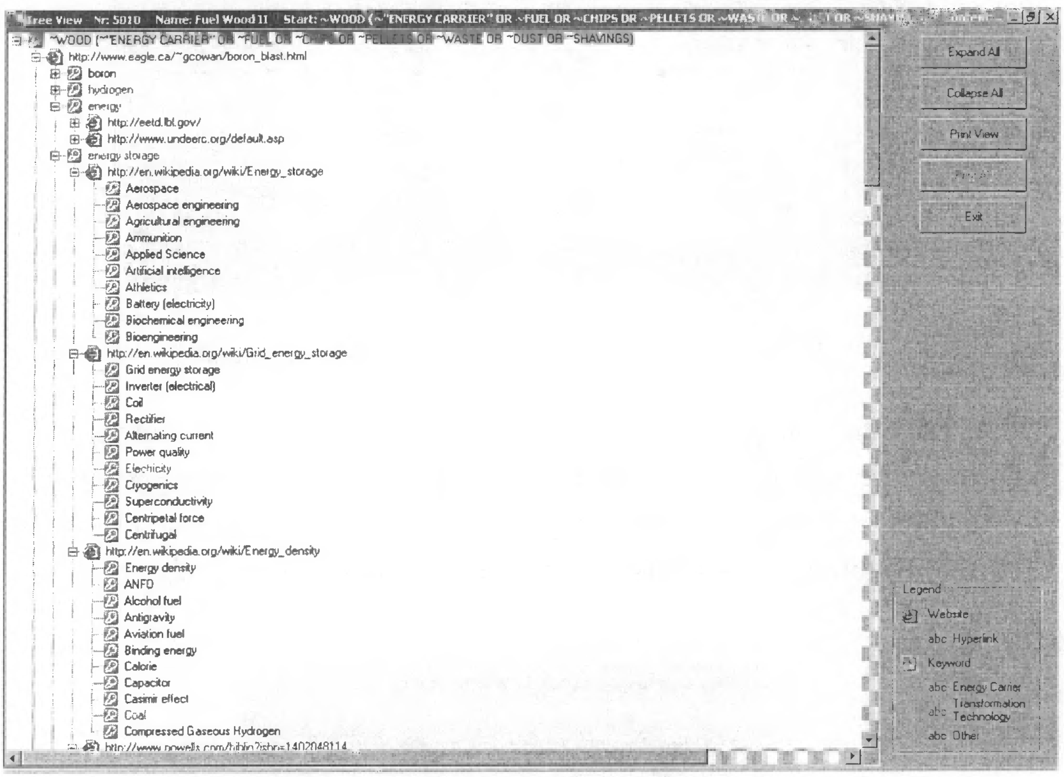


Figure L.4: Tree View

Option Tree Matching Management, to match option trees as selected in the two lists on the left hand side, to display the results in form of a table, or to display the results in form of a graph. Furthermore, parameter settings regarding the graphical output can be made.

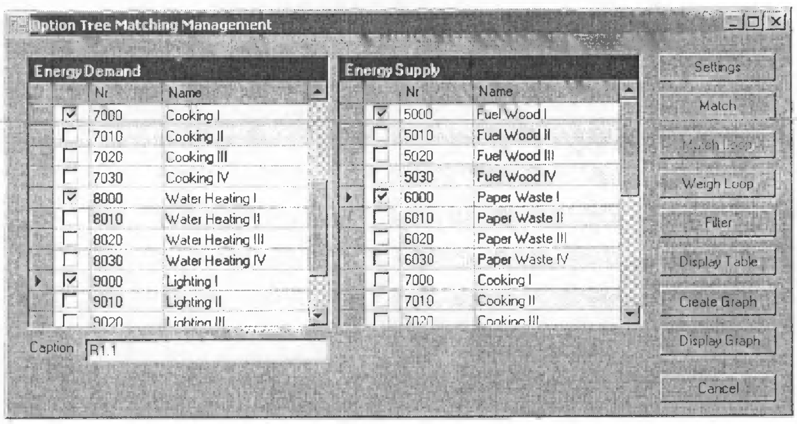


Figure L.5: Option Tree Matching Management

As can be seen in figure L.6, the user defines the sorting orders and the weighting factors for each of the four parameters in the form 'Parameter Settings'. The sorting order for each parameter can either be set to 'ascending' or 'descending', and the weighting factors must be set in such a way that their sum is equal to 100%.

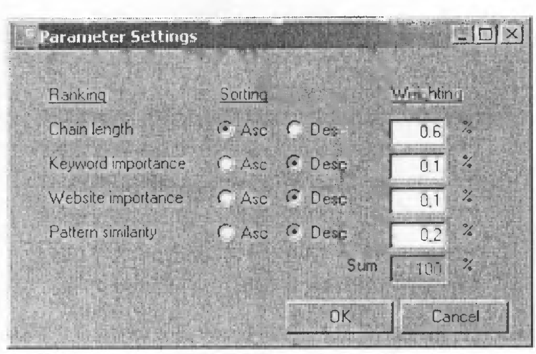


Figure L.6: Parameter Settings

In the form 'Evaluation' as given in figure L.7, the results of the option tree matching exercise are displayed in the form of result chains, alternating the keywords and corresponding URLs. Moreover, results regarding the calculation of the different parameters, as well as intermediate results regarding the weighting and ranking of the different chains are given. Furthermore, the user has the option to export these data to an MS Excel spreadsheet, offering the opportunity to generate flexible user defined graphs based on the generated data.

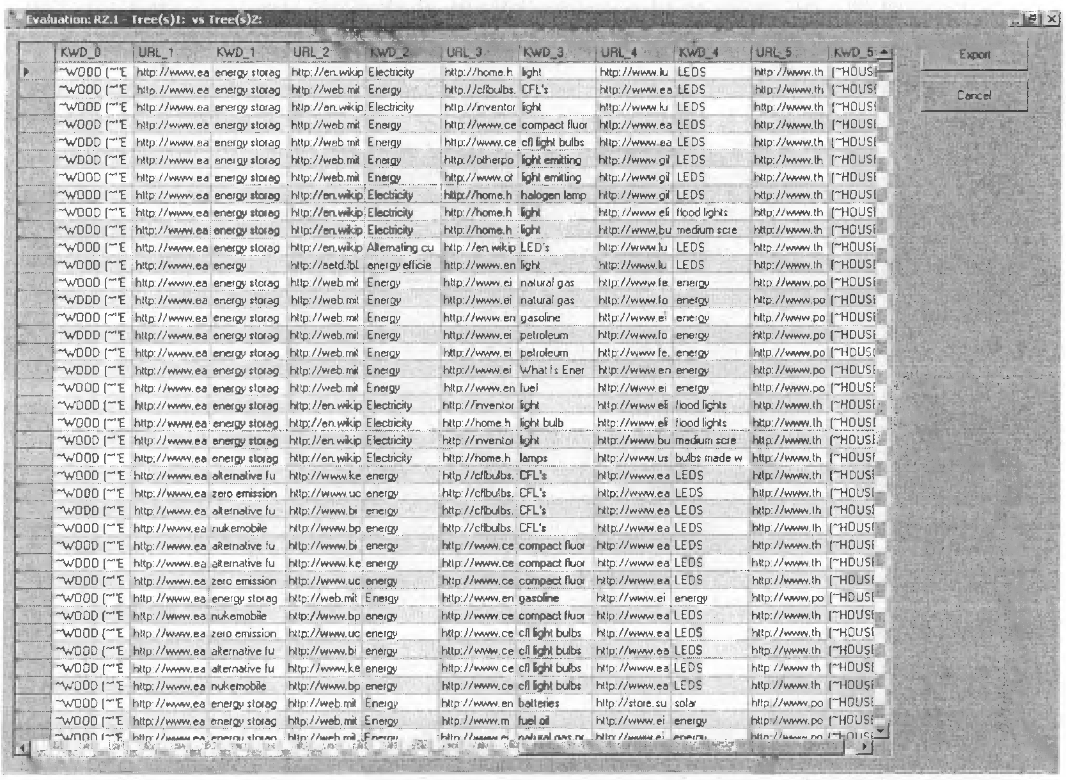


Figure L.7: Evaluation

The graphical representation of the results happens in the form of a box-and-arrows flowdiagram, and a list of corresponding URLs (see appendix N). In order to compile the diagram based on the generated data, a MiKTeX 2.4 environment is being utilised.[1] A Yet Another Previewer (YAP) 2.4.1803 DVI-viewer suffices for displaying the graph, which is included in the standard MiKTeX package.

On top and at the bottom of the flow sheet superstructure, the starting points

[1]It is a system requirement to have a MiKTeX 2.4 (or higher) framework installed on the user machine for being able to run the graphical representation.

of the tree matching exercise are displayed. All subsequent keywords are connected via arrows. All connected URLs of a keyword are displayed as a number in the respective keyword box. This number helps to find the connected URL in the list of URLs. Matching keywords in both trees have been connected with dotted lines.

The goal of this graphical representation is to give the user an overview of the top 10 results of an option tree matching exercise. To display more than 10 results would render the graphical representation unclear and confusing.

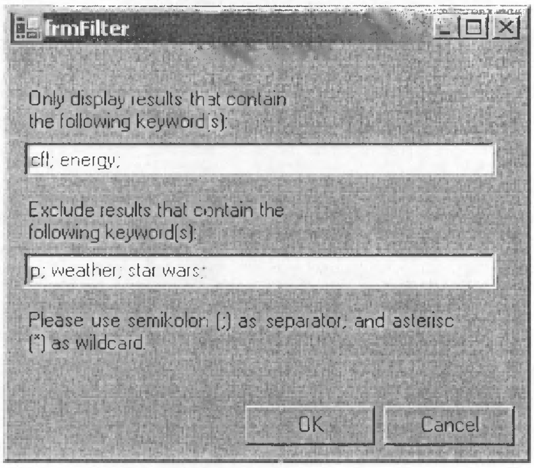


Figure L.8: Filter

As depicted by figure L.8, a filter can be utilised for the refinement of displayed results, applying for both the tabular and graphical representation. The user can specify a list of words that must be included in the displayed result chains, and a list of words that are not allowed in the result chains. Furthermore, the option is given to add the excluding words to the table of excluding words utilised for the generation of option trees.

Appendix M

Performance Analysis - Option Tree Generation

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
5	4	19,68444	4,921111	29,28302		
6	4	20,21056	5,052639	35,82591		
7	4	13,32917	3,332292	4,894144		
8	4	47,17194	11,79299	170,0072		
9	4	39,49222	9,873056	52,66337		
A	5	49,61417	9,922833	11,7611		
B	5	53,52194	10,70439	191,4801		
C	5	21,92917	4,385833	10,33452		
D	5	14,82306	2,964611	1,993203		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	211,1723	4	52,79309	0,97299	0,457736	3,259167
Columns	226,9178	3	75,63926	1,394051	0,292272	3,490295
Error	651,1032	12	54,2586			
Total	1089,193	19				

Figure M.1: ANOVA Experiment Duration by Series and Scenario

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
5	4	29582	7395,5	1,9E+08		
6	4	23757	5939,25	74465588		
7	4	22359	5589,75	51178721		
8	4	28736	7184	58906913		
9	4	39552	9888	92603063		
A	5	97305	19461	23615602		
B	5	31695	6339	60924032		
C	5	14158	2831,6	2351171		
D	5	828	165,6	12353,8		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	45784854	4	11446213	0,455076	0,767187	3,259167
Columns	1,1E+09	3	3,66E+08	14,55394	0,000266	3,490295
Error	3,02E+08	12	25152315			
Total	1,45E+09	19				

Figure M.2: ANOVA Number of Connectors per Experiment by Series and Scenario

M. PERFORMANCE ANALYSIS - OPTION TREE GENERATION

Appendix N

Option Trees

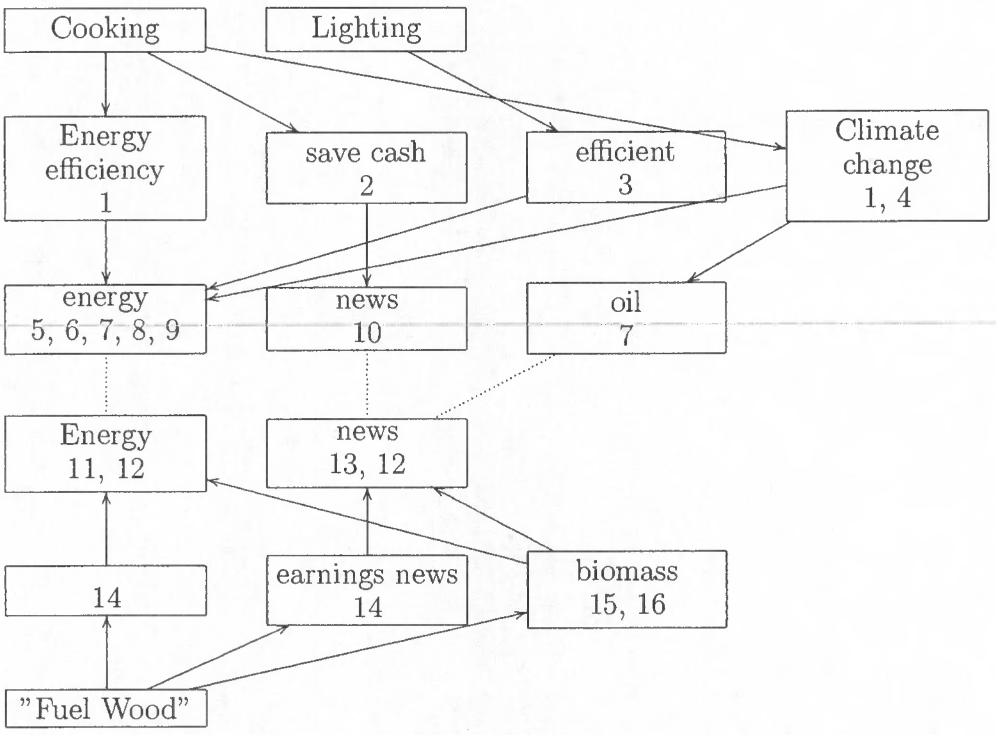


Figure N.1: Option Tree - R1.1 Top 10 Results

List of Websites - R1.1 Top 10 Results

1 `http://www.climatecare.org/projects/index.cfm`
2 `http://www.foe.co.uk/living/tips/cooking_veggies.html`
3 `http://www.energystar.gov/index.cfm?c=lighting.pr_lighting`
4 `http://www.climatecare.org/guardian/money/index.cfm`
5 `http://www.energystar.gov/`
6 `http://www.efficientwindows.org/`
7 `http://www.iea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4106`
8 `http://climate.wri.org/`
9 `http://www.climateark.org/`

10 http://www.edie.net/library/view_article.asp?id=90&channel=0

11 http://www.energyquest.ca.gov/

12 http://www.energyquest.ca.gov/story/chapter10.html

13 http://bizneworleans.com/109+M58bd72cbf54.html

14 http://www.cbsnews.com/stories/2005/11/11/business/main1039220.shtml

15 http://www.eia.doe.gov/cneaf/solar.renewables/at_a_glance/wood/woodenfa-06.htm

16 http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/html/woodenfa-06.htm

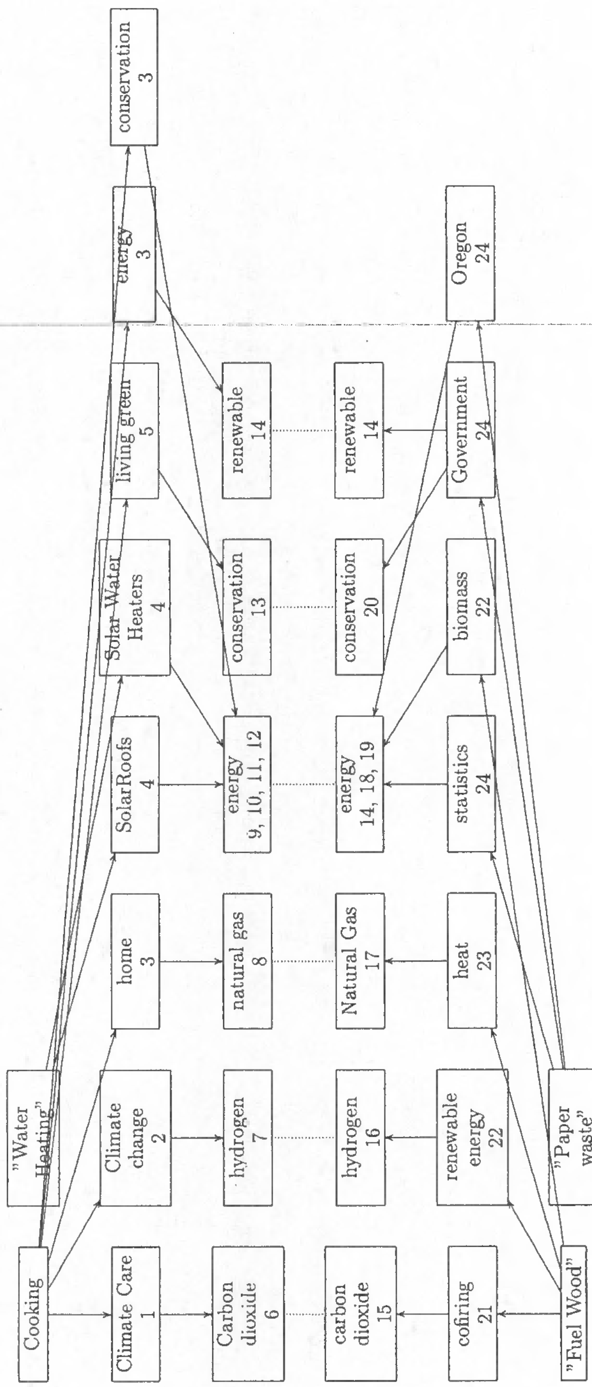


Figure N.2: Option Tree - R1.2 Top 10 Results

List of Websites - R1.2 Top 10 Results

1 http://www.climatecare.org/guardian/money/index.cfm
2 http://www.climatecare.org/projects/index.cfm
3 http://www.focusonenergy.com/page.jsp?pageId=1293
4 http://www.solarroofs.com/
5 http://www.foe.co.uk/living/tips/cooking_veggies.html
6 http://www.climatecare.org/guardian/
7 http://www.iea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4106
8 http://www.fe.doe.gov/
9 http://www.renewableenergyaccess.com/rea/market/business/viewstory?id=32636
10 http://www.solarenergy.com/
11 http://www.renewableenergyaccess.com/rea/news/story?id=45343
12 http://www.ukace.org/
13 http://www.nrdc.org/cities/living/default.asp
14 http://www.eia.doe.gov/
15 http://www.epa.gov/cleanrgy/renew.htm
16 http://www.crest.org/
17 http://www.energyquest.ca.gov/story/chapter01.html
18 http://www.oregon.gov/ENERGY/RENEW/Biomass/BiomassHome.shtml
19 http://egov.oregon.gov/ENERGY/
20 http://www.focusonenergy.com/page.jsp?pageId=244
21 http://www.fpl.fs.fed.us/documnts/techline/wood-biomass-for-energy.pdf
22 http://www.eia.doe.gov/cneaf/solar.renewables/at_a_glance/wood/woodenfa-06.htm
23 http://www.cbsnews.com/stories/2005/11/11/business/main1039220.shtml
24 http://www.metro-region.org/article.cfm?articleid=5574

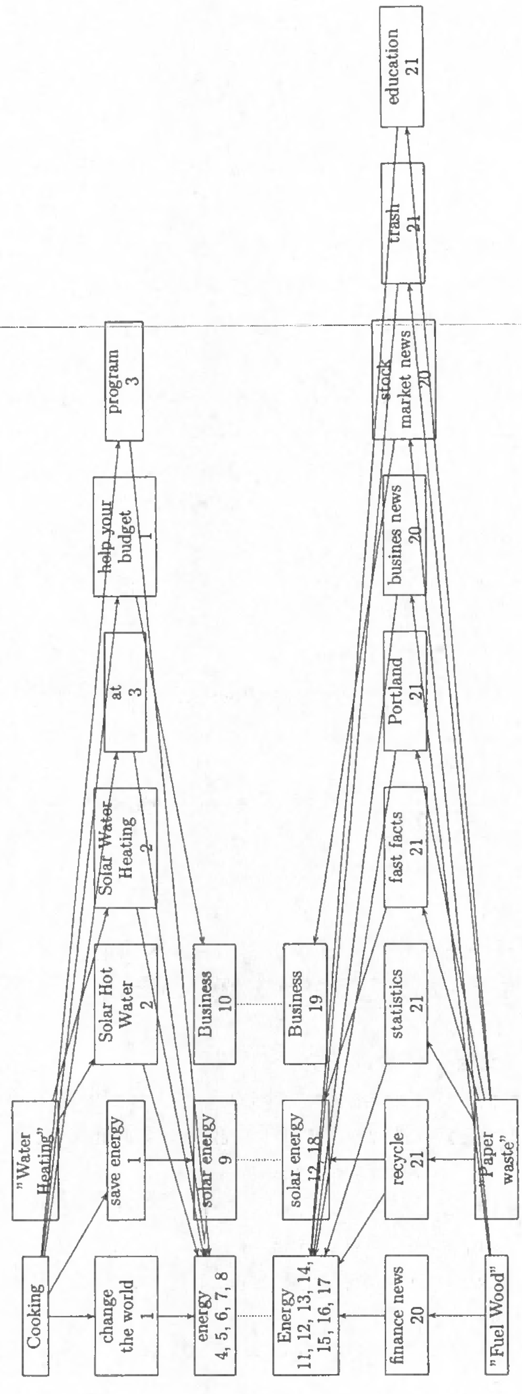


Figure N.3: Option Tree - R1.3 Top 10 Results

List of Websites - R1.3 Top 10 Results

1 http://www.foe.co.uk/living/tips/cooking_veggies.html
2 http://www.solarroofs.com/
3 http://www.focusonenergy.com/page.jsp?pageId=1293
4 http://www.energy.ky.gov/dre3/efficiency/changelight05.htm
5 http://www.greenbuilder.com/sourcebook/HeatCool.html
6 http://www.solarenergy.com/
7 http://www.nrel.gov/
8 http://www.focusonenergy.com/
9 http://hes.lbl.gov/
10 http://www.energystar.gov/index.cfm?c=business.bus_internet_presentations
11 http://www.nrglink.com/
12 http://energy.sourceguides.com/businesses/byB/serv/recycle/recycle.shtml
13 http://energy.cr.usgs.gov/energy/stats_ctry/Stat1.html
14 http://www.portlandgeneral.com/
15 http://www.citizenscampaign.org/cce_in_the_news.htm
16 http://www.energyquest.ca.gov/story/chapter10.html
17 http://www.energyquest.ca.gov/
18 http://www.solarbuzz.com/FastFactsGermany.htm
19 http://finance.yahoo.com/
20 http://www.cbsnews.com/stories/2005/11/11/business/main1039220.shtml
21 http://www.metro-region.org/article.cfm?articleid=5574

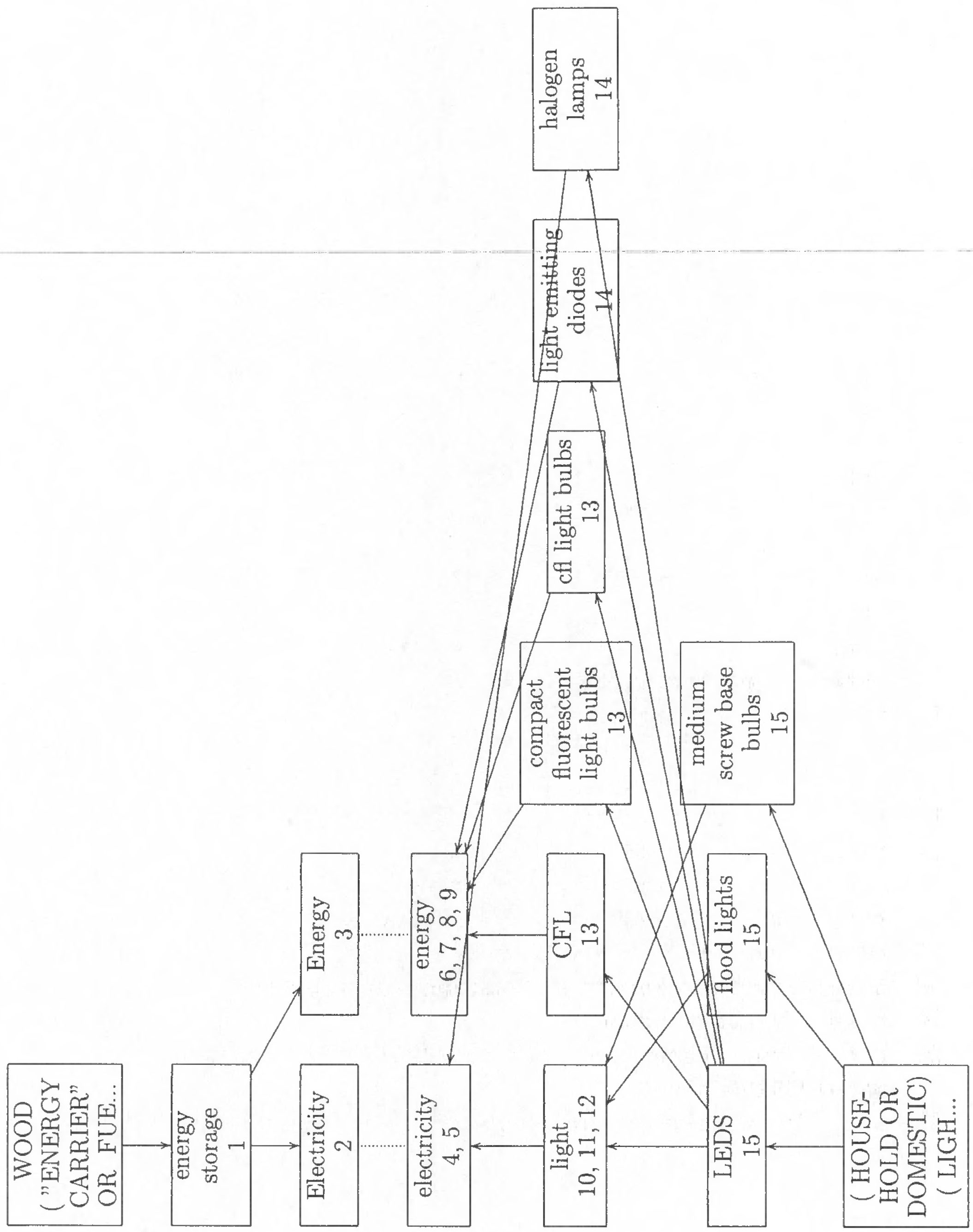


Figure N.4: Option Tree - R2.1 Top 10 Results

List of Websites - R2.1 Top 10 Results

1 http://www.eagle.ca/~gcowan/boron_blast.html
2 http://en.wikipedia.org/wiki/Grid_energy_storage
3 http://web.mit.edu/newsoffice/2006/batteries-0208.html
4 http://home.howstuffworks.com/question151.htm
5 http://inventors.about.com/library/weekly/aa980107.htm
6 http://cflbulbs.com/
7 http://www.cetsolar.com/compactfluorescent.htm
8 http://otherpower.com/otherpower_lighting_leds.html
9 http://www.otherpower.com/otherpower_lighting_leds.html
10 http://www.lumileds.com/
11 http://www.elights.com/fluor-flood.html
12 http://www.bulbs.com/products/product.asp?page=products\&class=692
13 http://www.eartheasy.com/live_energyeff_lighting.htm
14 http://www.gilway.com/
15 http://www.theledlight.com/120-VAC-LEDbulbs.html

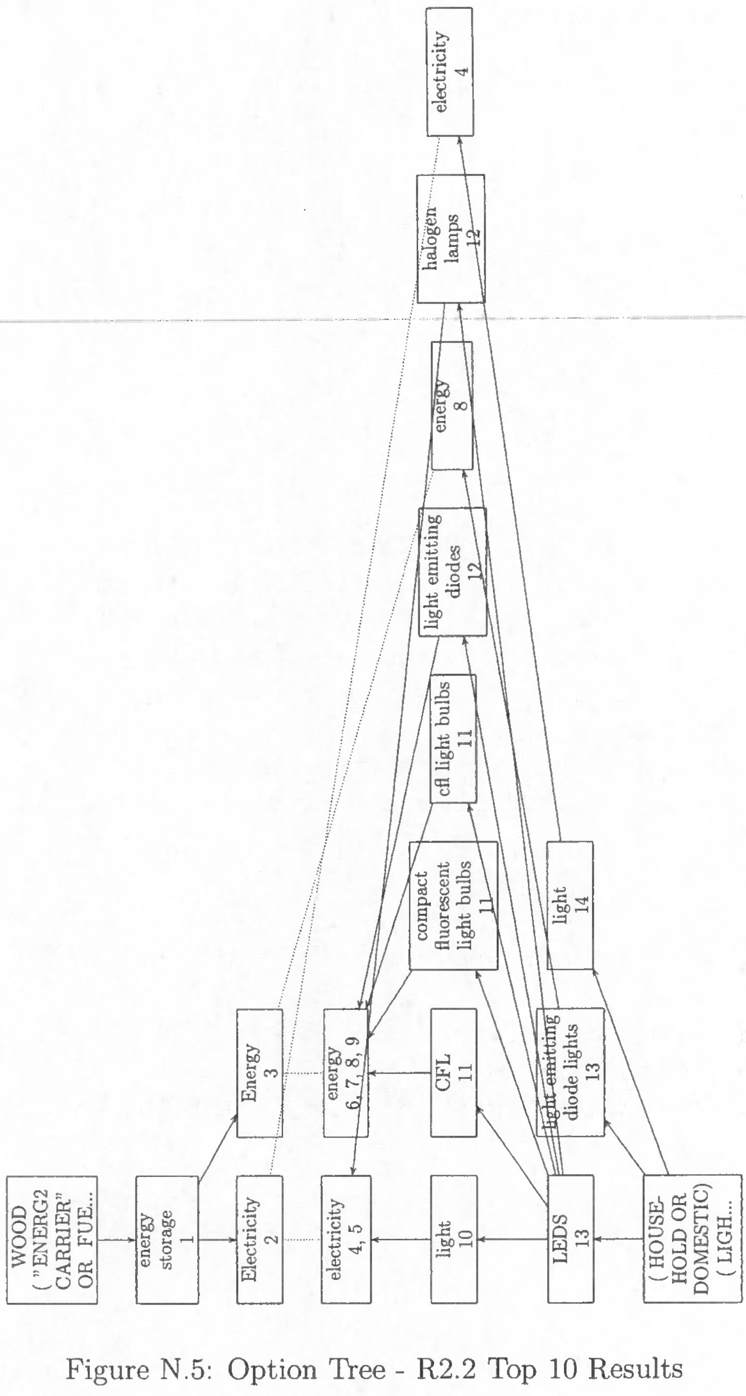


Figure N.5: Option Tree - R2.2 Top 10 Results

List of Websites - R2.2 Top 10 Results

1 http://www.eagle.ca/~gcowan/boron_blast.html
2 http://en.wikipedia.org/wiki/Grid_energy_storage
3 http://web.mit.edu/newsoffice/2006/batteries-0208.html
4 http://home.howstuffworks.com/question151.htm
5 http://inventors.about.com/library/weekly/aa980107.htm
6 http://cflbulbs.com/
7 http://www.cetsolar.com/compactfluorescent.htm
8 http://otherpower.com/otherpower_lighting_leds.html
9 http://www.otherpower.com/otherpower_lighting_leds.html
10 http://www.lumileds.com/
11 http://www.eartheasy.com/live_energyeff_lighting.htm
12 http://www.gilway.com/
13 http://www.theledlight.com/120-VAC-LEDbulbs.html
14 http://www.sizes.com/home/incandescent_household_light_bul.htm

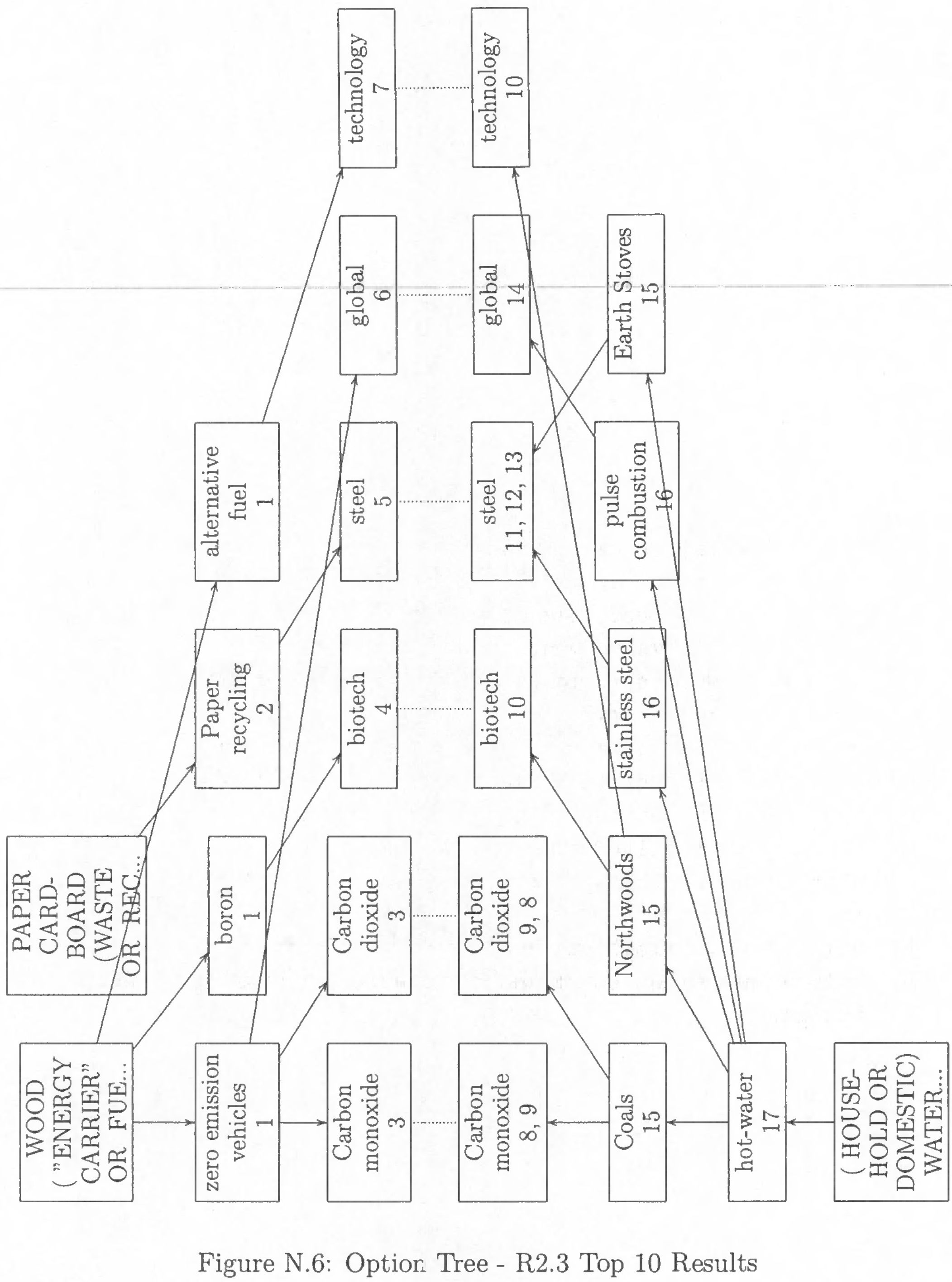


Figure N.6: Option Tree - R2.3 Top 10 Results

List of Websites - R2.3 Top 10 Results

1 http://www.eagle.ca/~gcowan/boron_blast.html
2 http://en.wikipedia.org/wiki/Paper_recycling
3 http://en.wikipedia.org/wiki/Zero-emissions_vehicle
4 http://www.netsci.org/Resources/Biotech/Yellowpages/B/boron.html
5 http://www.wasteonline.org.uk/resources/InformationSheets/paper.htm
6 http://www.ucsusa.org/clean_vehicles/cars_pickups_suvs/californias-zero-emission-vehicle-zev-program.html
7 http://www.popularmechanics.com/science/earth/2690341.html
8 http://en.wikipedia.org/wiki/Hygas
9 http://en.wikipedia.org/wiki/Manufactured_gas
10 http://wistechnology.com/article.php?id=3164
11 http://www.plumbingworld.com/waterconnectors.html
12 http://www.oldhouseweb.com/suppliers_of/13754_Solid-Fuel_Stoves_.shtml
13 http://www.oldhouseweb.com/suppliers_of/11268_Pellet_Stoves_.shtml
14 http://www.achrnews.com/CDA/ArticleInformation/RegionalNews_Item/1,6084,12716-East,00.html
15 http://www.charmaster.com/
16 http://www.hydrotherm.com/
17 http://www.popularmechanics.com/outdoors/tread_lightly/2723176.html

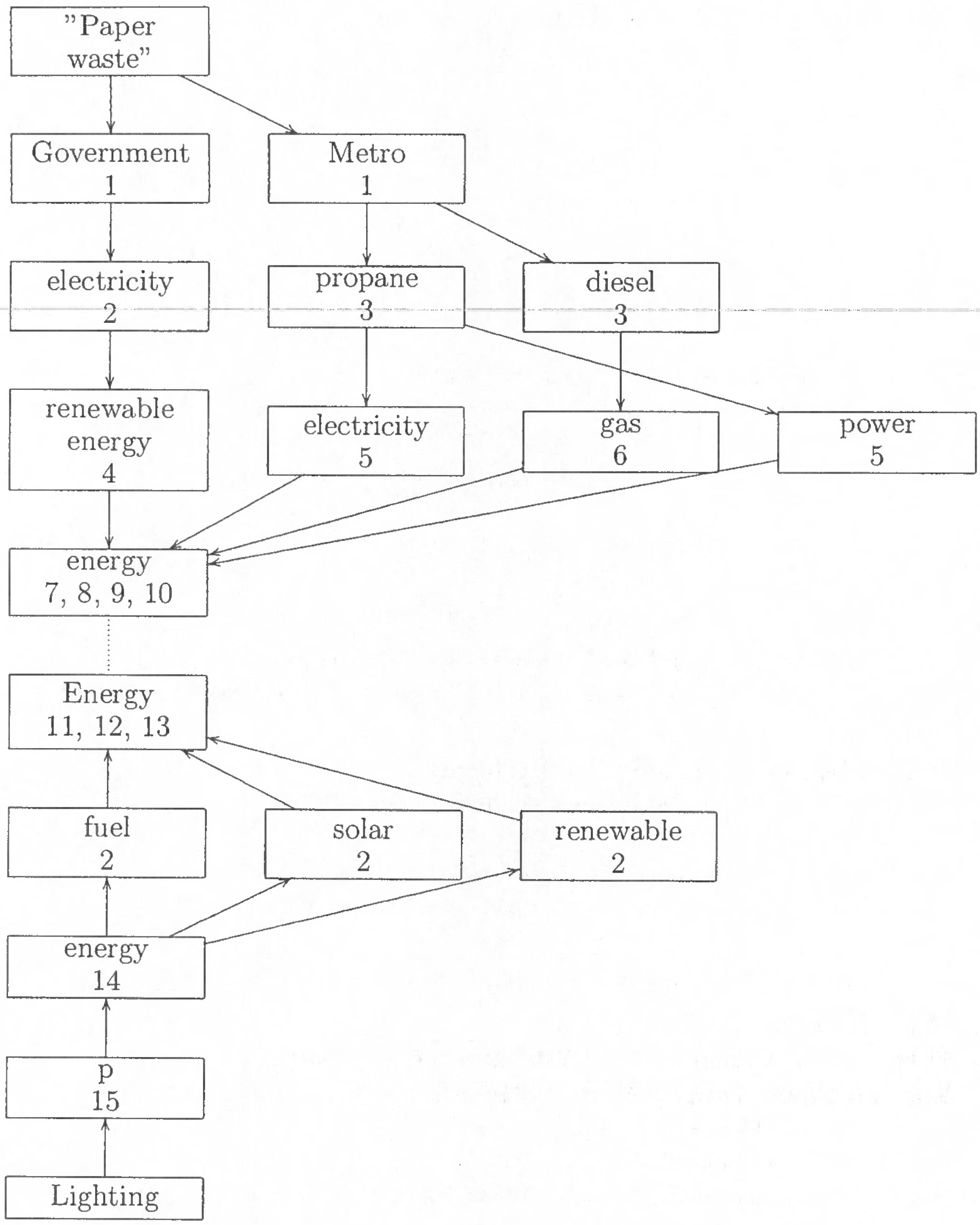


Figure N.7: Option Tree - R3.1 Top 10 Results

List of Websites - R3.1 Top 10 Results

1 http://www.metro-region.org/article.cfm?articleid=5574
2 http://www.eia.doe.gov/
3 http://www.metroenergy.com/
4 http://www.ferc.gov/
5 http://www.clarkenergy.com/prop.phtml
6 http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp
7 http://www.focusonenergy.com/portal.jsp?pageId=11
8 http://www.kidzworld.com/site/p1375.htm
9 http://www.semcoenergygas.com/
10 http://www.khake.com/page49.html
11 http://www.energyquest.ca.gov/story/chapter08.html
12 http://www.solarenergy.com/
13 http://www.teachers.ash.org.au/jmresources/energy/renewable.html
14 http://science.howstuffworks.com/roller-coaster2.htm
15 http://www.cl-p.com/clmres/energystar/lightingtips.asp

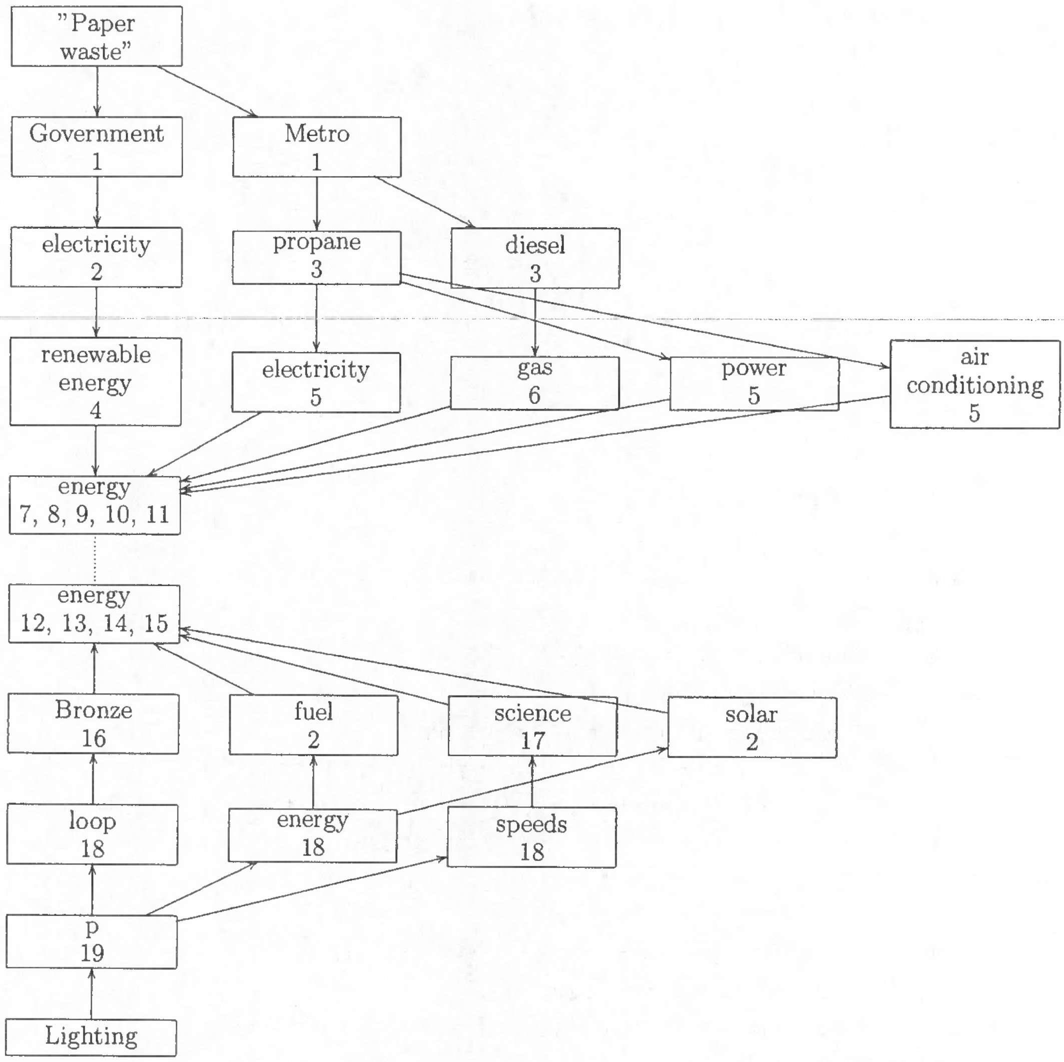


Figure N.8: Option Tree - R3.2 Top 10 Results

List of Websites - R3.2 Top 10 Results

1 http://www.metro-region.org/article.cfm?articleid=5574
2 http://www.eia.doe.gov/
3 http://www.metroenergy.com/
4 http://www.ferc.gov/
5 http://www.clarkenergy.com/prop.phtml
6 http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp
7 http://www.focusonenergy.com/portal.jsp?pageId=11
8 http://www.kidzworld.com/site/p1375.htm
9 http://www.semcoenergygas.com/
10 http://www.khake.com/page49.html
11 http://web.mit.edu/newsoffice/2006/buildings.html
12 http://www.sandi.net/energy/Page.asp?CategoryID=9\
&PageID=39
13 http://www.energyquest.ca.gov/story/chapter08.html
14 http://www.osti.gov/
15 http://www.solarenergy.com/
16 http://www.sculpture.net/community/showthread.php?t=2383
17 http://www.earthsky.com/shows/edgeofdiscovery.php?date=
20050217
18 http://science.howstuffworks.com/roller-coaster2.htm
19 http://www.cl-p.com/clmres/energystar/lightingtips.asp

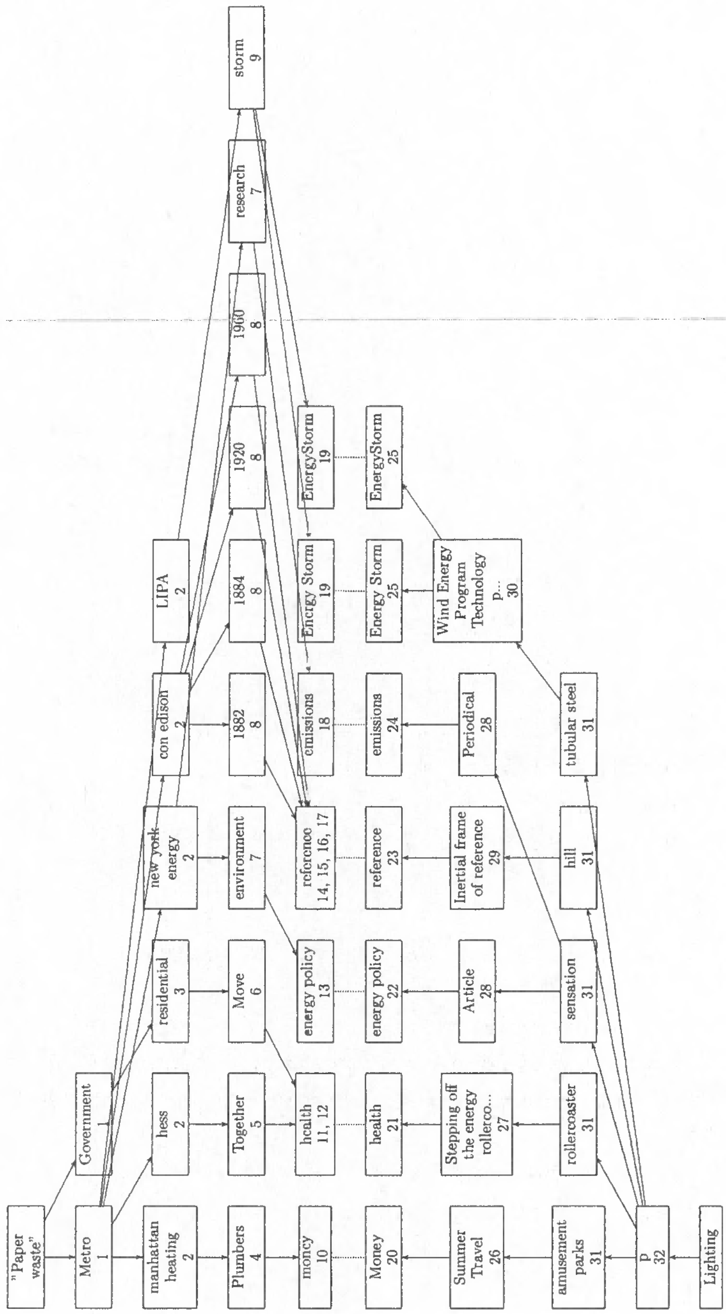


Figure N.9: Option Tree - R3.3 Top 10 Results

List of Websites - R3.3 Top 10 Results

1 http://www.metro-region.org/article.cfm?articleid=5574
2 http://www.metroenergy.com/
3 http://www.eia.doe.gov/
4 http://www.ndcpub.com/Category/Plumbers/Kansas/Manhattan/
5 http://tdworld.com/news/power_peoples_energy_hess/
6 http://www.txu.com/us/default.asp
7 http://www.nyserda.org/
8 http://en.wikipedia.org/wiki/Con_Edison
9 http://www.lipower.org/
10 http://weblogs.csmonitor.com/verbal_energy/
11 http://www.ionicsalts.com/aesthetics.htm
12 http://newsfromrussia.com/world/2006/01/05/70827.html
13 http://eetd.lbl.gov/
14 http://www.answers.com/topic/1882
15 http://www.answers.com/topic/1884
16 http://www.answers.com/topic/1920
17 http://www.answers.com/topic/1960
18 http://www.caer.uky.edu/
19 http://www.energystorm.us/
20 http://www.nbc4.com/consumer/9226785/detail.html
21 http://www.findarticles.com/p/articles/mi_m0FKA/is_n1_v60
22 http://www.grinningplanet.com/5005/energy-resources.htm
23 http://www.answers.com/topic/inertial-frame-of-reference
24 http://ecen.com/eee53/eee53e/ecen_53e_capital_productivity.htm
25 http://www.energystorm.us/Low_Wind_Speed_Technology_Phase_Ii_Development_Of_A_2_mw_Direct_drive_Wind_Turbine_For_Low_Wind_Speed_Sites_Northern_Power_Systems-r650858.html
26 http://www.forbes.com/travel/2006/05/31/world-amusement-parks_cx_sb_0601feat_ls.html
27 http://www.findarticles.com/p/articles/mi_m0FKA/is_n1_v60/ai_20152535
28 http://goliath.ecnext.com/coms2/summary_0199-4657655_ITM
29 http://en.wikipedia.org/wiki/Kinetic_energy
30 http://www.nrel.gov/docs/fy06osti/37942.pdf
31 http://science.howstuffworks.com/roller-coaster2.htm
32 http://www.cl-p.com/clmres/energystar/lightingtips.asp

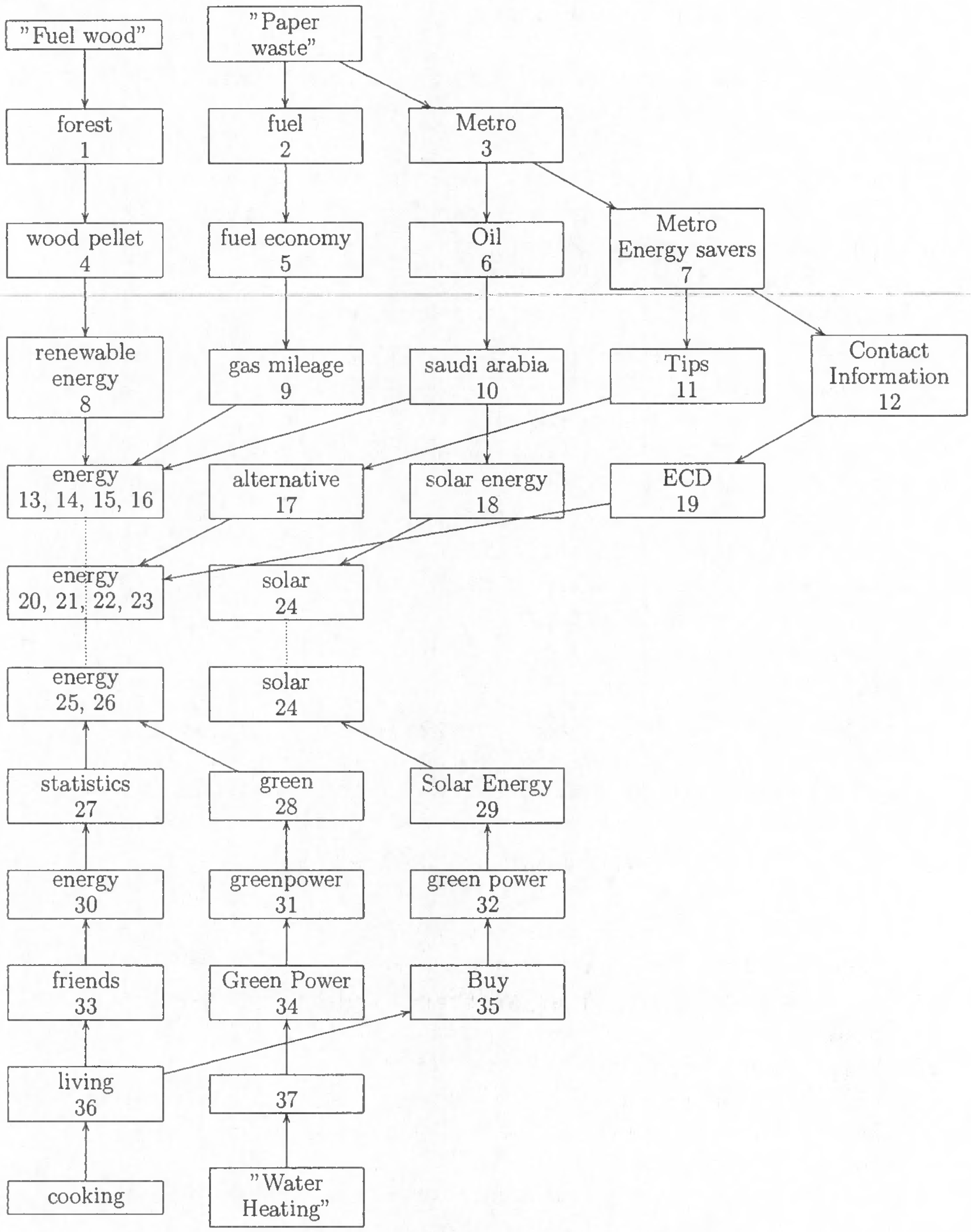


Figure N.10: Option Tree - R4.1 Top 10 Results

List of Websites - R4.1 Top 10 Results

1 http://www.eia.doe.gov/cneaf/solar.renewables/page/wood/wood.html
2 http://www.wasteage.com/mag/waste_wasteenergy_paperderived_fuels/index.html
3 http://www.metro-region.org/article.cfm?articleid=5574
4 http://www.forestenergy.com/
5 http://www.fueleconomy.gov/
6 http://www.metroenergy.com/
7 http://www.metroenergysavers.com/
8 http://www.renewableenergyaccess.com/rea/news/podcast?id=45010
9 http://www.fueleconomy.gov/feg/findacar.htm
10 http://www.eia.doe.gov/emeu/cabs/saudi.html
11 http://www.metroenergysavers.com/tipsglossary.asp
12 http://www.metroenergysavers.com/contactus.asp
13 http://www.focusonenergy.com/page.jsp?pageId=806
14 http://www.focusonenergy.com/portal.jsp?pageId=11
15 http://www.energy.iastate.edu/news/pr/pr-gasmileage.html
16 http://www.eia.doe.gov/emeu/international/saudi.html
17 http://www.knowledgehound.com/topics/altenerg.htm
18 http://energy.sourceguides.com/businesses/byGeo/byC/SaudiArabia/SaudiArabia.shtml
19 http://www.ovonic.com/contactus.htm
20 http://www.backwoodshome.com/energy.html
21 http://www.ovonic.com/sol_srv/3_1_solar_sol/solar_solutions.htm
22 http://www.ovonic.com/our_company/1_5_jobs/careers.htm
23 http://www.ovonic.com/our_company/1_0_ourco.htm
24 http://www.solarenergy.com/
25 http://eia.doe.gov/
26 http://www.nrglink.com/
27 http://www.eia.doe.gov/
28 http://www.eere.energy.gov/greenpower/buying/buying_power.shtml
29 http://www.montanagreenpower.com/
30 http://www.sustainable.energy.sa.gov.au/pages/programs/households/households.htm
31 http://www.eere.energy.gov/greenpower/
32 http://www.moea.state.mn.us/energy/greenpower.cfm

33 http://profile.myspace.com/index.cfm?fuseaction=user.viewprofile\&friendid=34521408
34 http://bbs.electric-entertainment.com/archive/index.php/t-1259.html
35 http://www.nextag.com/energy-living/search-html
36 http://www.foe.co.uk/living/tips/cooking_veggies.html
37 http://www.tanklesswaterheaters.com/

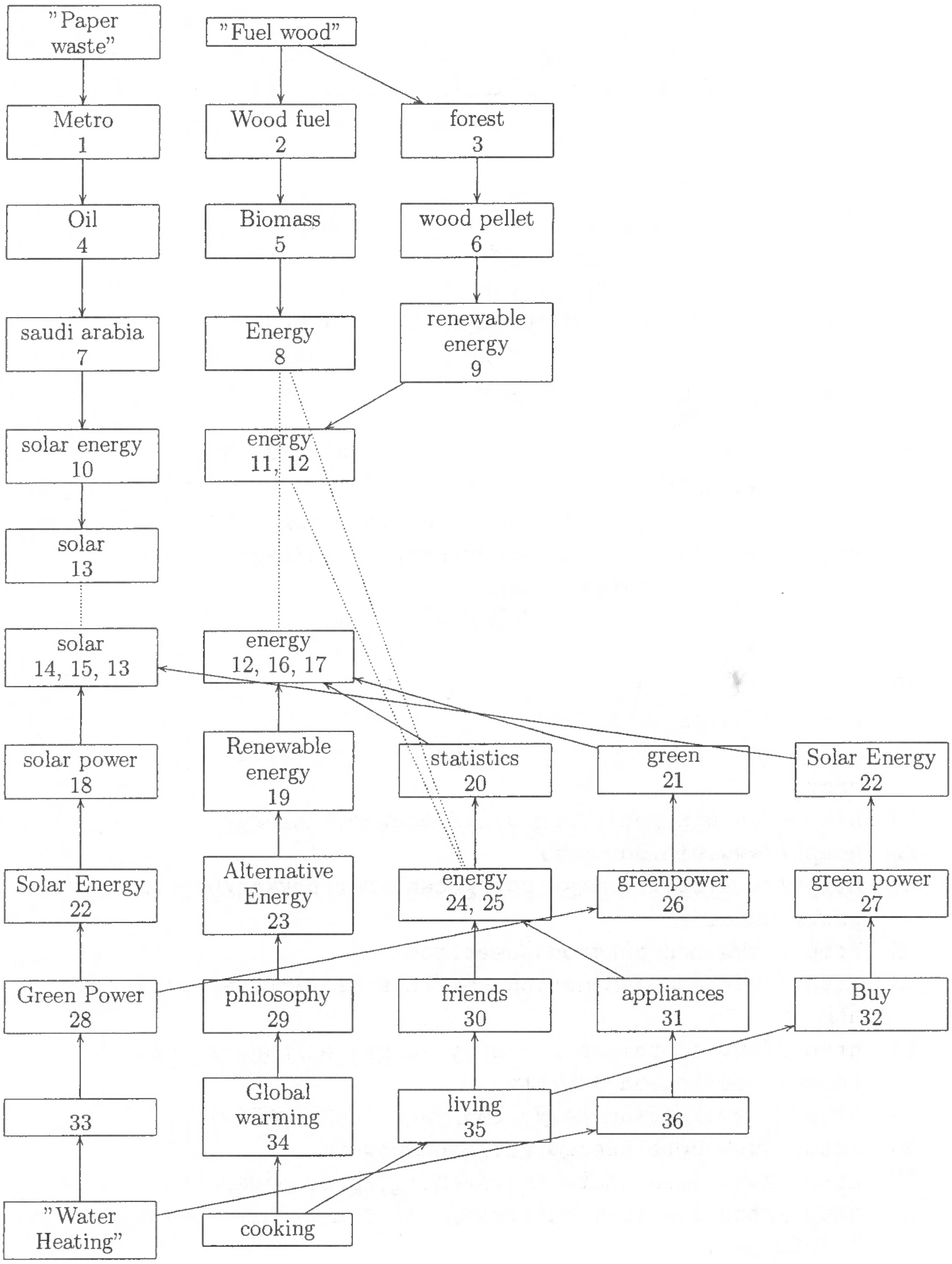


Figure N.11: Option Tree - R4.2 Top 10 Results

N. OPTION TREES

List of Websites - R4.2 Top 10 Results

1 http://www.metro-region.org/article.cfm?articleid=5574
2 http://en.wikipedia.org/wiki/Wood_fuel
3 http://www.eia.doe.gov/cneaf/solar.renewables/page/wood/wood.html
4 http://www.metroenergy.com/
5 http://www.fpl.fs.fed.us/documnts/techline/wood-biomass-for-energy.pdf
6 http://www.forestenergy.com/
7 http://www.eia.doe.gov/emeu/cabs/saudi.html
8 http://www.energyquest.ca.gov/story/chapter10.html
9 http://www.renewableenergyaccess.com/rea/news/podcast?id=45010
10 http://energy.sourceguides.com/businesses/byGeo/byC/SaudiArabia/SaudiArabia.shtml
11 http://www.focusonenergy.com/page.jsp?pageId=806
12 http://www.focusonenergy.com/portal.jsp?pageId=11
13 http://www.solarenergy.com/
14 http://www.solarserver.de/index-e.html
15 http://www.homepower.com/
16 http://eia.doe.gov/
17 http://www.nrglink.com/
18 http://www.sciencedaily.com/news/matter_energy/solar_energy/
19 http://en.wikipedia.org/wiki/Renewable_energy
20 http://www.eia.doe.gov/
21 http://www.eere.energy.gov/greenpower/buying/buying_power.shtml
22 http://www.montanagreenpower.com/
23 http://www.spaceandmotion.com/Physics-Alternative-Energy.htm
24 http://www.sustainable.energy.sa.gov.au/pages/programs/households/households.htm
25 http://www.focusonenergy.com/page.jsp?pageId=27
26 http://www.eere.energy.gov/greenpower/
27 http://www.moea.state.mn.us/energy/greenpower.cfm
28 http://bbs.electric-entertainment.com/archive/index.php/t-1259.html

29 http://www.working-minds.com/energy.htm

30 http://profile.myspace.com/index.cfm?fuseaction=user.viewprofile\&friendid=34521408

31 http://www.energystar.gov/

32 http://www.nextag.com/energy-living/search-html

33 http://www.tanklesswaterheaters.com/

34 http://www.climatecare.org/projects/index.cfm

35 http://www.foe.co.uk/living/tips/cooking_veggies.html

36 http://www.energyright.com/waterheat/index.htm

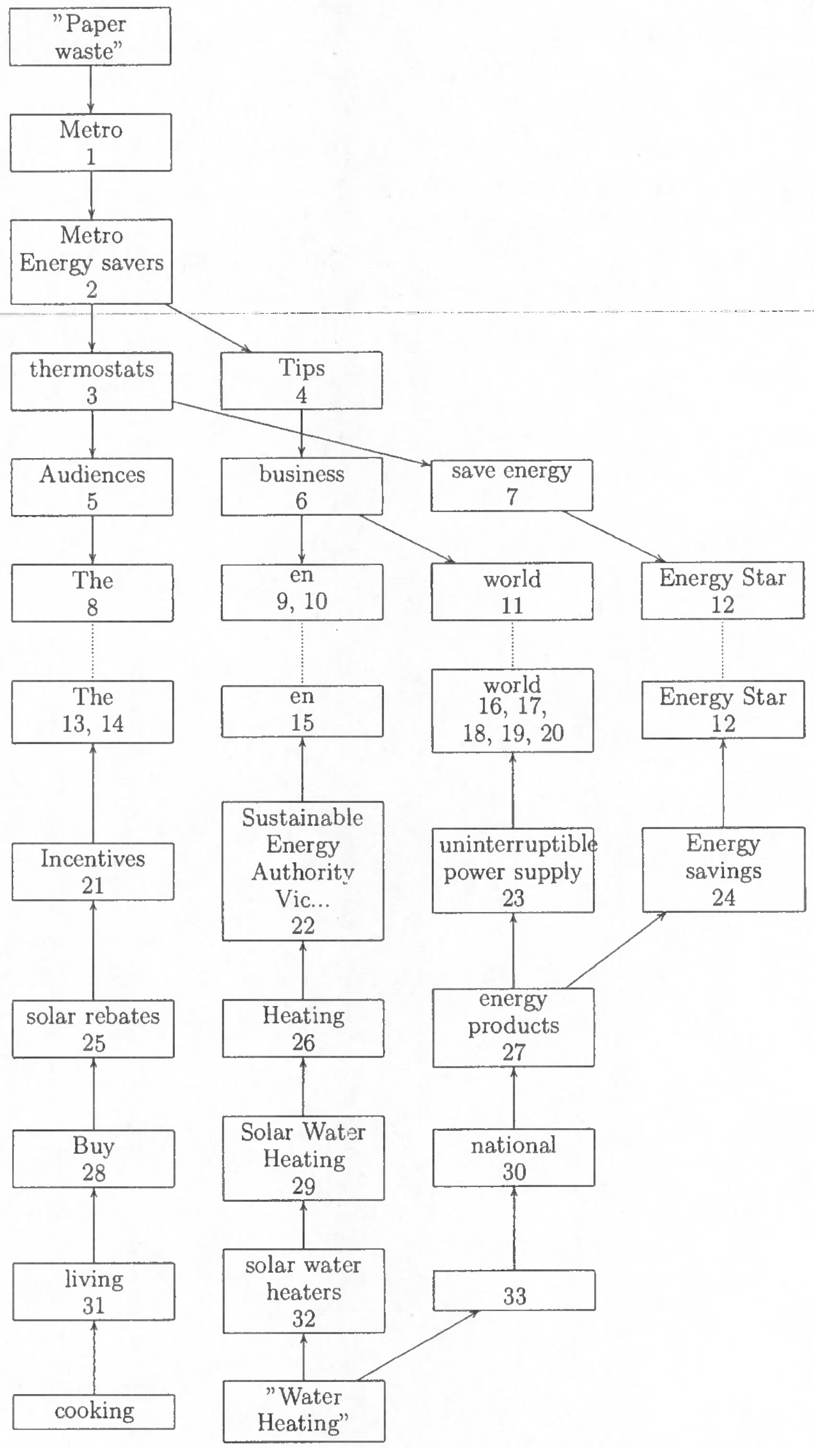


Figure N.12: Option Tree - R4.3 Top 10 Results

List of Websites - R4.3 Top 10 Results

1 http://www.metro-region.org/article.cfm?articleid=5574
2 http://www.metroenergysavers.com/
3 http://www.metroenergysavers.com/tipsthermostats.asp
4 http://www.metroenergysavers.com/tipsglossary.asp
5 http://www.energystar.gov/index.cfm?c=thermostats.pr_thermostats
6 http://www.pge.com/biz/energy_tools_resources/small_biz/
7 http://www.espenergy.com/thermostats.htm
8 http://www.eere.energy.gov/greenpower/conference/10gpmc05/aboussie.pdf
9 http://www.energy-business-review.com/
10 http://www.mitsubishicorp.com/en/bg/energy/udev.html
11 http://energy.sourceguides.com/businesses/index.shtml
12 http://hes.lbl.gov/
13 http://cansia.ca/government.asp
14 http://www.cansia.ca/government.asp
15 http://www.austehc.unimelb.edu.au/asaw/biogs/A001651b.htm
16 http://energy.sourceguides.com/businesses/byP/ups/byB/serv/install/install.shtml
17 http://energy.sourceguides.com/businesses/byP/ups/byGeo/byGeo.shtml
18 http://energy.sourceguides.com/businesses/byP/ups/UPS.shtml
19 http://energy.sourceguides.com/businesses/byP/ups/byB/mfg/mfg.shtml
20 http://energy.sourceguides.com/businesses/byP/ups/byB/mfg/byGeo/byGeo.shtml
21 http://www.dsireusa.org/
22 http://www.sustainable-energy.vic.gov.au/SEInfo/your-home/heating/
23 http://www.stacoenergy.com/
24 http://www.essnrg.com/
25 http://www.consumerenergycenter.org/erprebate/
26 http://www.greenbuilder.com/sourcebook/HeatCool.html
27 http://www.nee.ca/
28 http://www.nextag.com/energy-living/search-html
29 http://www.solarroofs.com/

30 http://www.nrel.gov/
31 http://www.foe.co.uk/living/tips/cooking_veggies.html
32 http://www.aetsolar.com/
33 http://www.energyright.com/waterheat/index.htm

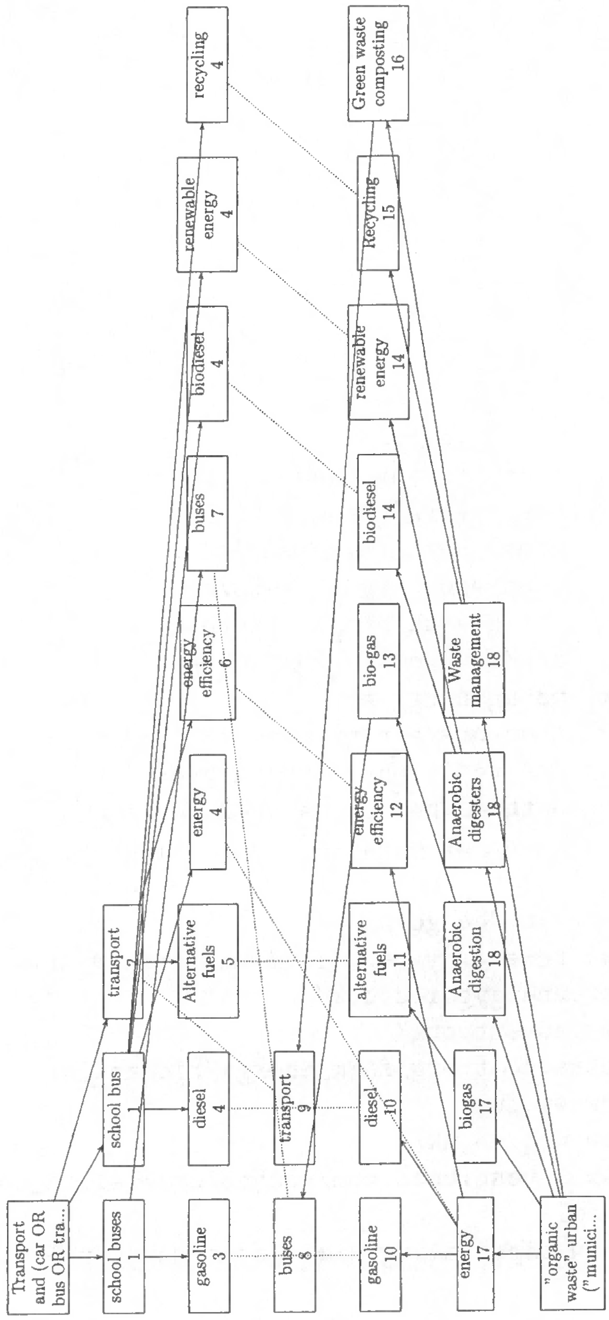


Figure N.13: Option Tree - V1 Top 10 Results

List of Websites - V1 Top 10 Results

1 http://www.stnonline.com/
2 http://ec.europa.eu/environment/air/transport.htm
3 http://www.ucsusa.org/clean_vehicles/big_rig_cleanup/alternative-fuel-school-buses.html
4 http://www.biodiesel.org/markets/sch/
5 http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_029321.hcsp
6 http://www.managenergy.net/
7 http://www.nrdc.org/air/transportation/qbus.asp
8 http://engines.tedom.eu/stationary-engines-bio-gas.html
9 http://www.bathnes.gov.uk/BathNES/media/press+releases/2006/Environment/Green+waste+composting+helps+council+scheme.htm
10 http://www.eia.doe.gov/
11 http://www.re-energy.ca/t-i_biomassenergy.shtml
12 http://www.energyguide.com/
13 http://www.adnett.org/
14 http://attra.ncat.org/farm_energy/biomass.html
15 http://www.wm.com/
16 http://www.wrg.co.uk/
17 http://www.livescience.com/technology/041103_convert_garbage.html
18 http://en.wikipedia.org/wiki/Waste_management

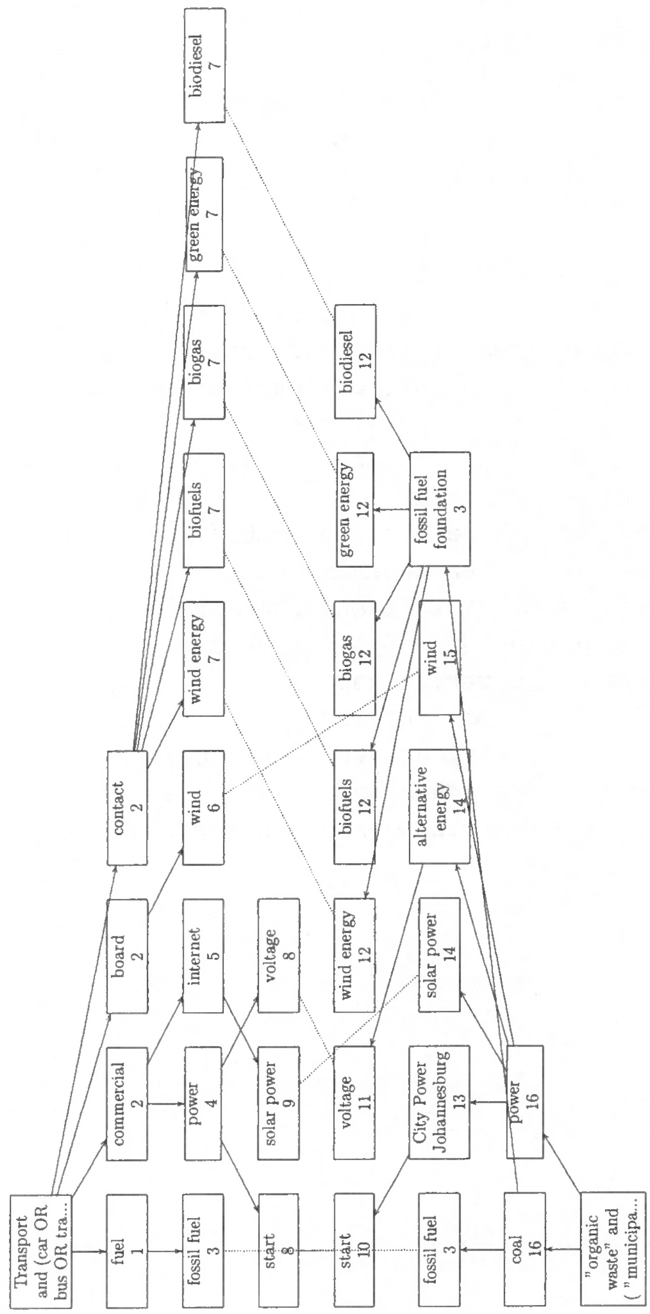


Figure N.14: Option Tree - V2 Top 10 Results

List of Websites - V2 Top 10 Results

1 http://motoring.iafrica.com/buyingacar/458141.htm
2 http://www.news24.com/News24/World/News/0,,2-10-1462_2050353,00.html
3 http://www.fossilfuel.co.za/
4 http://www.southafrica.info/doing_business/economy/key_sectors/energy.htm
5 http://www.mbendi.co.za/indy/oilg/af/bo/p0005.htm
6 http://www.afriwea.org/en/board.htm
7 http://www.agama.co.za/index.php?option=com_contact\&task=view\&contact_id=1\&Itemid=17
8 http://www.eagle.co.za/display_cat.php?subcategory_id=352
9 http://www.gunda.co.za/
10 http://www.mybroadband.co.za/nephp/?m=show\&id=650
11 http://www.mltdrives.com/home.html
12 http://www.agama.co.za/index.php?option=com_content\&task=blogcategory\&id=6\&Itemid=53
13 http://www.citypower.co.za/
14 http://www.kgelectric.co.za/
15 http://www.southafrica.info/doing_business/economy/infrastructure/windpower.htm
16 http://www.engineeringnews.co.za/eng/features/sewage/?show=48479

Appendix O

Search Queries and Contexts

	Initial Search query (max 10 words)	Search context (max. 22 words)
Calibration		
Fuel Wood	~WOOD (~"ENERGY CARRIER" OR ~FUEL OR ~CHIPS OR ~PELLETS OR ~WASTE OR ~DUST OR ~SHAVINGS)	(~"THERMAL TREATMENT" OR ~GASIFICATION OR ~PYROLYSIS OR ~BIOLOGICAL OR ~PHYSICAL OR ~COMBUSTION OR ~FIRE OR ~BURN OR ~"CALORIFC VALUE" OR ~FERMENTATION OR ~LANDFILLING OR ~INCINERATION OR ~RECYCLING OR ~REUSE)
Paper Waste	~PAPER ~CARDBOARD (WASTE OR ~RECYCLED OR ~PULP OR ~"BLACK LIQUOR" OR ~SLUDGE OR ~EFFLUENT OR ~FIBRE)	(~"ENERGY RECOVERY" OR ~"THERMAL TREATMENT" OR ~GASIFICATION OR ~"PROCESS HEAT" OR ~PYROLYSIS OR ~BIOLOGICAL DR ~PHYSICAL OR ~COMBUSTION OR ~FIRE OR ~BURN OR ~"CALORIFC VALUE" OR ~FERMENTATION OR ~LANDFILLING OR ~INCINERATION OR ~RECYCLING OR ~REUSE)
Cooking	(~HOUSEHOLD OR ~DOMESTIC) (~COOKING OR ~"FODD PREPARATION" OR ~STEAMING OR ~GRILLING OR ~BOILING OR ~FRYING OR ~BAKING)	(~"ENERGY SOURCE" OR ~OVEN DR ~MICROWAVE OR ~FIRE OR ~STOVE OR ~"SOLAR COOKER" OR ~"BIOGEL COOKER" OR ~"BOILING WATER" OR ~"FRYING PAN" OR ~"HOT OIL" OR ~"HOT FAT" OR ~HEAT OR ~RADIATION OR ~"OPEN FLAME")
Water Heating	(~HOUSEHOLD OR ~DOMESTIC) ~WATER (~HEATING OR ~BOILING OR ~HOT OR ~COOKING)	(~ENERGY OR ~ELECTRICITY OR ~"ELECTRICITY USAGE" OR ~POWER OR ~"POWER SUPPLY" OR ~"kWh" OR ~"ELECTRIC GEYSER" OR ~"SOLAR GEYSER" OR ~"SOLAR WATER HEATER" OR ~"WATER HEATER" OR ~BOILER)
Lighting	(~HOUSEHOLD DR ~DOMESTIC) (~LIGHTING OR ~LIGHT OR ~ILLUMINATION OR ~"NATURAL ILLUMINATION" OR ~"ARTIFICIAL ILLUMINATION")	(~"ELECTRICITY USAGE" OR ~"POWER SUPPLY" OR ~"kWh" OR ~"ARTIFICIAL LIGHT" OR ~"NATURAL LIGHT" OR ~DAYLIGHT OR ~"INTERIOR DESIGN" OR ~"LIGHT BULB" OR ~CFL OR ~LED OR ~NEON OR ~FLUORESCENT OR ~INCANDESCENT OR ~XENON OR ~LAMP OR ~HALOGEN)
Verification		
Transport	~Transport and (~"land based" or ~people or ~goods)	(~Energy or ~power or ~urban or ~"fuel" or ~"energy demand" or ~"energy supply" or ~"resource" or ~"renewable" or ~"sustainable" or ~"energy carrier" or ~"technology" or ~"transformation technology" or ~"recycling" or ~"motion" or ~"mechanical energy" or ~"emission reduction" or ~"energy recovery")
Organic waste	~"organic waste" and (~"municipal solid waste" or ~"MSW" or ~sewage or ~"green waste")	(~Energy or ~power or ~urban or ~"energy demand" or ~"energy supply" or ~"resource" or ~"renewable" or ~"sustainable" or ~"energy carrier" or ~"technology" or ~"transformation technology" or ~"recycling" or ~"reuse" or ~"recycle" or ~"emission reduction" or ~"energy recovery" or ~"fuel")

Figure O.1: Specific Search Queries and Contexts