Lund University Master's Programme in
International Environmental Science

Thesis submitted in partial fulfillment of the requirements of the Masters Programme in International Environmental Science
In collaboration with the Heat and Power Technology division at KTH Energy Technology Department

Towards a Sustainable Energy Production:

A study and comparison of the coal and biomass energy production systems

Supervised by:
Barry Ness
PHD-student
Lund University Centre
for Sustainability Studies
Lund University
Sölvegatan 10
221 00 Lund, Sweden
+46 (0) 222 05 12
barry.ness@lucsus.lu.se

Submitted by:
Nélida Jocelyn Donají González Cantú
Mónaco 319 Col. San Patricio
Garza Garcia, Nuevo León
66270 México

Lund, Sweden. 21 November, 2005

ABSTRACT

The energy industry has been considered as an economic development driver. Nonetheless as the industry's productivity increases, its impacts on the environment do so as well. A main concern of the industry is the emission of GHGs meanwhile other environmental problems have been neglected, as waste generation and chemical discharges. The continuous generation of waste and release of chemicals suggests that a sustainable energy production should consider minimizing them along with GHGs and SO_2 emissions. After analyzing the coal and woody biomass energy systems it was clear that there is a lack of studies specifically on these impacts. The fuel cycles corresponding to each energy system demonstrated the impacts are accumulating. Results from the system analysis denoted that the factor that acts upon the reduction of waste and chemical releases is research and development. The coal energy system will reduce waste and chemical releases if they were seriously considered in research and development of technology especially in the mining and conversion processes. On the other hand the reduction of these impacts throughout the wood biomass energy system must take place in the research and development of crop production. Through the comparison of the impacts of each system it was determined that biomass and coal are similar; therefore there is no basis to ensure that the biomass energy system is a more sustainable solution for energy production. Nevertheless, a great concern of the study is the deficiency on evidence for either system to show the magnitude of the impacts other than air emissions. This implies that the solution for waste and chemicals through more research might be obstructed as there is not evidence that quantify or measure the impacts. Hence, foreseeing this impediment, it is concluded that a precautionary action must take place in order to promote studies and minimize these impacts.

ACKNOWLEDGEMENTS

In form of my love and appreciation I would like to dedicate this work to my parents as this project would not have been possible without their support, comprehension, and continuous encouragement.

In my personal way I would like to thank them all with no order as follows:

I would like to thank my parents once again for being there 24/7. My mom has always been my push factor. I want to thank her for having so much faith on me and making me see I can do and achieve. I want to thank my dad as he has always been an example to me. Their patience and love have given way to make of me the person I am and work really hard on this thesis.

I would like to thank my brother Sergio, for many reasons. He made possible along with my parents my studies here in Sweden. If it was not for his financial aid I would not have been able to come and pursue master's studies in the first place. He has always inspired me to look forward and seek. He has been a role model whose love for life has made me pursue goals. Also I would like to thank him for his objectiveness and encouragement.

I would like to thank my sister, Nelva, for always being there. She has lived with me all the stress and hard moments. She has been so understanding, supporting, caring, and above all patient. I want to thank her for all those days she gave me company and made me no despair in the process of the thesis. She made my crazy work days more pleasant.

I would like to thank my brother, Eduardo, for giving me ease. He has been responsible for making my stay here easier and has made everything outside school less problematic. He really brought tranquility to me and allowing me to focus on thesis work.

There are so many people who have been supporting me and have always believed in me. I want to thank Erik Durhan as he opened my view on opportunities. I want to thank Joakim Almtorp for being my homeward bound here in Sweden. His help and unconditional friendship made my life throughout the studies and thesis work easier. I would like to thank Cynthia Arochi and Becky Curtis for being my all day, hours, minutes consulting friends, simply I have no words to thank them. I would like to thank Lisa and Cicci for their support and care. I am so grateful with Karin Nilsson, Åsa Bergström, and Weronica Borg for sharing my stress with thesis work and relaxing me with their care, support, and understanding. I want to thank them all for being my family here and coming along with me through the journey of my thesis work. I would like to show my appreciation to Teodor Berglund for his technical help while my stay in Uppsala.

I would like to give special thanks to Ingegerd Ehn as she has been guiding me through all things, thesis and non- thesis in my studies. I want to thank her for her optimism and energy to help me out since I started my thesis quest. I would like to thank Barry Ness as I know how hard it has been to deal with my work all the way from Stockholm and that he started working with me really late, but his efforts and mine together made my thesis from raw material to end product. Barry has been so encouraging and made me work as never before. Also I would like to thank Marianne Salomon and Paulina Bohdanowicz for their efforts and help in the supervision of my thesis work. I would like to thank Dr. Reza Fakhrai for being always so positive, energetic, and optimistic, he really made me work harder. And I would like to thank everyone else in KTH- HPT for being so open, friendly and helpful.

Last but not least, I would like to thank God for my family, my friends, and my teachers; for giving me this opportunity in life to explore more things and learn. I am endlessly grateful for being given the chance to live the LUMES experience and try to find ways to make life even better!!!

List of Acronyms

Al	Aluminum
Al_2O_3	Aluminum oxide
As	Arsenic
ASTM	American Society for Testing and Materials
Ba	Barium
BaO	Barium oxide
Btu	British thermal units
Ca	Calcium
CaO	Calcium oxide
Cd	Cadmium
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cu	Copper
CO_2	Carbon Dioxide
EC	European Commission
EEA	European Environmental Agency
EMAS	Environmental Management and Audit Schemes
EPA	Environmental Protection Agency
EU	European Union
EJ	Exa joules
Fe	Iron
Fe_2O_3	Ferric oxide
GDP	Gross Domestic Product
GHG	Green houses gases
GJ	Giga joules
GWh	Giga watts hour
H	Hydrogen
ha	Hectares
Hg	Mercury
IEA	International Energy Agency
K	Potassium
Kg	Kilogram
K_2O	Potassium oxide
kWh	Kilowatt hour
Mg	Magnesium
Mg	Million grams
MgO	Magnesium oxide
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
Na_2O	Sodium oxide
Ni	Nickel
NOx	Nitrogen oxide
O, O_2	Oxygen
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PAH	Polyaromatic hydrocarbons
PJ	Petajoules
PM	Particulate Matter
Pb	Lead
S	Sulfur
Si	Silicon
SiO_2	Silicon dioxide
SO_2	Sulfur Dioxide
SO3	Sulfur Trioxide
Sr	Strontium
t	1.1025 ton
TiO	Titanium oxide
UN	United Nations
UNEP	United Nations Environmental Programme
USA, US	United States of America
V	Vanadium
Zn	Zinc

TABLE OF CONTENT

List of Figures

List of Tables

The energy industry has encountered several setbacks to its development as it contributes to environmental problems. Energy services are important for economic and social development as they yield benefits for both in ways of income, employment, and other (UN, 2005). Nevertheless as stated by the United Nations in the Energy challenge for achieving the Millennium Development Goals (2005) sustainability in the energy sector must be improved to decrease environmental and health impacts. The UN along with the European Commission have established that a sustainable energy production will be approached through increases in energy efficiency, developing and diffusing clean technology for energy production and use, and by opting and further developing renewable energy (UN, 2005; UN, 2002; EC, 2001a). These approaches are thought to reduce the amount of greenhouse gases emission, consequently decreasing the potential climate change (EC, 2001b). On the other hand there are several other environmental problems that are caused by the energy industry activities.

Different energy production systems differ in their environmental impact. It has been recognized that depending on the energy source, the impact on the environment will vary (Nieuwlaar, 2004). For instance, it has been remarked the differences in GHGs emissions, in particular of CO_2, between fossil fuel power generation and renewable sources power generation (EC, 2001c). In fact, the fossil fuel based energy industry is attributed as the largest carbon dioxide emitter (UN, 2002). Resulting from that comparison, currently, efforts have been set on the development of renewable energy (Alexander, 1996). Thus, the energy system influences the types and the magnitude of the impact.

It is often that environmental impacts from the various renewable and non-renewable energy systems are referenced to climate change, and ozone depletion affecting emissions (Carter, 2001). The impacts and consequences have been continuously studied. Other impacts as acid depositions have also been globally discussed. Differences in emissions of SO_2, a major air pollutant, between energy sources have been studied (c.f. Holdren and Smith, 2000). Other chemical releases have also been targeted. For instance, recently in the U.S. mercury releases have been scrutinized. This has been particularly focused to power plants. The recognition of mercury impacts has provoked changes in the legislation, resulting in the Cleaner Skies Act in the USA (EPA, 2005a). By this it can be said that as there is growing evidence of the impacts from the emissions attention is set to counteract them. Not surprisingly, the insufficiency on studying effects from wastes and various other chemicals discharged from energy systems has lead to their omission as a relevant problem. Their effects have only vaguely been attributed to specific environmental impacts.

Due to insufficient studies and variation on existing information, problems such as solid waste generation and other chemicals discharged by the energy industry have lacked the attention to be properly tackled. These externalities of the energy industry are variable in data, experts' opinions vary, and relevant information is absent (EC, 1995). Basically, studies if performed have been questioned as there is an existing concern regarding the reliability on data given by industry, representativeness of the statistical data, the way by which analytical methods have taken place, and considerations made while their realization (EPA, 2000). These factors definitely contribute to uncertainty on whether the impacts of such are relevant to counteract. Perhaps the absence of scientific evidence stating the impacts of wastes and chemical releases in the short and long term undermines its role in a larger scene as GHGs environmental impact.

From the acknowledgment of an existing waste generation and the discharge of chemicals into the environment from energy production systems, and the prevailing importance of sustainability within the energy sector, a discrepancy has been encountered. That is, sustainability approaches in the energy sector are focused significantly on climate change factors, setting aside the environmental impacts caused by wastes and chemical releases. In defense, it could be said that at least for waste, waste management strategies have been applied although; results have not been proven to go in accordance to the goals of sustainable development (Chadwick et al., 1987). Also, it could be argued that waste amounts and their impacts might not be significant as it has been considered in the Externalities of Energy study performed by the European Commission (1995). Although, if there is lack of studies that demonstrate so, then sustainability in the energy production systems might try to explore the magnitude of these impacts in order to be more credible. Thus, will the analysis of the energy production systems, coal and biomass, denote the significance of environmental problems other than GHG emissions as solid waste generation and chemicals releases? If so, will such analysis give sufficient grounds to compare the sustainability of the biomass energy system with respect to the coal energy system? Hence, the overall aim of this thesis is to provide a more comprehensive understanding of the impacts of energy production from one focused significantly on GHG emissions to one focused also on waste generation and chemicals releases. It will carry out this aim by performing an assessment of two key forms of energy generation from a fuel cycle perspective. These two forms are energy generation from coal and generation from biomass. The assessment will be approached by analyzing the overall systems and the coal and biomass fuel cycles respectively. Channeling driving factors, environmental impacts, and analyzing relations will help to understand the existence and importance of the problem. It will determine how sustainable these energy systems are, and somehow will indicate which one is closer to a real sustainable energy production.

1.1 Objectives and Scope

Currently, environmental pressures in the energy sector have urged for the research and development of cleaner technologies and alternative renewable energy resources. Basically, cleaner technologies are designed for the existing heavily exploited non renewable energy sources, fossil fuels, to reduce emissions (EC, 2002). The switch to renewable energy sources gives way to energy generation with less environmental impacts compared to those from the use of fossil fuels (EC, 2002). The purpose of the continuous research and development of both pursue the minimization of environmental impacts as the goal for sustainability in energy production is enhancing a healthy environment (EEA, 2002). Therefore this analysis will discuss two important energy systems, the coal energy system, and the biomass energy system. A limited fuel cycle approach will be assessed in order to convey relevant findings that will be comparable between the energy systems in study.

The coal energy system will be studied throughout its production chain processes. The study will cover the mining, preparation, and conversion processes of coal. The coal that is referred for energy production are hard coal and brown coal, nonetheless the production processes discussed are based on the consideration of hard coal only. Transportation of the raw coal and coal as intermediate product will be omitted. The distribution of the energy product is also excluded from the study.

Similarly, the biomass energy system will be studied throughout its production processes. In this case, the study will cover crop production, preparation, and conversion as the study contemplates woody energy crops. Due to the variety of biomass sources, the study will be limited to wood biomass. Still, there are various types that reside under this energy source, hence specific considerations will be given as the analysis will try to be adapted only to willow species. Nonetheless, it is important to note that several aspects of the production chain are applicable to other types of wood. Some wood- biomass processing generalizations will be considered as variations mainly correspond to quantities and quality as it is dependant on the wood species.

After going through a system analysis by causal loop diagrams, the systems are analyzed throughout their fuel cycle. The realization of the fuel cycle study will not perform experiments for measurements or quantifying the wastes and chemical releases. This study is qualitative, yet relevant quantities obtained from the researched literature are used to envisage the approximate amounts of wastes and chemicals released at some processes. As it was mentioned previously, this approach is meant to cover the process stages from the production of the raw material (energy source) to final product (power). As the aims of the thesis are not on engineering or technical grounds, the study is limited to discuss the generation of waste in the different stages as well as the releases of chemicals other than chemical compounds in GHG, NOx, and SO_2: therefore neither calculations nor simulations regarding design, production rates, conversion rates, etc of power plants or technology will be carried out. Waste and chemicals generated in each stage will be analyzed in the basis of existing data and statistics. Regarding the causal loop diagrams, specific considerations will be given accordingly along the paper. Also, no specific chemical will be addressed. On the contrary, it will be shown the various chemicals that are released.

In other words this study will attempt to analyze:

- What wastes and chemical are generated and released to the environment?
- How and when do they occur?
- What are their impacts and are these relevant?
- From the perspective on these impacts, is biomass (renewable) a more sustainable energy system than coal?

This will help to answer:

- Is the current emphasis to counteract climate change factors, GHGs, really moving towards a sustainable energy production?
- Has sustainability been approached appropriately in the energy sector?
- Is there sufficient basis for including waste and chemical releases in the aims for sustainable energy production?
- What will be affected in order to counteract waste and chemical releases from the energy systems and how will this affect the general energy sector system?
- In all, is biomass energy a sustainable solution?
- How can the systems be more sustainable?

1.2 Methods and Material

As the energy sector is conformed of various systems, a broad research on the sector per se was the basis. Other than technology improvements and changes in legislation, the energy sector and the industries within it have been established during the mid and late 20th century. Therefore many relevant studies and findings of the energy systems were indeed produced then. After a thorough analysis of the energy sector and the development of a general energy system causal loop diagram shown in figure 1.1 (see Chapter 2 for the background analysis for the energy sector shown in the diagram), a clear picture of the system was displayed. This gave allowance to the understanding of the dynamics of the system, and how currently sustainability is being dealt. Since the energy sector is too broad the selection of two sources' energy systems was opted. The first energy system to be discussed is the coal energy system. The second energy system is biomass.

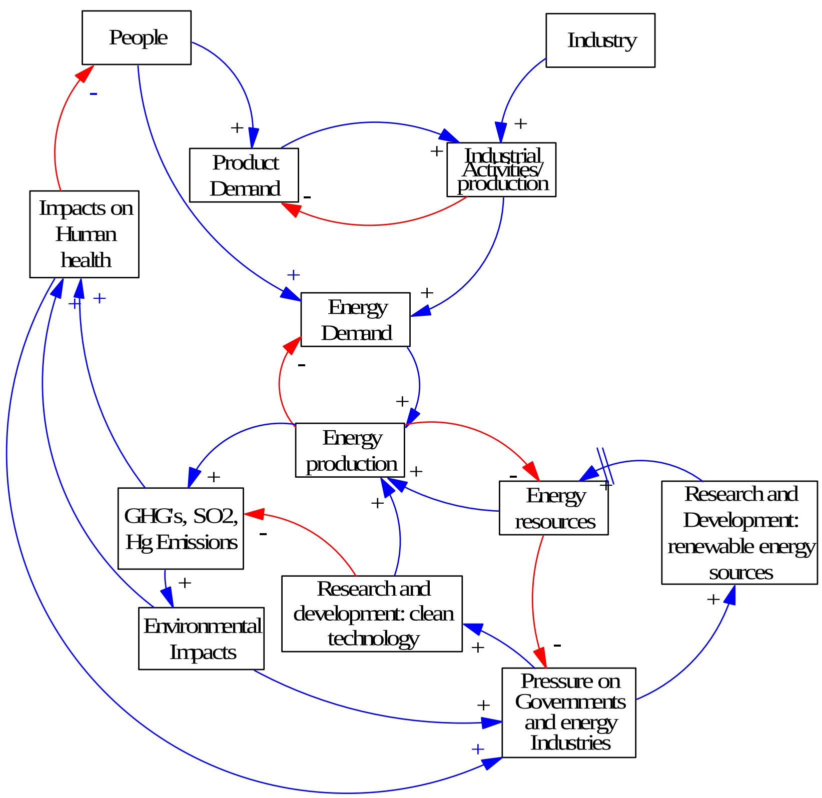


Figure 1.1 Energy System causal loop diagram.

Coal was selected from the group of fossil fuel base energy systems. As a non renewable resource and its long-lived presence in the electricity competing scene, the coal energy system has interest set on it to prevail much longer. Reasons for its selection as case study include: its presence in the energy sector, its negative environmental reputation, and the continuous efforts downplayed to transform it into an environmentally friendly system. Also, an important aspect was that for certain regions of the world, the coal energy system is intended to secure energy supply and substitute oil energy dependency (EC, 2001a).

The biomass energy system is considered to be an alternative energy source, which has existed in all times. Biomass energy or bio-energy is one of the main areas of study in the field of renewable energy sources. Historically, biomass has also been present in the energy production scene first in form of heat and later as source for power. Compared to non-renewables, biomass is easily accessible for most and spread throughout the earth. Important aspects for its selection as case study are: it's growing presence in the energy sector, its recognition as a clean energy source or low impacting, and the constant studies and improvements to make of it a larger industry.

Furthermore, an analysis of the existing coal and biomass energy systems accordingly will be done adapting the energy sector diagram to each case. This will be followed by the proposing inclusion of other environmental affecting problems: waste and chemical releases. After their inclusion, it will be analyze how the dynamics of the systems are affected. This will help visualize how each system contributes to impact the environment and how significant it is.

Another important part of the analysis is, that after displaying the inclusion of the impacts into the system, it must also be applied along the chain of processes that the coal or biomass undergo. That is to study the systems in a fuel cycle perspective. Whenever a cradle to grave process is studied, it is easier to grasp what really happens to the energy source and how the system works, with inputs and outputs, from and into the environment. The system analysis helps to see the relations between cause and effect factors, whereas a energy cycle approach will portray where, why, and how the impacts are generated along the energy production systems.

Based on this, the research was founded on the review and analysis of secondary resources. The information was carefully selected on the basis of legitimacy, scientific proven grounds, and relevance to the purposes of the study. General concepts of the energy systems where first analyzed, mainly from recognized field related industrial encyclopedias and books and official documentation from international organizations and bodies. After the selection of the energy systems, specific studies in scientific journals and specialized books were also thoroughly reviewed.

Energy has been considered as the solution and at the same time as problem for sustainable development (UN, 2002). Energy is a key element for development according to the United Nations World Summit on Sustainable Development (2002). Nevertheless, energy production systems contribute largely to environmental problems as GHGs and SO2 emissions as already known. Including other effects as waste and chemical release to the dimensions where GHGs and SO2 are of relevance already is indeed closer in attempting a real sustainable energy system. As this effects also cause air pollution, contamination of water and soil consequently having negative impacts on human health and the environment (Holdren and Smith, 2000). In this way the benefits of energy production and utilization will still be provided while its drawbacks will be minimized. With this in mind, it is important to understand the role energy plays in the social, economic, environmental, and political scenes, and visualize how the whole system is related. Identifying the key factors for the current state will allow finding pertinent ways to introduce waste and chemical release into the system as an environmental problem that questions the actual efforts for sustainable energy development.

2.1 Society and Energy: well- being?

Energy services bring various benefits to people. Energy has been thought as the mean to improve living standards. It provides people with heat and electricity, as well as fuels for transportation and other activities. According to the European Environment Agency (2002) energy is essential for social well- being. It was stated that energy supply is a source of employment as well as wealth. Notwithstanding, it has been discussed in several occasions that energy should be available to everyone. Statistics have shown that around 2.5 billion people do not have access to modern energy services (UN, 2002). On the other hand, studies have reported that an uneven distribution of services take place. Moreover, though energy production has increased, still energy services do not reach those who live in poverty (UN, 2005) and rely on burning biomass for heat and lighting in their homes, affecting their health. In fact, each year around one million children under five die due to indoor air pollution (UN, 2002). Hence, these has served as base to support the increase of energy production, the diffusion of clean technology between developed and developing countries, and the continuous research and development of renewable energy as a Millennium Development Goal (UN, 2005a).

Also energy production has another impact on people. It has been indicated that the advantages of having energy services are very important and that everyone should have access to it. On the other hand, modern energy services or production systems contribute to serious health damaging effects. All energy sources release pollutants and/ or wastes into the atmosphere. For instance, considering the release of mercury from combustion processes into water bodies, this metal accumulates in the water and in the fish (EPA, 2005b). When unborn babies and children consume fish contaminated with methylmercury (the form in which Hg is found in fish) their neurological development is affected. Coal energy production is attributed as the largest source for mercury releases in the air in the USA (EPA, 2005b). Another example is the inhalation of particulate matter. This one causes premature deaths, respiratory and visibility problems just to mention a few. The release of PM is accredited to the burning of fossil fuels and biomass (Holdren and Smith, 2000). Hence, human health plays an important role on the direction research and development of energy technology as if releases are decrease people will be less exposed to them.

2.2 Economic growth and Energy: a global picture

The energy sector, as any other economic sector is driven by the supply, demand, and pricing in the market (Rogner and Popescu, 2000). However, economic growth has been considered to be directly influenced by the behaviour of the energy sector. It has been stated by the Division of Industry and Environment (UNEP, 2004), that the amount of energy utilized in a country is strongly related to the size of its economy. Some major economies, as those within the European Union must ensure the supply of energy to have their economies properly functioning (EC, 2001a). Figure 2.1 illustrates the GDP growth along with the total consumption of energy from various European countries. In figure 2.2 it is viewed the entire European GDP and its total energy consumption. Both figures display that as the gross domestic product increase, there is a raise in the consumption of energy. Thus, if economic growth is influenced by the energy sector, it is important for the economies to ensure that as consumption increases so will do its supply. Figure 2.3 shows the share of total primary energy supply held by the different regions of the world. The figure indicates that proportion of energy supplies corresponding to each region, while in figure 2.4 it can be observed the representation of the actual supply of energy sources by type.

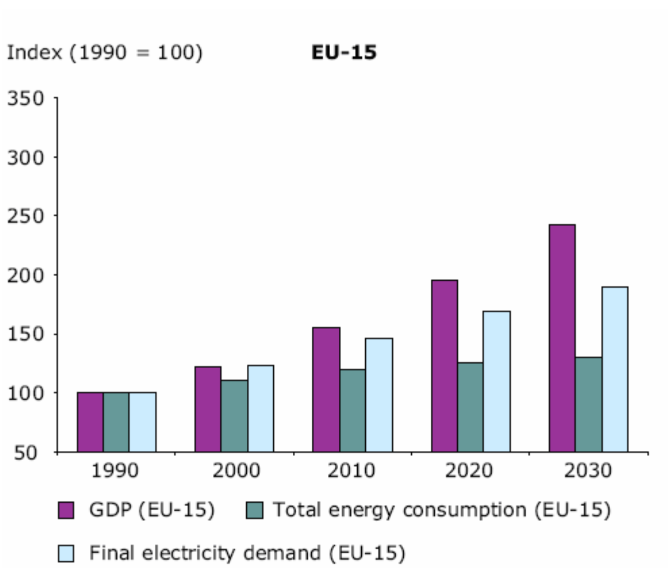


Figure 2.1 Total energy consumption, electricity demand, and GDP growth in EU- 15.
These graphs show the energy consumption patterns in some European countries. The gross domestic product is also shown. Projections were made until year 2030. Source: EEA, 2005.

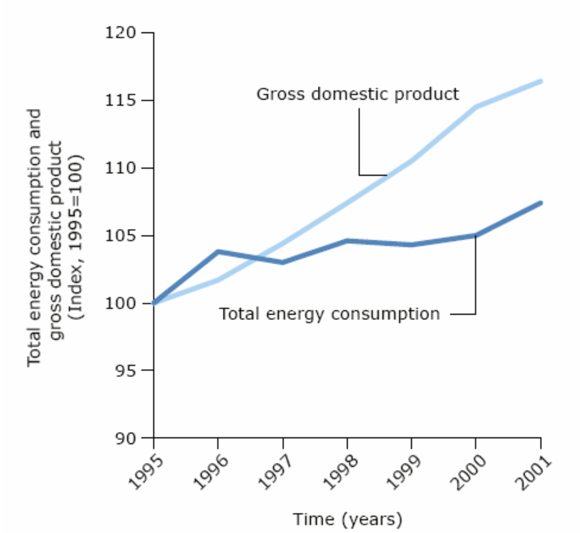


Figure 2.2 This graph illustrates the energy consumption patterns along with GDP growth that took place from the mid 1990s until 2001 in Europe. *Source: EEA, 2004.*

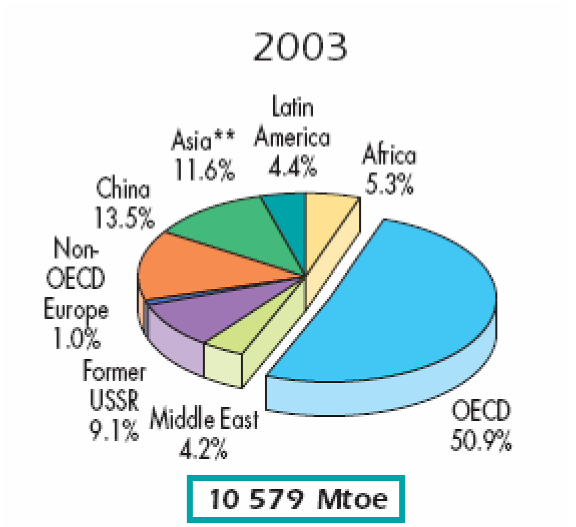


Figure 2.3 Total Primary Energy Supply-World Regional Share. *Source: IEA, 2005*

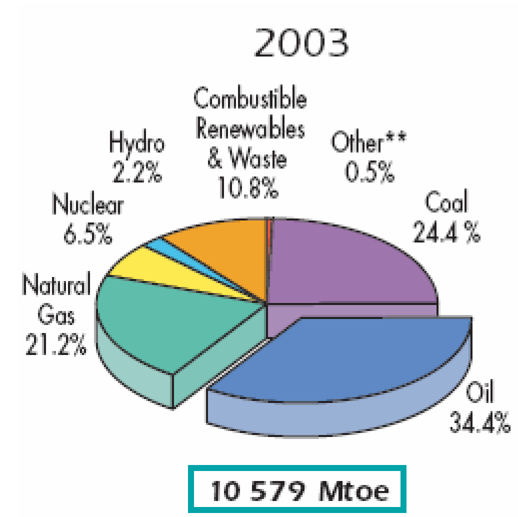


Figure 2.4 Total Primary Energy Supply by fuel. *Source: IEA, 2005*

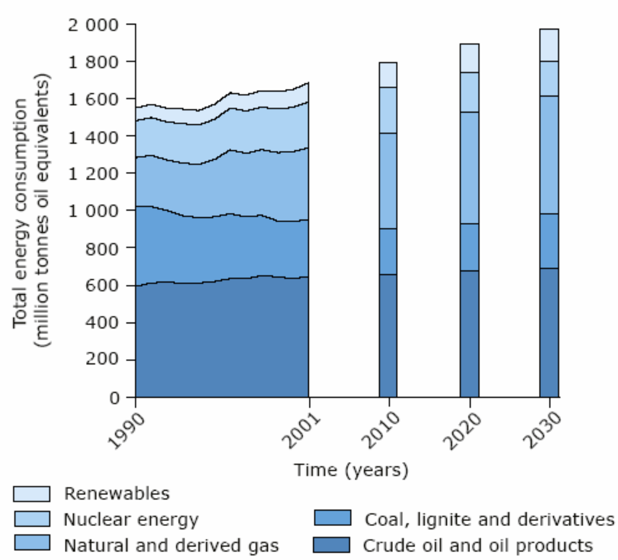
Understanding the existing differences with respects to production of energy sources and their distribution facilitates the continuous discussions on strategies to promote the development and strengthening of the renewable energy sources. As few countries have control over the fossil fuels market, those depending on them for their economic activities rely on market prices to import energy into their countries (EC, 2001a). Yet, another problem that worries is the availability of reserves. It is well known that fossil fuels have finite reserves therefore another reason for stressing renewables is encountered. Whether economies intend to switch from non renewable energy sources to renewable ones or not, economic development is a main reason to pursue so. As it was previously explained, energy production provides services that give way to social and industrial activities which activate economic development. People and industries are responsible for entailing the prevailing consumption and production patterns of energy (EEA, 2003). With this it can be seen that people in a way rule the consumption patterns of the industry. Although, it is society and industries together who drive the production patterns of the energy industry. Altogether, these yield to economic development. (EEA, 2003)

2.3 Energy and the Environment: an overview

Even though energy production and consumption practices account importantly to economic development and are key to sustainable development, apart from affecting human health they also pose environmental burdens that contribute to global issues such as climate change. Energy production systems distress ecosystems, agriculture and the built environment as affirmed by the Third Assessment on Europe's Environment (EEA, 2003b). The environmental pressures produced depend on the source.

In brief, major impacting energy sources are fossil fuels, followed by nuclear power, and renewables. In general fossil fuels impact the environment when they are extracted, transported, processed, converted, and distributed. Extracting fossil fuels generate waste in forms of emissions, leakages, sludge, or ashes in between others. Even so, the production of all energy sources disrupts the landscape, habitats, and biodiversity just to mention some (U.S. Department of Energy, 2001). The European Environment Agency (2003b) reported impacts with respect to main energy sources. It was stated that coal use contributes high levels of greenhouse gases, acid gas, and particulate emissions as well as solid and liquid pollution as a result of its extraction and disposal of ash. Oil, as it has lower carbon content than coal, puts less pressure to the environment. Oil is attributed to have reduced share in GHGs emission. Natural gas is the cleanest of the fossil fuels as it has lower carbon content than oil and it is the least propensity to cause acid emissions. In regards to greenhouse gas emissions and air pollution, nuclear and renewable energy sources are positioned as the least pressuring to the environment. Nuclear sources are considered too risky as radioactive waste is produced and concerns arise regarding safety and disposal. Renewables, altogether are considered the most environmentally friendly, although if considering loss of natural amenities, loss of habitat, visual disruption, and noise, then they are heavily impacting the environment. Figure 2.5 shows the different energy sources that are being consumed and also shows projections until 2030. As observed, trends on fossil fuels are still in raise. It was emphasized in the Third Assessment (EEA, 2003b) that he energy sector in Europe remains directed by fossil fuels, even though the energy supplied by renewables has increased.

Figure 2.5 This graph indicates the energy consumption with respect to the energy source. This data corresponds only to Europe. *Source: EEA ,2004.*



According to Rogner and Popescu (2000), counteracting environmental impacts from the energy production activities has involved efforts on not overloading the carrying capacity of the ecosystems through a control over releases to the environment, using efficiently the energy sources and energy end products, developing cleaner conversion processes, and developing renewable energy sources. In other words, decreasing demand of energy production will result in less release of pollutants. If resources are used efficiently, less will be needed while the same levels of energy production will be maintained or if energy products are used efficiently (avoiding energy losses), less energy would be consumed. For instance, it has been observed that energy consumption in Europe has declined (EEA, 2003b). Two reasons made this possible. One of them was the increase in energy efficiency in Western Europe. Nonetheless the second reason was economic problems and restructuring in central and Eastern Europe, the Caucasus and central Asia. There is great concern on the fact that the recovery of the economies will see an offset in the improvements that have been outlined, unless energy efficiency is improved as well as low carbon sources are used to supply energy. It was pointed out that little progress has been achieved to shift into higher efficiency of resource use (EEA, 2003b). In overall, the impacts of the energy production systems on the environment are various, nonetheless, many problems have been disregarded as the emission of GHGs and other few have captured the attention in a global scale.

2.4 Environmental Politics on Energy

Pursuing on sustainable energy production deals with matters such as measuring the impacts, acknowledging the ways by which it is unsustainable, finding alternatives to decrease its impacts, etc. This is handled differently depending on the environmental problems that are to counteract. Indeed, the environmental politics on energy are various as the effects correspond to various areas. According to Carter (2001), environmental politics embrace two main regimes; ozone depletion and climate change. National politics may be encircling engagements to meet emission targets agreed on international levels through specific means (Carter, 2001). Thus, this endures international and national political implications. The role of laws and policies in regards to the energy industry is heavily loaded as it affects several stakeholders.

Nonetheless, environmental politics applicable on energy systems are comprehensive and embrace different issues. For example in the USA there are various laws that could be applied to energy productions systems such as the clean air act, the clean water act, the pollution prevention act, and the toxic substances control act (EPA, 2005c). Table 2.1 shows the criteria air pollutants for the USA and standards for the quality of air are stated. These standards where established on the clean air act. On its part, the European Community has intended to improve the application of its environmental legislation through the Sixth Action Programme for the Environment. The European Community has adopted among several environmental policy instruments eco- labeling and EMAS. Special attention has been set on environmental taxes, though unless properly implemented within the legislation, these instruments should act as incentives for producers and consumers not otherwise. Also the European Union has developed the directive on waste landfilling, the directives on quality of water intended for human consumption and quality of bathing water, and as a world priority they have created the clean air for Europe programme, and a more targeted directive on the limitation of emissions of certain pollutants into the air from large combustion plants (EU, 2001). As it can be noted, the scope of the laws and policies revolve around the same issues and if analyzed profoundly, commonly they make reference to concerns on GHGs, SO_2, and NOx.

Table 2.1 U.S. National Ambient Air Quality Standards

Pollutant	Primary Stds.	Averaging Times	Secondary Stds.
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour	None
	35 ppm (40 mg/m^3)	1-hour	None
Lead	1.5 µg/m^3	Quarterly Average	Same as Primary
Nitrogen Dioxide	0.053 ppm (100 µg/m^3)	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM_{10})	50 µg/m^3	Annual (Arith. Mean)	Same as Primary
	150 ug/m^3	24-hour	
Particulate Matter ($PM_{2.5}$)	15.0 µg/m^3	Annual (Arith. Mean)	Same as Primary
	65 ug/m^3	24-hour	
Ozone	0.08 ppm	8-hour	Same as Primary
Sulfur Oxides	0.03 ppm	Annual (Arith. Mean)	-------
	0.14 ppm	24-hour	-------
	-------	3-hour	0.5 ppm (1300 ug/m^3)

Source: EPA, 2005d.

Even though most existing policies and laws are targeted to combat GHGs emission, consequently climate change, or SO_2 to counter acid depositions, some laws are applicable to wastes and chemical releases from energy production systems. The division for sustainable development of the United Nations' Department of Economic and Social Affairs (2005b) has stated as independent issues wastes with respects to their type; hazardous, solid, and radioactive. For the hazardous wastes they urge an environmentally sound management as it was indicated in Agenda 21 on its 20th chapter. They stated that effectiveness is required in the control of this waste in its generation, storage, treatment, recycling and reuse, transportation, recovery and disposal. Raising concern on wastes prompted in 2004 the Ministerial statement on Partnerships for meeting the Global Waste Challenge created at the Conference of the Parties 7. In this statement it is recognize that waste management is part of broader issues such as water protection, sanitation improvement, management of solid waste and consequently, social and economic development. Solid waste management is considered a major issue as it affects the quality of the environment as it includes domestic and non- hazardous waste. This waste management concerns a safe disposal, recovery as well as the production and consumption patterns that cause it (UN, 2005a). Independently, the European Union has also placed concern in the issue, for that in 2001 it was developed a strategy for sustainable development which emphasized the focused to de-link economic growth, use of resources, and waste generation (European Commission, 2001a).

Moreover, the European Commission has encouraged as a priority area the sustainable use of resources and the management of waste in their sixth environment action program (EC, 2001b).

Another way to tackle environmental problems caused by energy is by changing consumption and production patterns as has been noted earlier. Consumption and production patterns were discussed first in 1992 in the United Nation's Summit on Environment and Development. There was concern particularly on those countries with developed economies as their activities were unsustainable.

> "Excessive consumption by affluent populations place damaging stress on the environment. Governments recognized the need to redirect international and national plans and policies to ensure that all economic decisions fully took into account any environmental impact. Patterns of production — particularly the production of toxic components, such as lead in gasoline, or poisonous waste — are being scrutinized in a systematic manner by the UN and Governments alike." (UN, 1992)

This was affirmed in August 2002 in the World Summit on Sustainable development. It was declared that there should be a fastened shift towards a sustainable consumption and production promoting still both social and economic development decreasing negative effects on the environment. A 10 year framework program was created, following the aim to separate economic growth from environmental impacts through efficiency and sustainability in use of resources and production processes as well as reduction of degradation of the environment, pollution, and waste. (in EEA, 2003b)

Although the various impacts it conducts to the environment, energy production is a need not only for industries but also for people. Therefore, sustainability should be achieved. Research and technological, industrial, and people's efforts for sustainable development are also framed by the national political structures, furthermore by the international ones. The relation between economic growth (industrial activities), society (population/ people), and government actions play important roles in driving the energy sector. The direction energy systems take are consequently dependent on them as well as the impacts of the energy systems affects them. With this respect, the analysis of the energy system results in figure 1.1 (see pg. 4).

After downplaying the factors and relations surrounding the energy production systems, it is feasible to make an analysis of the coal and biomass energy systems. Based on the resulting dynamics of the overall system, these two systems will be adapting it. Of course, the relations of the systems will be similar but obviously differences will be encountered. Nevertheless, the important aspect for the analysis is to understand how the dynamics for these systems will be affected when waste and chemical releases are included as environmental problems.

3.1 The Coal energy production system

The coal energy generation system differs from others as coal has been considered as the most polluting energy source (EEA, 2002). Issues surrounding sustainability within the coal energy system revolve around greenhouse gas emission as major driver. This has stressed the development of technologies that will minimize these emissions. The development of a sustainable coal energy system should endure further inclusions such as wastes and chemicals that are generated and discharged. Moreover, the system should account them throughout the production chain. That means channeling wastes generated since coal is in its natural reserves until it has become an end energy product. Sustainable energy production can be indeed obtained through coal if the traditional way of viewing the system is changed and leaving aside the wholly dependency on the development of clean technology to reduce GHGs emission.

3.1.1 Changing the traditional coal energy generation impacts focus

The process from which energy is obtained as final product in form of electricity and heat from coal is conformed by several stages. Generally the process is considered to be the input of coal into a power plant and its output as a form of energy as shown in figure 3.1 framed in gray. The traditional way by which this system is perceived takes into consideration the following statements and has its base on figure 1.1 (see Chapter 1):

- As in the rest of the energy systems the coal- energy industry is driven by consumption patterns.
- The focal point regarding environmental impacts is greenhouse gas emissions.
- The coal energy industry or system consists only of a conversion process.
- Efforts on declining environmental negative effects are based on the development of technology that when coal is combusted (conversion of coal into energy products), CO_2, SO_2, and NO_x will be released in reduced concentrations to the atmosphere. (Hg is included as it is being tackled by law already in the US.)

A change from that habitual perspective will help to put into picture other issues of concern. Enhancing the traditional view of the system allows perceiving other problems that are encountered as the impacts from waste and chemical releases. Therefore other considerations must be set.

- Coal conversion implies waste and release of chemical substances apart from GHGs.
- Coal combustion for energy generation contributes to other environmental impacts different to climate change.

- Waste and chemicals released from coal conversion may be discharged and disposed into air, water, and soil.
- The pollution caused by the wastes is a driving factor for governments to draw their attention upon its implications and national level strategies must be established.
- Climate change is a long- term (gradual) environmental problem while waste and its consequent effects are short term.

Now, considering these facts a different perspective of the system will follow. Figure 3.1 illustrates the changes in the system and the inclusion of waste and chemical releases framed in red. As indicated in the statements these impacts come in a faster way than those by GHGs as they affect directly life. The government factor has been omitted as it has been clearly appointed in figure 1.1 that the actions from government derive research and development of technology and renewables through application of laws, regulations and/or policy instruments.

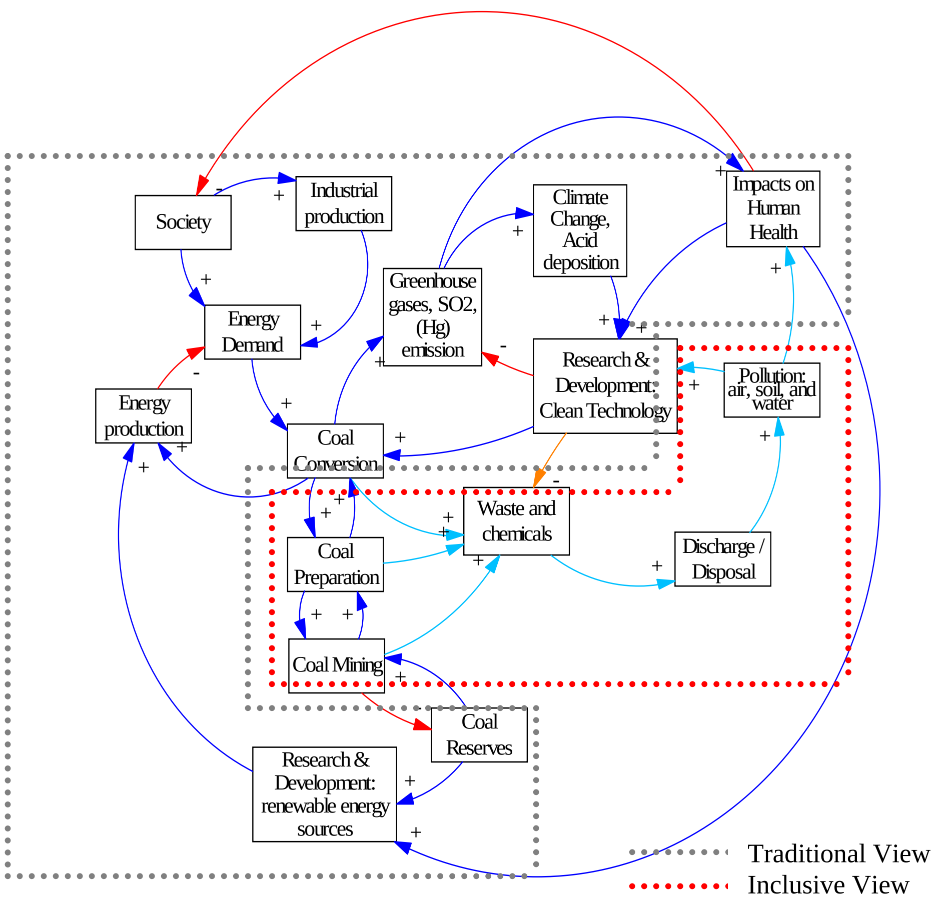


Figure 3.1 Inclusive view on the Coal Energy System

3.1.2 The Nature of Coal: why is it environmentally damaging?

In order to understand how coal emits harmful chemicals to the environment it is necessary to have an insight on what coal is. According to Crelling and Hagemann (2002c) coal is conformed of organic and inorganic matter. The organic matter is known as maceral content while the inorganic is known as mineral content. The proportion of these materials is what determines the physical and chemical properties of coal, including its energy value and its wastes constituents. Coal is classified according to its maceral composition labeled as type, its degree of maturity, labeled as rank, amount of impurities (ash and sulfur), labeled as grade, and industrial properties. Following the ASTM standard D388 coal is categorized into anthracite, bituminous, sub bituminous, and lignite. Coal classification has been a focal point internationally as the quality of the coal has impact not only in an economic base, but also on the environmental one, due to ash and volatile matter it contains. (Crelling and Hagemann, 2002a).

It has been explained by Dieter Sauter (2002) that the content of specific elements is what makes of coal effluents a matter of concern. Trace elements are the elemental matter that determines the effluents that are produced when coal is processed (Chadwick et al., 1987). According to von Elsner and Riepe (2002), the trace elements found in coal are in their mineral content and might represent hazards to the environment. In table 3.1 it can be seen a list of elements with its consequences. Also, when combined the elements behave differently as different properties and reactions characterize compounds.

Table 3.1 List of elements found in coal and its hazards.

Element	**Molecular Formula**	**Hazards and Toxicity**
Arsenic	As	Toxic and carcinogenic
Barium	Ba	Toxic and explosive
Lead	Pb	Poisonous and carcinogenic
Cadmium	Cd	Toxic and carcinogenic
Chromium	Cr	Poisonous if ingested
Copper	Cu	Toxic only in excess
Mercury	Hg	Poisonous
Strontium	Sr	Non- toxic
Sulfur	S	Irritant, poisonous, explosive, and toxic.

Data Source: The combined Chemical Dictionary. 2005.

Studies have been carried out on existing coal compounds (Chadwick et al., 1987). Chemical analyses of ash indicate that coal’s major constituents include: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, BaO, TiO_2, P_2O_5, and SO_3 (Sauter, 2002). These oxides found in the coal ash represent different hazards and vary in toxicity. According to the Dictionary of Inorganic and organometallic compounds (2005) these chemicals represent different hazards and vary in toxicities. SiO_2 also known as silica is an acute irritating dust consider being toxic. It causes the pulmonary dust disease. If exposed for a long time it may result in silicosis. Also, in its crystalline form it is thought to be a carcinogen for humans. Al_2O_3, aluminum oxide, though it is still in studies there is relevant evidence indicating this chemical may cause pulmonary fibrosis if expose to a doses of 10 milligrams per cubic meter of inhaled dust. Other chemicals as calcium oxide (CaO) are irritants or as sodium oxide (Na_2O) and barium oxide (BaO) are corrosives. Nonetheless the latter is also considered as a toxic substance. Still one attention driving chemical is that which contains sulfur, SO_3 or sulfur trioxide. This chemical is very toxic and corrosive. Nevertheless, regardless of the properties and the effects, the release of these varies in amount and form according to the process. Therefore it is relevant to go through each process coal undergoes.

3.1.3 Complete coal energy system

In essence, the coal energy production system consists of extraction, processing, and energy generation. In a cycle view extraction will be further subdivided into mining, extraction, and transportation; processing will involve preparation process which is subdivided into several procedures finalized as well by transportation; energy generation will include coal conversion process. The system is culminated by the distribution of the energy product. Figure 3.2 shows the complete process of the coal energy system. Identifying the wastes and chemical releases at each process will make feasible counteracting impacts and at the same time it will make of the coal energy industry a more sustainable one. This is of great importance as coal has been considered to become a plausible substitute for oil, as it is more available and economically viewed as inexpensive according to European Commission's technical document anteceding the Green Paper on energy supply security (2001).

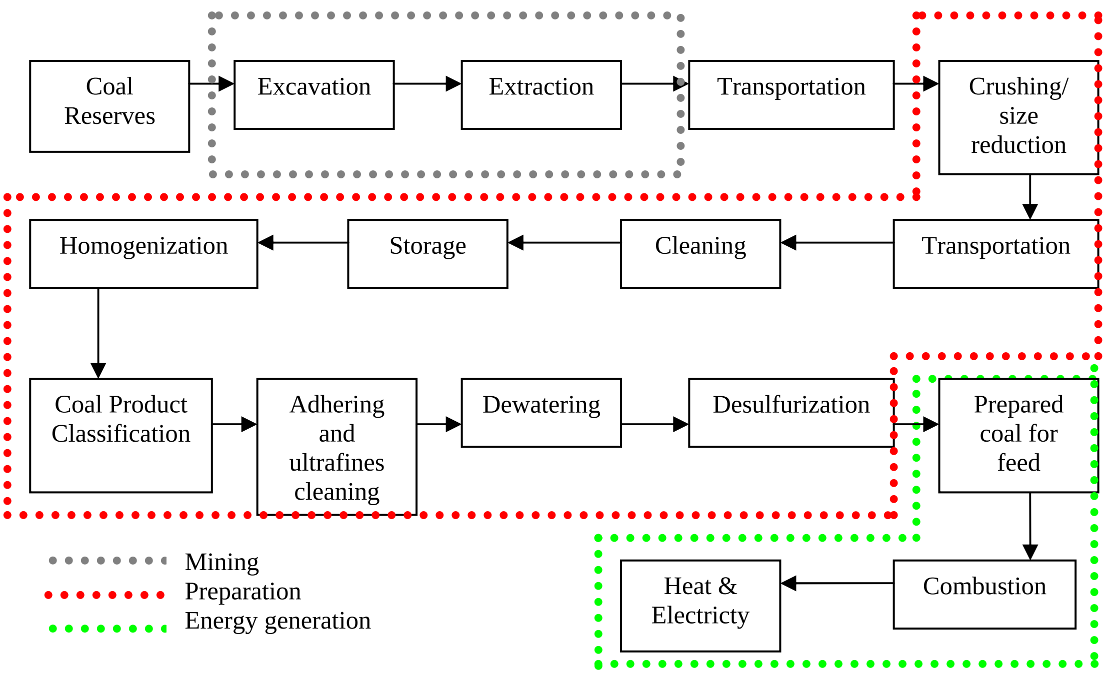


Figure 3.2 Coal cycle chart. *This complete cycle chart was concluded after thoroughly studying the processes involving coal according to various literatures. By no means this is a certified or official coal energy cycle chart. This is the resulting map of the research of various sources (Leininger et al., 2002; Ramini and Vogt, 2002; von Elsner and Riepe, 2002).*

A. Mining

As coal occurs in seams which range in thickness its production requires mining. Several seams have a limited size area and some are lying under large areas (Crelling and Hagemann, 2002b). There are two types of coal mining that are used. According to Ramani and Vogt (2002), coal mining is possible through two general methods: surface or underground. Both of them have impact on the environment. For instance, underground mining disturbs land surfaces in ways of subsidence, dislocation of inclined planes, stretching and wrenching faults (von Elsner and Riepe, 2002). Open cast mining needs seam and strata to be drained. Another concern is that open cast mining might reach large depths; consequently groundwater levels in the close areas may be lowered. Therefore wells are built at the border of the mines and entrances of groundwater (von Elsner and Riepe, 2002). Regardless of the type of mine established it can be pictured the magnitude of the activity and its various consequences apart from waste.

The method chosen depends on whether the coal is exposed and it is recoverable, or if it has to be approached through openings. The geology is a main constraint for technological appliances, mining engineering, and method to be used (von Elsner and Riepe, 2002). A tool used on determining the method is the stripping ratio. This ratio estimates the number of cubic meters of strata that overlays he coal seam for each ton of coal in that seam. This calculation is followed by the estimation of the break- even stripping ratio. In this one the underground mining cost per ton of coal is subtracted by the surface mining and reclamation cost per ton of coal. The results are fractioned by the surface mining cost per cubic meter of strata above the coal seam. After observing which parts of the coal seam for which the stripping ratio does not exceed the break even ratio, they will go under surface mining methods (Ramani and Vogt, 2002). Indeed these calculations are significant to the amount of waste, as they represent the amount of soil and earth layers that will be removed and deposited in another area. It should be pointed out that depending on the method differences in the amount of waste removed and to be disposed will be presented. When stripping is planned properly in advance, coarse material is deposited and covered by fertile soil. In case any toxic waste is detected it is channeled to the bottom of the deposit (Chadwick et al., 1987, 38). Another environmental concern different from the waste is that different measures to recover the land after mining. This is a serious impact as large land areas have been disrupted and existing ecosystems are affected differently. Notwithstanding, a relation between waste and land disruption exists. It has been reported in a study made by the Beijer Institute and the Environment Program of the United Nations (Chadwick et al., 1987) that in fact a class of mining land disturbance is the surface waste deposits. Therefore mining waste has a direct impact on the environment in either perspective: the blending of mineral (chemicals) into the soil and waste deposits.

Another important aspect, after choosing the mining method, is the type of excavation to be used. This is determined by the hardness or cutting resistance. Whenever rock formations are too resistant, loosening techniques are used: blasting and ripping. Nevertheless, it is important to remark that blasting has encountered aversion as it has greater environmental impacts (Ramini and Vogt, 2002). Currently, as asserted by von Elsner and Riepe (2002) coal mining is carried out by equipment that consists of bucket-wheel excavators, conveyor belts, and stackers. The performance of such technologies is approximately 100,000 cubic meters per day. As the machinery goes deeper into earth in a depth between 700 and 1100 meters, 3 to 5 cubic meters of soil are removed per ton of coal. The removed soil and rocks are the first types of waste generated from coal production. This waste regardless of its chemical properties is directly place onto other coal spent and reclamation areas. Ramini and Vogt (2002) have explained that overburden and other mining waste is placed in an inside dump by cross pit hauling or around the pit hauling. In the other hand blasted rocks are transported by truck, usually in the amount 300 tons of waste per truck. The dump site is later reclamed when mining operations have finished. The waste is covered with fertile soil and the area becomes of use for agriculture or forestry.

Once again in this part of the mining activities waste products have an important role. If reclamation is pursued environmental conditions of the land must be closely analyzed. Therefore classification strategies are applied. Waste material is classified into spoil type, relief, composition, and properties that will enable vegetation. Through reclamation it is intended to counteract some of the impacts of extracting and depositing waste. Nevertheless it has been affirmed by a study (Chadwick et al., 1987) that classifications are insufficient. This is thought particularly in cases where some chemicals further react when deposited with water or oxygen becoming toxic constituents. Also this may further result in a nutrients deficiency caused to the soils. Moreover these chemicals may filter to underground water systems, emerging as water poisoning.

As mining has taken place, raw coal also known as run of mine coal continues its way through the energy system. From mining it has been learnt that waste generation is dependant on the type of coal reserve being mined, the amount of land that will be ripped for mining, and the excavation systems to be used for extraction. Waste during the mining stage varies in form and composition. As explained before it is its mineral and maceral content which determine the releases. Though in mining no measures have been reported to be in used in order to counteract air releases, the main waste problem is the disposal of solid material removed to build the mine plant and the mixture of minerals and soils extracted from the mine along with coal which are disposed in dump sites. Whatever happens to this material while deposit also represents hazards. On the whole, the starting point for coal based energy produces a mainly solid waste product which impacts may go beyond what existing studies are able to put into picture.

B. Preparation

The largest section of the coal energy system, as indicated in figure 3.2, is the preparation stage. Leininger et al. (2002) have specified that after coal has been extracted, it undergoes a preparation process. The way by which this proceeds has effects on water, ash and sulfur content, and grain size of the coal. Notwithstanding the different purposes for preparation, it has been pointed out by von Elsner and Riepe (2002) that primarily in the preparation stage, coal is treated to minimize sulfur content. This separation is possible through crushing coal into pyrite size grains. Thus, waste in forms of dust containing the trace elements (von Elsner and Riepe, 2002) are generated basically in this stage.

Basically, coal preparation turns it from raw material to a product with well- defined properties. The preparation process consists of homogenization, breaking, crushing, and screening; cleaning; dewatering; and blending. The way by which preparation takes place relies on three aspects: 1) properties and demands regarding further technological processing, 2) requirements on end product quality, and 3) economic and environmental matters. Generally the type of coal that it is utilized for energy production is hard coal and brown coal. In fact 80 per cent of the produced hard coal is used for this purpose whereas all the brown coal produced is directed to this. In their raw form they contain various minerals and layer formations that must be removed (Leininger et al., 2002) during the preparation process in order to be used later in the energy generation stage and specific unwanted minerals are not emitted then (Önal et al., 1994).

Sometimes coal does not go through all the procedures as that depends on the specifications that are requested. Though, two basic procedures are indeed followed during the preparation process for all the coal: reduction and screening. During the reduction stage coal is pulverized. Pulverization is a source of particulates. Once pulverized, coal is slurred with water into pipelines to reach the power plants as reported by Leininger et al (2002). In some cases a more profound cleaning is required. So far, a waste concern is wastewater from the pipelines. Also, leakage from pipelines is possible and soil and groundwater can be contaminated. Thus, the two primarily wastes coming from preparation are dust particulates and waste in water.

Approximately one third of the hard coal being prepared undergoes cleaning and dewatering (Leininger et al., 2002). During the cleaning stage all the coal is crushed. First, coarse dirt is converted to particle size as the coal and is then removed. After, the coal is stored and homogenized. During the homogenization process coal is converted into even sized grains and its moisture content, dirt, and volatile material is uniformed. When homogenized, the coal is separated into coarse coal and smalls. The coarse coal is wet cleaned to get rid of adhering smalls and ultrafines. For instance, if technology such as cleaning by flotation is used, coarse coal pulp can flow in volumes of 1000 cubic meters per hour corresponding to a throughput of 100 ton per hour of particulate. On the other hand, smalls go through a complex procedure to remove the ultrafines. For this equipment such as air separators or cyclone separators are used, discharging mechanical dust. Throughputs for this consist of 700 tons per hour.

The following step in the reduction and screening process is dewatering. This is possible by centrifugation, vacuuming, or pressurizing. For example, smalls are normally dewatered in centrifuges with capacities of 250 tons per hour. Water content can be reduced up to 7 per cent depending on the size of the smalls. Meanwhile, coarse coal would normally have a throughput of 40 tons per hour. Its water content can be reduced up to 15 per cent. Mainly in this process waste in form of floatation concentrate is also dewatered by either solid- bowl screen centrifuge, chamber filter press, or screen presses. The technology selected depends on the desired moisture in the waste. Another important aspect apart from the floatation concentrate is the amount of water used. It has been pointed out that the flow of water can be as high as 6 cubic meters per ton of raw feed coal and it could rise 1 cubic meter per ton of feed coal if the floatation waste is required to be discharged to an external deposit site. Although water is decanted to reduce concentrates, still there is a remainder of approximately 120 grams per liter. (Leininger et al, 2002).

Even though coal has been cleaned, sulfur may be presented in forms of sulfate, organic sulfur, or sulfide pyrite. Therefore coal is screened. First dirt larger than 40 millimeters is taken off. The floatings are decreased and fed with product coming from sizing into a blending section and are then homogenized. The product is cleaned and through low density separation, a low sulfur content coal is obtained. The sulfur containing floatation is then dewatered.

C. Converting coal into energy

The stage of energy generation is to improve its utility value as fuel and its transformation into forms of energy. For energy production coal conversion is possible by thermo chemical processes as combustion. By combustion processes the energy content of coal is acquired, nevertheless combustion products are indeed wastes. They generate effluents in gaseous and liquid phases and solid wastes. The combustion products are generated dependently on the reaction conditions and on the chemical and physical properties of the coal. For example, considering a power plant producing 1,000 mega watts per year (8.76×10^6 kilowatt hour per year); burning 3,000,000 tons of coal with a reduced content of sulfur to 2 per cent; containing 2.74×10^7 kilojoules per ton of energy value; and a thermal efficiency of 38 per cent, it will produce: 3,000 tons of particulate, 66.2 tones of organic matter, 82.5 tons of sulfuric acid, 26.3 tons of chloride, 41.7 tons of phosphate, 331 tons of boron, 497 tons of suspended solids, and 360,000 tons of bottom and fly ash (UNEP, 1981, in Chadwick et al., 1987)

Three main combustion processes are widely used: entrained phase, fluidized bed, and combustion on a moving grate. These operate efficiently when the coal used has specific qualities and blends. Development on combustion systems has gained partial control on pollution and emissions of GHGs as reduction has been enhanced. (Krzack et al., 2002). The technology used for combustion does affect the amounts of effluents released. Though modifications in technology may reduce GHGs emissions in the other hand they may enhance other releases to the environment (Chadwick et al., 1987).

It is understood that it is essential to develop and optimize technology to reduce environmental burdens. The coal energy industry contributes 3 tons of carbon dioxide per ton of coal combusted that is 1500 cubic meters. Coal consumption, estimated in 100,000 PJ, results in 10^{16} cubic meters of CO_2 emissions. Though, Krzack et al. (2002) have affirmed that power coming from coal has decreased from 1200 to 300 grams per kilowatt hour. Also it was indicated that through dust precipitation, dust emissions have decreased from 800 to 50 milligrams per cubic meter of flue gas. Along with these, the generation of other adverse constituents, conformed mainly by trace elements and polyaromatic hydrocarbons, has declined. Still the focused is on sulfur and nitrogen oxide emissions (Chadwick et al., 1987, 90) though the relevant impacts of trace elements and polyaromatic hydrocarbons. There is evidence that several PAH are carcinogenic.

Basically, waste generated in the combustion process can be categorized into: particulate effluents, and solid effluents. Particulates are found in dust, smoke, and flyash. They are produced by chemical and physical reactions that occur in combustion chambers as the minerals in coal are transformed into ash. This type of effluents varies in size and composition. Large particulates remain in the furnaces and are called bottom ash while small ones are carried out to the atmosphere with the flue gas and are called flyash. Flyash is of particular concern as it escapes to the atmosphere and it is contaminated with trace elements (Güney, 1994). At the end of the coal cycle several solid wastes are produced. According to the International energy agency (in Güney,1994) 40 to 300 kilograms of ash and 200 to 300 kilograms of end products are obtained from 1 ton of coal. Generally all this waste is deposited above the ground or disposed in landfilling sites. Moreover during disposing the waste into these sites, large amounts of dust is generated. Consequently, soil in the surrounding areas is polluted as well. In some cases water is added during transportation of waste to avoid dust, nonetheless leaching of toxic solutions may occur. Therefore suitable ponds or lagoons are used to discharge it.

At this final stage of the coal energy system coal waste problems can also be perceived. Certainly the forms of waste have changed compared to the other stages. The major waste products in the energy generation stage are in solid phase and released through air or directly collected from the plant. The particulates can also be carried out by water, though most attention has been set on airborne effluents that are directly emitted to the atmosphere. The main problem with these effluents is they further reaction and no controlled over that is possible. Impacts may come in ways of acid rain, acidic depositions, and soil, water, and air pollution. Effects are upon human health and the environment alike to those explained in the previous stages.

Finally, from the fuel cycle approach followed it was possible to show that there are other important chemicals in the wastes released to the environment. Also it was envisaged that the coal energy system is conformed by several stages therefore the current considerations of the system should be modified. GHG emissions is a very important environmental damaging consequence of the coal energy industry, nevertheless sustainability ought to be inclusive of all the environmental degrading by-products of the system. Enabling a sustainable production should further pursue on managing the coal processes minimizing all existing wastes productions. Certainly, wastes come in different ways along the system, so different management approaches should apply, but altogether this way of seeing the system will help to develop the strategies.

3.2 The Biomass energy production system

Biomass as energy source has seen growth in the share for supply in the last decades. In developed countries biomass energy is thought to be 8 EJ, and worldwide 55EJ which represent 14 per cent of the energy consumption (Ramage and Scurlock, 1996). Different types of biomass can be used to produce energy. Variation on the energy produced depends on its energy content as shown in table 3.2. Indeed, an important aspect about the use of biomass for energy is the release of CO_2. Wood biomass will produce 77 kg of CO2 per GJ while coal produces 90 kg of CO2 per GJ. Nevertheless according to Klass (1998) biomass release of CO2 may affect its concentrations much more compared to fossil fuels. In overall, the biomass energy system, regardless of its type, has focused on the emission of greenhouse gases, and the impact of other releases has been neglected in most studies.

Table 3.2 Biomass fuels and their energy content

Fuel	Energy content (GJ/t)	Fuel	Energy content (GJ/t)
Wood	15	Straw	14
Paper	17	Sugar cane	14
Dung	16	Domestic waste	9

Source: Ramage and Scurlock, 1996

3.2.1 Cultivated biomass system with an impact inclusive focus

As the coal energy system, the biomass energy system consists of various stages. For virgin wood biomass, as for other types of biomass, controlled productions have been established (Klass, 1998). Depending on whether the wood (for this case) is from natural forests or from energy resource managed forests, the processes may vary. If the wood is considered from a natural forest the system stages will not include the cultivation processes. Nevertheless, it will be considered that the system is corresponding to a cultivated forest as it has been reported as an increasing global trend (Hanegraaf et al., 1998). Following the work of Donald Klass (1998), the current biomass system considers:

- The purpose of developing biomass energy is to reduce impacts from burning fossil fuels and their high level of GHGs emission.
- It is intended to create cost effective procedures to enable higher biomass production for energy.
- The state of development of the biomass energy is concentrated in researching: harvesting methods, coppicing techniques, and genetic improvement to yield higher energy production, basically crop production systems.

The addition of other impacts such as waste and chemical releases has not been attended, similarly to the case of the coal energy system. Therefore, these effects to the environment from the system will be addressed in a more comprehensive system. The intention on its consideration on the biomass energy system is to link waste and chemical release problems to the focus of the efforts of current research and development. Moreover, the inclusion of these problems will be shown in fig 3.3. The system model is also based on the general energy system taking in consideration the following aspects:

- Cultivation of energy woody crops requires the use of herbicides, and fertilizers. Concerns on soil and underground water pollution.
- The preparation of land for energy crops may require special cleaning which produce wastes.
- Increasing forests allow higher degree of CO_2 sequestration which is positive for GHGs concerns.
- Harvesting contributes to waste generation.
- Wood processing and conversion also generate waste as well as release chemicals into the atmosphere.

Downplaying these considerations the system functions in a different way. Though, currently there is no link marked between the waste and chemical releases, if done, cultivation procedures would be particularly at stake with respect to the use chemicals to fertilize and diminish weeds and pests. This is of special interest as through these factors short rotation wood crops are achievable.

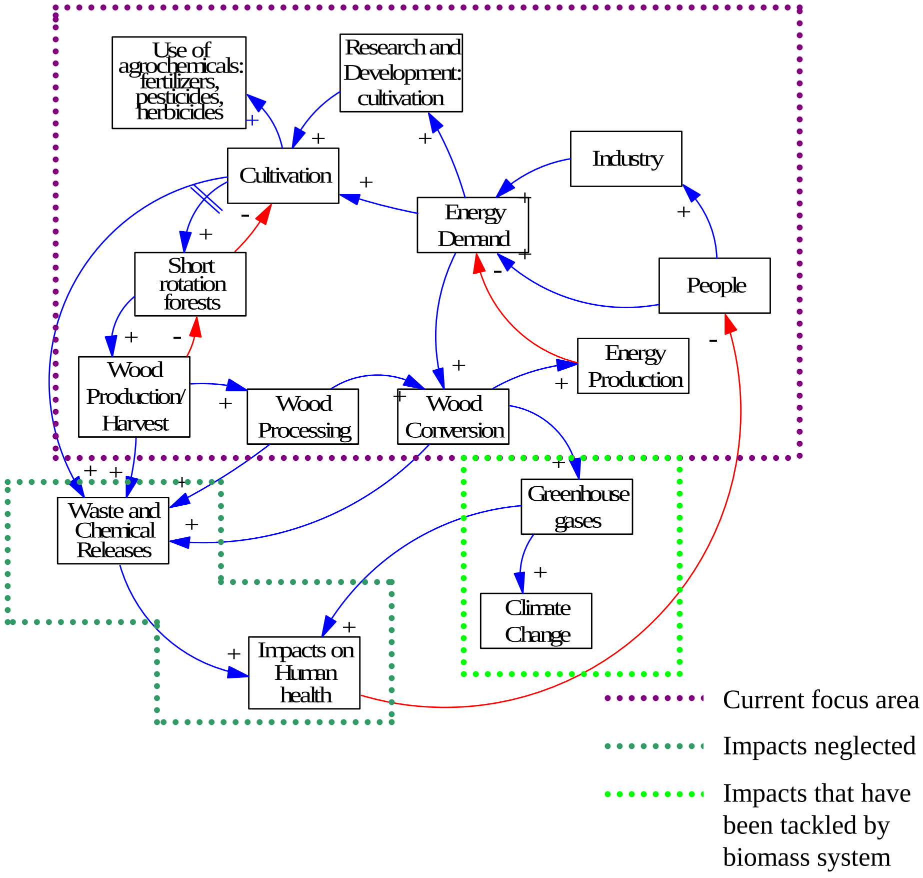


Figure 3.3 Inclusive woody biomass energy system.

3.2.2 The nature of wood energy crops

Wood forests in essence contribute as CO_2 and O_2 recyclers. Compared to the nature of fossil fuels, woody energy crops in their natural form might not contain many chemical constituents that may represent hazards. Table 3.3 shows the main characteristics of willow biomass. Other chemicals may be presented depending on the composition of the soil and the agrochemicals such as those in pesticides, herbicides, and fertilizers.

Table 3.3 Willow mass composition

Element	Dry weight %
C	49.4
S	0.05
O	42.9
H	6.01
N	0.45
Cl	265 ppm
Ash	1.24
Moisture (at harvest)	~ 50 %

Source: Heller, M.C. et al., 2003

Indeed, it was indicated by Obernberger et al. (1996), that inorganic elements of environmental relevance are presented in wood ash. Special concern is concentrated on heavy metals such as Cd and Zn. In table 3.4 it is enlisted all the chemicals that have reported to be found in wood ash. As it can be observed most of the chemicals found are the same as those found in coal ash.

Table 3.4 Chemicals found in Wood ash.

Main ash constituents				Heavy metals found in ash			
Si	Ca	S	Fe	Cu	Mo	Cr	V
Mg	K	Cl	Mn	Zn	As	Pb	Hg
Na	P	Al		Co	Ni	Cd	

Source: Obernberger et al., 1996.

3.2.3 Complete woody biomass energy system

As established before, the wood based biomass energy system goes through cultivation, harvesting, processing, and conversion processes. Each of these processes generates different wastes and release of chemicals. A complete view of the biomass energy system processes is shown in figure 3.4. It is important to note that as it is being considered a woody energy crop, no existing natural reserve is therefore existent.

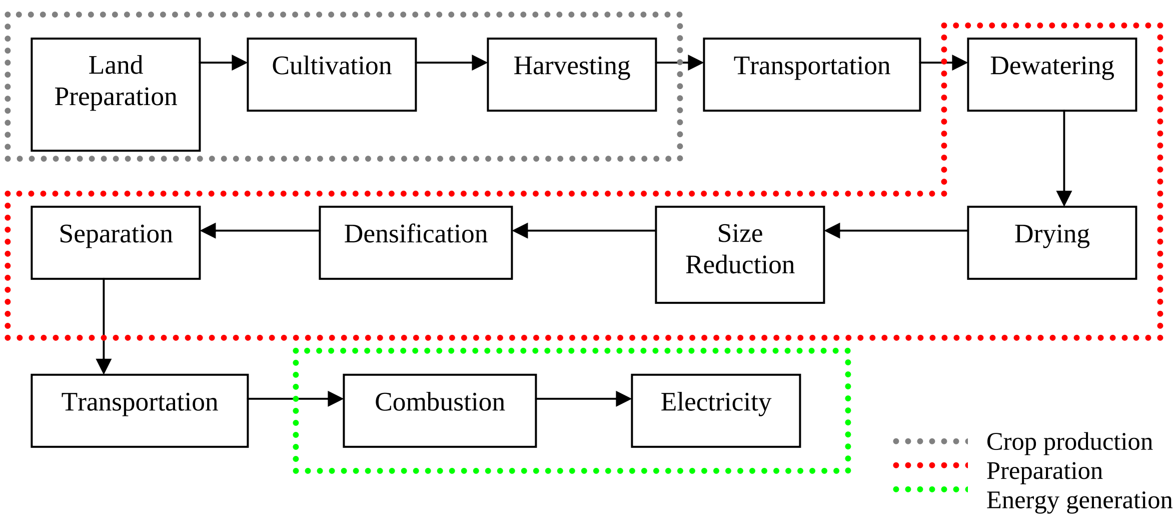


Figure 3.4 Biomass cycle chart. *This cycle chart was based on the literature by Klass, Donald L.,1998.*

A. Cultivation of woody energy crops

The production of woody energy crops involves three main activities as shown above. In order to grow crops suitable land for the species has to be prepared. It has been indicated (Klass, 1998) that factors such as density, irrigation, fertilization, weed control, disease control, and nutrients available in the cropland are required. Willow species are grown through short rotation method. In this method willow trees are harvested as soon as they grow. Furthermore, studies in the US have pointed that applying coppicing techniques yields larger amounts of biomass (Klass, 1998). Perhaps the main purpose of cultivation is to obtain more biomass; nevertheless a big concern rises as different agrochemicals are used to accelerate it.

The use of agrochemicals is of big environmental concern as they may lead to soil and water pollution. Soil conservation has been an issue in energy crops as there has been evidence of nutrient leaching from the experience in agricultural practices. In experimental experience Heller et al. (2003), have stated that in the 23 year lifespan of a willow crop, there is reduction of nutrients under application of 150 kg of N per ha per rotation. They also stated that perhaps it may be preferable to yield higher crop productions per ha though higher application of fertilizers may result in surplus of N and consequently leaching. A study performed by Park et al. (2004), indicated that when wood ash, as a way to recycle ash from wood combustion, is used as fertilizer it produces accumulation of K, Ca, and Mg.

Another impact on soil is the concentration of heavy metals from herbicides and pesticides. It has been recognized the pest outbreaks take place and pesticides, though avoided, must be used (Abrahamsson et al., 1998). However, it has been reported by Börjesson (1999) that Salix energy crops in fact reduce such impacts in soil as they have higher intakes of nutrients and heavy metals compared to other biomass energy crops. In contrast it has been stated by Ledin and Agnetha (in Abrahamsson et al., 1998) that when short rotations take place, nutrients will indeed be removed in the stem wood and nutrients will have to be applied in the amounts that have been removed.

Regarding the problem with waste, it has been stated that during cultivation nutrient containing leaves are left above ground. Typically the senescence of willow leaf is in the range of 3.8 ± 0.2 Mg per ha per year. According to Heller et al. (2003) this liter leaves amplify the loss of GHGs through microbial decomposition. Nevertheless, there was no reporting on accumulation of certain chemicals from these leaves on the ground.

B. Preparation of wood fuel

The next process after crop production is preparation. Similarly to the coal, biomass preparation is a long process chain. The first closely related processes are dewatering and drying. There exist several methods to dewater biomass. One of these methods is using chemical flocculants and surfactants (Klass, 1998). The impacts on dewatering and drying would rely on the properties of the water and water vapor that result as output of the processes. Or in the case of the chemical dewatering, the chemicals used that will be release with the water, therefore concentrations of those chemicals will be presented.

These two processes are followed by reduction in where the wood is transformed to chips or particle size depending on the requirement for the further processes (Klass, 1998). In the reduction stage the probable release will be wood dust this is based on the acknowledgment by the Government of Alberta (2004) that wood dust is presented in every stage of wood processing. The effects of wood dust are variable as they depend on the exposure and the chemical properties of the wood. At least, it has been reported by Alberta's Government that studies on human health effects have taken place and common impacts are dermatitis, asthma, conjunctivitis, among many others. The impacts of wood dust on the environment have not been recorded.

Densification and separation are the last processes of preparation. As in the case of reduction, these two are mainly regarding wood processing. Therefore it can be assumed that the waste produced or the release is in form of wood dust. This impact applies to these as densification deals with processing wood and compressing it into pellets or briquettes, while separation is delimbering and debarking. Nonetheless it has been explained by Klass (1998) that separation is not required in thermochemical processes, as combustion.

C. Conversion of wood into energy

As the coal, the biomass energy system ends with the combustion process. In here the wood is burnt. On the other hand, different to coal combustion technologies, for biomass all technologies have in common four ash fractions: bottom ash, boiler and cyclone fly ash, filter fly ash, and flue dust (Obernberger et al., 1996). The bottom ash contains mineral impurities and ash particles. The boiler and cyclone fly ash is inorganic ash particles which are carried out with the flue gas. The filter fly ash is finer fly ash which contained in fibrous filters or is condensed as sludge in flue gas. Finally the flue dust is the finest fly ash and is emitted with flue gas. It is important to remark that in their study by Obernberger et al. (1996) it was shown that the amount of heavy metals increased from bottom ash to flue ash. It was recognized that high amounts of Zn and Cd were found in the ash. The ash from filter fly is disposed to landfills, otherwise treated to recover the heavy metals. It was emphasized in the study that the filter fly ash fraction should not be recycled into the soil as fertilizer as it is possible with the bottom and cyclone ash. Finally it was reported that Cl was also presented in the flue gas. All these chemicals found on the ash are deposited into soil, landfills, or as Cl, into the air. Though it was mentioned previously some of these chemicals may be used as fertilizers, nevertheless, different chemicals combined in the soil may be accumulated and cause soil and water pollution. Ash from combustion is therefore a residue or waste.

The coal and biomass energy systems have considerably resulted in similarities and differences. In the assessment of both systems it was shown the wastes and the chemicals are released determining their relevance. Though, the relevance of these environmental problems was not quantified as there were no records found on the rates of generation throughout the fuel cycle processes. Also, through the analyses it was observed that the biomass energy system is as impacting as the coal energy system, which is opposite to the main goal of further developing renewables. In addition the current emphasis on GHGs is not necessarily moving towards a sustainable energy production as it has been shown that short term impacts are accumulating. These results are better understood through a comparison on the system analyses and the fuel cycles.

4.1 Comparison of the systems

In the general energy system (figure 1.1) it was perceived that mainly the energy production systems are driven by the consumption from people and industry. Nonetheless, tackling waste and chemical releases through production and consumption patterns of energy is not easy and might not be feasible. On the other hand, there is another factor in the system directly engaged to waste and chemical releases that is essential to reduce these impacts. Through the implementation of appropriate laws and policies the enhancement of research on these impacts will take place. Hence, this would result in the development technology. Although, different research approaches must be adopted to the coal energy system and to the biomass energy system.

If in the coal energy system, the environmental impacts due to the processes and their effects on human health were studied and quantified they could lead to further development of clean technology. Different studies from various coal power plants reviewed on the research have shown mass balances of the various chemicals produced during coal combustion that are discharged in the wastes, but they have not gone further in studying their impacts nor accounting them throughout the duration of the production activities. A first consideration to enable development of technology to reduce these problems is through continuous monitoring of existing active systems. Such extensive study may require not only the energy industry interest, but also it will require the support from the governments. With that, research and development for clean technology could be inclusive of studying not only GHGs and SO_2, but also solid wastes, waste water, and flue gas containing heavy metals, among other trace elements.

Studying the behavior of the waste produced and the chemicals released and having accountings of them will serve to understand the impacts. Perhaps, it would be not realistic to counteract the emission of every chemical that is released. Therefore, maybe targeting the most health and environmental affecting ones, as it was done with the case of Hg in the USA as noted earlier, is more feasible as coal contains many chemicals that are hazardous. Also, studies on targeted chemicals will affect the way by which current research and development on renewable energy sources is being done. This is for the same reason as for clean technology; renewables research and development will have to be aware of the targeted chemicals that must be tackled in the processes. This is applicable to wood crop energy systems, as it has been established that coal and biomass wastes (solid, water, air) contain almost the same chemicals.

Perhaps, it is important to note that for the woody biomass energy system the focus of the current research and development is set on cultivation and its productivity as indicated in chapter 3. It is in crop production where attention to chemicals usage should be scrutinized. The chemicals used to produce are those later released in the soil, water, dust, and combustion ash (later in the fuel cycle). Therefore, to link wastes with research and development of crops production is only a minor change. It could be a starting point though, to study the accumulation of the chemicals from pesticides and herbicides, as well as N and P from fertilizers as it is done with food crops. As stated by Faaij, et al. (1998) the use of fertilizers has led to nitrification of underground water and poisoning of soil with phosphates. And the use of pesticides has caused human health problems as well as the quality declination of surface water. Moreover in the discussions of their study it was confirmed that the effects from the use of agrochemicals is unknown or not all understood in woody energy crops.

One important consideration for the applicability of these studies is to develop controlled and standardized schemes. This is as both systems are active in a local scale, and the impacts being dealt are also local, unless of transboundary air and water pollution. Especially for the case of the woody biomass system, concerns will come about. Different companies opt for different products to enrich and prepare the land for cultivation. Therefore each case study will be entirely different as different chemicals are used. One way to promote it effectively would be that countries developing wood energy crops of the same species were determined through governmental policies and measures to use specific agrochemicals. By this it will be more realistic to perform impact studies and have records to focus on further research and development.

Apart from these, another way to reduce waste and chemical releases could be done through efficiency in the processing of coal and wood. As it is a mean to reduce GHGs it will also be a mean for waste and chemicals reduction. This is due to the fact that there is less input of run of mine coal into the process or less requirement to grow crops. Hence, reducing coal production reduces directly the waste from coal mining and coal preparation while reducing wood cultivation it will reduce directly the accumulation of chemicals in the soil and water. Nevertheless, optimizing processes to endure coal and biomass resource efficiency might be achieved in a long time after experimenting and developing the technology. Though, if made possible, efficient use of coal and biomass will counteract every impact.

On the other hand, there should also be research and development on wood preparation and conversion processes. If taking in consideration that larger amounts of wood are processed compared to coal in order to produce the same amount of energy, then it is reasonable to expand research and development on this area for the reduction of wastes. Although, it is important to restate that wood conversion as coal is through combustion processes, and there is special concern on release of GHGs and SO_2 as biomass is intended to produce less of these than coal.

In addition, it is relevant to acknowledge that the systems are driven differently. The coal energy system is governed directly by energy demand whereas woody biomass energy system is governed by the outcomes from current research and development of alternative energy sources and on crop production. Hence, reducing wastes and chemical releases is complex and challenging. There is a prevailing uncertainty of the effects on one hand, and uncertainty of the amounts being disposed onto the ground and discharged into the water and air on the other. Different studies show different results.

4.2 Comparison of the fuel cycles' outputs to the environment

From the assessment of the coal and wood fuel cycles it was notable various similarities. Both systems carried out three main processes, and the wastes and chemical releases from them were as well alike. Table 4.1 enlists each system and its outputs onto the environment according to each process. As it can be observed there are some main differences. During the source production process, coal produces already dust and solid waste. Wood biomass does not produce the problem itself, but the methods to produce the wood indeed release chemicals on the ground and the water. Also there is no solid waste produced. In the preparation processes both produce dust containing chemicals or particulate matter and waste water, though coal does produce solid waste in two forms that require disposal. In the final process of the fuel cycle both undergo combustion and waste is mainly ash, either solid or as airborne effluent. It is important to note all these wastes and releases from the processes because they show how many other environmental problems are faced in the energy systems that have not been carefully studied in order to know their real impact on the environment and human health. Certainly, if all existing coal systems and biomass systems were put together, the big question would be how much these impacts will affect. Unfortunately, none of these wastes has been assessed quantifiably to have a clear picture except for airborne effluents or discharges of dust into the atmosphere.

Table 4.1 Coal and woody biomass energy systems and their outputs to the environment

	Coal Energy System			**Woody Biomass Energy System**		
Resources	907.3 billion tons (IEA, 2003)			Energy crops may vary in size		
Process	***Mining***	***Preparation***	***Combustion***	***Crop production***	***Preparation***	***Combustion***
Outflows	Coal dust	Coarse refuse	Fly ash	Fertilizers in soil	Wood dust	Bottom ash
	Mining water	Fine refuse	Bottom ash	Agrochemicals in soil	Waste water	Cyclone fly ash
	Coarse refuse	Coal dust	Sludge	Run off water containing agrochemicals		Filter fly ash
		Waste water	Waste water			Flue dust
						Waste water

Table 4.2 shows the amount of pollutants in tons per kWh from the energy system following the fuel cycle: extraction of the energy and plant construction and operation. Then considering that wood contains 15 GJ per t and coal 28 GJ per t (Ramage and Scurlock, 1996) and assuming from conversion units that 1 GJ per ton is equivalent to 0.8603 x 10^6 Btu per ton and that 1 kWh is 3412 Btu it can be obtained the amount of pollutants per ton of coal or wood fuel processed. The results are shown on table 4.3 in tons of pollutant per tons of energy source. From these results it can be seen that regarding air emissions, there is evidence that the amounts of GHGs and SO_2 are larger than those from particulate matter and hydrocarbons. Therefore, in the case of air pollutants it can be agreed that

significantly sustainability in the energy production systems can be slightly centered on CO_2. Nevertheless, it cannot be omitted that the chemicals presented in the suspended particles and the hydrocarbons are also large and they represent short term impacts especially on human health, according to the toxicities discussed on Chapter 3. On the other hand it would be very interesting and helpful to have such studies on emissions to water and soil. Unless there are studies indicating amounts of pollutants from waste and discharges it is hard to state if the impacts of such are significant or not, but from the results of the total impacts from table 4.1 and the amount of particles and hydrocarbons emitted to the air, a picture of the amounts on soil and water can be foreseen. In that sense, the magnitude of the impacts could be assumed to be significant for consideration in the framework for sustainability in energy production.

Table 4.2 Comparison of resulting amounts of pollutants by energy system per energy produced.

Energy System/ pollutants	Total suspended particles	CO	Hydrocarbons
Coal	1.63E-06	2.67E-07	1.02E-07
Biomass	5.12E-07	1.136E-05	7.68E-07

*Source: Everett and Boyle, 1996 (table prepared by the Council for Renewable Energy education) Note: modifications to the original table were done through conversion of units from GWh to kWh. * Biomass is considered to have cero emissions as it is accounting to have had sequestered CO2 with the regrowth of the crops.*

Table 4.3 Comparison of resulting amounts of pollutants per amount of energy source processed.

Energy System/ pollutants	Total suspended particles	CO	Hydrocarbons
Coal	0.011479	0.001885	0.00072
Biomass	0.001936	0.0429683	0.002905

Note: see appendix 1 for all calculations for conversion.

From the tables on air pollutants emitted it can be seen that in regards to particulates and other chemicals (hydrocarbons) the coal energy system and the biomass energy system are different. Biomass is only 16 per cent of the emissions from coal. Nevertheless with respect to the emission of hydrocarbons coal only emits 24 per cent of what biomass emits. With respect to CO, the coal system emissions represent only 4 per cent of those from biomass. Considering all the emissions, excluding GHGs and SO_2, coal emissions would represent 29 per cent of the emissions from biomass. With this results it could be stated that biomass with respect to other emissions different than GHGs and SO_2 might not be a more sustainable alternative compared to coal.

Overall results have shown that major impacting processes respectively are different. For the coal energy system most of the waste occurs during mining. Effluents to the water occur particularly in the preparation. Opposite to coal, the biomass energy system produces the most waste at the conversion process. The chemical releases as explained earlier happen basically during cultivation. If more profound studies were performed at each process of the fuel cycle it would help to find a focal point to reduce these impacts where it is needed the most.

In addition, from the way the systems were analyzed some concerns come about. The lack of current studies on the different processes has lead to a very ample perspective of the issues of concern. Yet, several aspects should be appointed. First, if future research will be endured the selection of one type of affected source should be selected. That is, choosing from analyzing soil, water, or air. Nonetheless the latter has been a focus for major global environmental issues. Then, a stage of the fuel cycle must be selected according to the dimension of the impacts. By dimension is meant amount of people that could be affected, size of area affected, etc. These would be finalized by recording and collecting sufficient data to make more appropriate comparisons that will result in sustainable energy production systems.

In an overall, the approach given to analyze the systems was not optimal for a study based on the review of literature of the current state of the energy sector, as still results are not sufficient to determine the sustainability of both systems as a whole. On the other hand, the results from the comparison give way to state that analyzing the coal and energy production systems from the perspective on waste and chemical releases demonstrates there is an environmental burden that must be taken care of. This was plausible as qualitatively it was given a picture on all the processing activities and the impacts. By the system analyses it was made clear that the focus of research and development plays an important role with respect to adapting a fuel cycle impacts study. Also it showed that wastes and chemical releases affect the dynamics of the whole system because they impact directly human health. Though a major setback is that different studies are based on different criterion, therefore the results on amounts and impacts are subjective and not applicable to set a comparable scheme properly. Moreover, it was notable, that there is a lack of knowledge on the dimension of these environmental problems. Although it was mentioned that both systems have had counteracting activities such as recycling of waste and disposal, the way how this waste management takes place is not well founded, as placing wastes back onto the environment without learning the behavior of the chemicals in them results on further environmental and health impacts.

Since it is unclear how far these releases are from exceeding the carrying capacity of the environment, and it is unclear the effects they produce in a dose- exposure relation some recommendations could be appointed. It is clear that research and studying these impacts represent expenses basically to the governments (as shown in analysis of the energy sector). On the other hand, it can also be envisaged that counteracting health impacts and environmental impacts from them also represent an economic disadvantage to the governments in means of social and health care, and treating soils just to mention a few. But what is more feasible, having expenses on analyzing and researching these problems and developing technology and political measures that will control and minimize them or rather let energy production systems to work as they do and after some years acknowledge that the impacts have damaged irreversibly the environment and the lives of people? Why waiting to see impacts overcoming the thresholds of the environment and humanity to do something about it? It is hard to solve the problems of waste and chemical discharges when there is not enough evidence that proves it is harmfully impacting and to what extent. Yet, how can these be perceived as problems if there is no evidence indicating that waste and discharges that are not GHGs are there in various amounts and forms? It is highly recommended that attention should be placed on this issue because in this respect the solution of developing renewable energy as biomass is not showing more sustainability.

Perhaps, the problem with waste and release of chemicals from the energy production systems has no solution. Energy is viewed as a key for sustainable development, therefore energy production will never seize. Yet, the purpose is not to stop energy production but to yield a sustainable energy production system. As GHGs have been tackled on behalf of a potential climate change, then wastes and releases could be tackled on behalf of securing clean soils, clean water, and clean air, consequently food security and healthiness. This will enhance ensuring the availability of a clean and healthy environment for the future generations. In brief, a sustainable energy production should embrace a precautionary view and on its behalf expand the current scope of research and development of clean technology and renewable energy to include wastes and chemical releases.

REFERENCES

Abrahamsson, L.P.,et al. (1998). *Sustainability and Environmental Issues Associated with Willow Bioenergy Development in New York (U.S.A.).* Biomass and Bioenergy. Vol. 15. Elsevier.

Alexander, Gary. (1996). *The Context of Renewable energy Technology. Renewable energy Power for a sustainable future*. Edited by Godfrey Boyle(oxford, UK the Open University)

Börjesson, Pål. (1999). *Environmental effects of energy crops cultivation in Sweden: identification and Qualification.* Biomass and Energy. Vol. 16. Elsevier.

Carter, Niel. (2001). *The Politics of the Environment: Ideas, Activism, Policy*. Cambridge University Press.

Chawick, M.J. et al. (1987). *Environmental Impacts of Coal Mining and Utilization.* Pergamon Press

Crelling, John C. and Hagemann, Hans W. (2002a).. *Coal: Classification.* Ullman's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

Crelling, John C. and Hagemann, Hans W. (2002b). *Coal: Coalification.* Ullman's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

Crelling, John C. and Hagemann, Hans W. (2002c). *Coal: Coal Petrology*. Ullman's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

Dictionary of inorganic and organometallic compounds. (2005). on the web. Chapman & Hall/ CRC Chemical Database. Available through http://www.lib.kth.se.

EPA (Environmental Protection Agency). (2000). *Comment Summary and Response documents. Report to Congress Wastes from the combustion of fossil fuels*. April 2000. http://www.epa.gov/epaoswer/other/fossil/ffc.-resp.pdf

EPA (Environmental Protection Agency). (2005a). *Clear Skies Legislation*. Government of the United States.http://www.epa.gov/air/clearskies/

EPA (Environmental Protection Agency). (2005b). *Mercury: basic information*. Government of th U.S. http://www.epa.gov/mercury/bout.html

EPA (Environmental Protection Agency). (2005c). *Mayor Environmental Laws*. Government of the U.S. http://www.epa.gov/epahome/laws.html

EPA (Environmental Protection Agency). (2005d). *National Ambient air quality Standards.* Government of the U.S. http://epa.gov/air/criteria.html

EC (European Commission). (1995). *ExternE: Externalities of Energy: Coal & Lignite*. Luxembourg: European Commission

EC (European Commission). (2001a). *Green Paper Towards a European Strategy for the security of Energy Supply*. http://europa.eu.int/comm/energy_transpor/en/lpl_en.html

EC (European Commission). (2001b). *Environment 2010: Our Future Our Choice*. Communication from the Commission to the Council, The European Parliament, The Economic and Social Committee, and the Committee of the Regions. On the Sixth Action programme of the European Community. Brussels.

EC (European Commission). (2001c). *Green Paper: Towards a European Strategy for the security of Energy Supply*. Technical report.

EC (European Commission). (2002). *Towards a European Strategy for the Security of Energy Supply*. Communication to the Council and the European Parliament. Final Report on the Green Paper. Brussels, 26, 6, 2002 COM(2002). 321 final.

EEA (European Environment Agency). (2002). *Energy and Environment in European Union*. Environment issues report No. 31

EEA (European Environment Agency). (2003). *Assessment of information related to waste and materials flows. A catalogue of methods and tools*. Technical report.
http://www.eea.eu.int

EEA (European Environment Agency). (2003b). *Europe's Environment: Third Assessment.*

EEA (European Environment Agency). (2004). *A European Environment Agency Updates on Selected Issues*. EEA Signals 2004. Copenhagen. 1 June, 2004
http://reports.eea.cu.int/signals_2004/en/ENSignals2004web.pdf

EEA (European Environment Agency). (2005). *European Environmental Outlook*. EEA Reports No. 4. Copenhagen 11 Sept, 2005).
http://reports.eea.eu.int/eea_report_2005_4/en/outlook_web.pdf

European Union. (2001*). Activities of the European Union. Summaries of Legislation.*
http://www.eu.int/scadplus/scad_en.htm

Everett, Bob and Boyles, Godfrey. (1996). *Integration Renewable Energy: Power for a Sustainable Future. Chapter 10.* Edited by Godfrey, Boyle.

Faaij, Andre et al. (998). *Externalities of Biomass based electricity Production Compared with power generation from Coal in the Netherlands.* Biomass and Bioenergy. Vol. 14. Elsevier Science Ltd.

Government of Alberta. (2004). *Health Effects from Exposure to Wood Dust.* Workplace Health and Safety. Bulletin Work safe Alberta.

Güney, Mehmet. (1994) *Environmental impacts of Coal-Related Activities.* Coal: Resources, Properties, Utilization, Pollution. Turkey. Klural Ed.

Hanegraaf, Marjoleine et al. (1998). *Assessing the ecological and economic sustainability of energy crops.* Biomass and Energy. Vol. 15. Great Britain: Elsevier Ltd.

Heller, Martin C. et al. (2003). *Life cycle assessment of a willow bioenergy cropping system.* Biomass and Bioenergy. Elsevier Science Ltd.

Holdren, John P. and Smith, Kirk R. (2000). *Energy, the environment, and health. World Energy Assessment. Energy and the challenge of sustainability*. United Nations Development Programme

IEA (International Energy Agency). (2005). *Key World Energy Statistics*. http://www.iea.org/bookshop/add.aspx?id=144.

Klass, Donald L. (1998). *Biomass for Renewable Energy, Fuels, and Chemicals.* Entech International, Inc. Academic Press.

Krzack, Steffen, Meyer, Bernd, Orywal, Rainer, Bonn, Bernhard and Bertmann, Udo. (2002). *Coal: Coal Conversion.* Ullmann's Encyclopedia of Industrial Chemistry.

Ledin, S. and Agnetha, A. (1996). in Abrahamsson, L.P.,et al. (1998). *Sustainability and Environmental Issues Associated with Willow Bioenergy Development in New York(U.S.A.).* Biomass and Bioenergy. Vol. 15. Elsevier.

Leininger, Dietar et al. (2002). *Coal: Preparation.* Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

Nieuwlaar, Evert. (2004). *Life Cycle Assessments and Energy Systems.* The Netherlands. Copernicus Institute, Utrecht University.

Obernberger, Ingwald et al. (1996). *Concentrations of Inorganic Elements in Biomass Fuels and Recovery in the Different ash Fractions.* Biomass &Bioenergy. Elsevier Science Ltd.

Önal, Güven et al. (1994). *Coal Preparation.* Coal: Resources, Properties, Utilization, Pollution. Turkey. Klural Ed.

Park, Byung Bae et al. (2004). *Wood Ash effects on Soil Solution and Nutrients Budgets in a Willow Bioenergy Plantation.* Water, Air, and Soil Pollution. Vol. 159. Klumer Academic Publishers.

Ramage, Janet and Scurlock, Jonathan. (1996). *Biomass.* Godfrey Boyle Ed. United Kingdom: The Open Press.

Ramani, Raja V. and Vogt, Werner. (2002). *Coal: Coal Mining.* Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

Rogner, Hans~Hdger and Popescu, Anca. (2000). *An Introduction to Energy*. *World Energy Assessment: Energy and the Challenge of Sustainability*. United Nations Development Programme.

Sauter, Dieter H. (2002). *Coal: Chemical Structure of Coal.* Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

The Combined Chemical Dictionary. (2005). On the web. Chapman & Hall/ CRC Chemical Database. Available through http://www.lib.kth.se.

UN (United Nations). (1992). Earth Summit. *United Nations Conference on Environment and Development (UNCED)*. Rio de Janeiro 3-14 June, 1992.
http://www.un.org/geninfo/bp/enviro.html

UN (United Nations). (2002). *World Summit on Sustainable Development Johannesburg, South Africa Facts About…Energy*.

UN (United Nations). (2005a). *The Energy Challenge for Achieving the Millennium Development Goals.*

UN (United Nations). (2005a). Division for Sustainable Development. *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* Sustainable Development Issues.
http://www.un.org/esa/sustdev/sdissues/energy/enr.html

UN (United Nations). (2005b). *Sustainable development Issues*. United Nations Department of Economics and Social affairs: Division for Sustainable development.
http://www.un.org/esa/sstdev/sdissues/

UNEP (United Nations Environmental Programme). (1981).*Environmental Impacts of Production and Use of Energy*. In Chawick, M.J., Highton, N.H. and Lindman, N. (1987).

UNEP (United Nations Environmental Programme). (2004). Division of Technology, Industry and Economics. *Industry and Environment: Cleaner Production.* 8th International High Level Seminar on Sustainable Consumption and Production. Monterrey Mexico. Vol. 27 No. 4
http://www.uneptie.org

United States Department of Energy. (2001). *National Energy Policy Report.* Government of the United States of America.
http://www.energy.gov/engine/content.do?BT_CODE=AD_AP

von Elsner, Otto, and Riepe, Wolfgang. (2002). *Raw Materials an Energy: Oil, Gas and Coal.* Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlang GmbH & Co.

APPENDIX 1

Original Table excerpt from Everett and Boyle, 1996							
Energy System	CO2	NO2	SO2	Total suspended particles	CO	Hydrocarbons	tons/GWh
Coal	1058.2	2.986	2.971	1.626	0.267	0.102	
Biomass	0	0.614	0.154	0.512	11.361	0.768	
	conversion from tons/GWh to tons/kWh				1 GWh is 1000000 kWh		
Energy System/ pollutants	CO2	NO2	SO2	Total suspended particles	CO	Hydrocarbons	tons/ kWh
Coal	0.0010582	2.986E-06	2.97E-06	1.63E-06	2.67E-07	1.02E-07	
Biomass	0	6.14E-07	1.54E-07	5.12E-07	1.136E-05	7.68E-07	
then if it is produced:							
	7059.9	kWh/ ton of coal					
	3782.09	kWh/ ton of wood biomass					
tons of pollutant/ ton of energy source processed							
Energy System/ pollutants	CO2	NO2	SO2	Total suspended particles	CO	Hydrocarbons	tons pullutant/ tons energy source
Coal	7.47078618	0.02108086	0.020975	0.011479	0.001885	0.00072	
Biomass	0	2.3E-03	0.000582	0.001936	0.0429683	0.002905	
		Percentages		16.86874	4.3869369	24.79166	%