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Master of Science Thesis

Assessment of Environmental Impacts of Power Generation

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Preface

This master's thesis was made in Czech Technical University in Prague under supervision of Professor Jiří Tůma from the department of power systems.

I would like thank Prof. Ing. Jiří Tůma, DrSc for supervising my master thesis and for helping and advising me with his expert knowledge. In addition I would like to thank Professor Satu Viljainen for all the help and advice she gave me in the end of the project.

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Abstract

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Through indisputable evidence of climate change and its link to the greenhouse gas emissions comes the necessity for change in energy production infrastructure during the coming decades. Through political conventions and restrictions energy industry is pushed toward using bigger share of renewable energy sources as energy supply. In addition to climate change, sustainable energy supply is another major issue for future development plans, but neither of these should come with unbearable price. All the power production types have environmental effects as well as strengths and weaknesses. Although each change comes with a price, right track in minimising the environmental impacts and energy supply security can be found by combining all possible low-carbon technologies and by improving energy efficiency in all sectors, for creating a new power production infrastructure of tolerable energy price and of minor environmental effects.

GEMIS-Global Emission Model for Integrated Systems is a life-cycle analysis program which was used in this thesis to make indicative energy models for Finland's future energy supply. Results indicate that the energy supply must comprise both high capacity nuclear power as well as large variation of renewable energy sources for minimization of all environmental effects and keeping energy price reasonable.

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List of Acronyms and Variables

Acronyms

AOX	Absorbable Organic Halogens
AQFWD	Air Quality Framework Directive
ART	Advanced Renewable Tariff
BAT	Best Available Technique
BOD	Biological Oxygen Demand
BPP	Back-Pressure Power
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium Uranium-Reactor
CCGT	Combined Cycle Gas Turbines
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CEC	Cumulated Energy Cost
CER	Cumulated Energy Requirement
CHP	Combined Heat and Power
CH_4	Methane
CMR	Cumulated Material Requirement
CO	Carbon monoxide
COD	Chemical Oxygen Demand
COP	Conference of Parties
CO_2	Carbon dioxide
ECCP	European Climate Change Programme
EIA	Environmental Impact Assessment
ELV	Emission Limit Value
EMAS	International standard for environmental management
EMS	Environmental Management System
EPR	European Pressure Reactor
ERU	Emission Reduction Unit
EU	European Union
FENCH	Full Energy Chain calculation
FGD	Flue-Gas-Desulphurization
FIT	Feed-In Tariff

GEMIS	Global Emissions Model for Integrated Systems
GHG	Greenhouse Gas
GhK	Gesamthochschule Kassel
GWP	Global Warming Potential
HF	Hydrogen Fluorine
HFC	Hydro Fluorocarbon
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
ISO	International Standardisation Organisation
LCA	Life-Cycle Analysis / Life-Cycle Assessment
LCI	Life-Cycle Inventory Analysis
LCIA	Life-Cycle Impact Assessment
LCPD	Large Combustion Plant Directive
N	Nitrogen
NECD	National Emission Ceiling Directive
NH_3	Ammonia
NMOVOC	Non-methane Volatile Organic Compound
NO_x	Nitrogen Oxides
N_2O	Nitrous Oxide
OECD	Organisation for Economic Co-operation and Development
P	Phosphor
PCB	Polychlorinated Biphenyl
PCT	Polychlorinated Terphenyl
PFC	Per-fluorocarbon
PM	Total Suspended Particulate Matter
PM_1	Particulate Matter $\leq$1 µm in Aerodynamic Diameter
$PM_{2.5}$	Particulate Matter $\leq$2,5 µm in Aerodynamic Diameter
PM_{10}	Particulate Matter $\leq$10 µm in Aerodynamic Diameter
ppm	Parts Per Million
PV	Photo Voltaic

PWR	Pressure Water Reactor
RES	Renewable Energy Source
REV	Reference Emission Value
SF_6	Sulphur-hexafluoride
TEMIS	Total Emissions Model for Integrated Systems
TOPP	Tropospheric O-zone Precursor Potential
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WFD	Water Framework Directive
WMO	World Meteorological Organisation
WWEA	World Wind Energy Association

Variables

A	GDP per capita, €
A_{maz}	income where T reaches T_{max}
c_0	Consumption in time 0
c_1	Consumption in time 1
c_h	Heat Capacity of fluid, kJ/kgC
c_p	Coefficient of performance
EC_i	Efficiency of control equipment for reaction of emissions of pollutant i, %
e_F	Fuel consumption expressed as an energy flow rate, GJ/y
e_{Fi}	Estimated fuel consumption by combustion device i, GJ/y for gas or L/y for liquid fuels
EF_i	Factor for emissions of pollutant I from specified type of source, GJ/y for gas or L/y for liquid fuels
E_i	Emissions of pollutant I form specified source (t/y)
g	Acceleration due to gravity, ~9,81 m/s^2
g_c	Conversion factor for kJ/s to GJ/y
H	Effective pressure head of water across the turbine, m
h_o	Outlet Enthalpie, kJ/kg
h_i	Inlet Enthalpie, kJ/kg
I	Environmental impact

m	Mass flow rate of process fluid, kJ/kgC
η	Thermal efficiency, %
P_W	Power, W
P	Population
Q	Volume flow rate, m^3/s
T	Technology
t_0	Annual operating hours
T_{maz}	maximum value of T
v	Wind speed, m/s
ρ	Density of air, kg/m^3
η_g	Efficiency of generator
η_b	Efficiency of gearbox/bearings
ε_{low}	income elasticity of T at low incomes
ε_{high}	income elasticity of T at high incomes
δ	Discount rate
γ	Flexibility of financial benefit

1 Introduction

Energy sector is going to go through changes during the following decades. Prices of fossil fuels have gone up and concern for environmental effects caused by the use of fossil fuels have aroused interest in changing current energy infrastructure for more sustainable and less polluting. Energy sector is one of the biggest sources of greenhouse gas emission source in the world, therefore big part of the change has to happen in this sector. Change can be made by switching to renewable energy sources or to other low emission production types. One possibility is also to invest in emission reducing technologies for existing plants or equipping new plants with them. But, as a matter of fact, these renewable energy sources and low emission production types have also environmental effects. Moreover, switching to these production methods comes with higher expenses.

Aim of this thesis was to examine legislative, technical and economical aspect involved in environmental effects caused by power generation and to form an opinion how power generation infrastructure should evolve with consideration of all these three aforementioned aspects.

This thesis begins with theory part by describing current situation in the world concerning energy and environment, in addition how environment is effected by human activities. Thesis continues by describing environmental legislations and conventions that influence energy industry followed by chapters describing the principles of power generation types and environmental effects caused by them.

Chapter 7 is practical part of the thesis where a case examination was made. Computations of the case were made with program GEMIS for generating scenarios for Finland’s energy production in 2007, 2015, 2020 and three different models for 2030. Computations for the scenarios environmental effects were made with Life-cycle Assessment method which the GEMIS uses. The method and GEMIS are further described in chapter 7.

2 Environment and Power Industry

Power industry and environment hold a link between each other through which there are effects both ways. Energy industry has environmental impacts through its activities and the effects may change the essence of the environment e.g. by causing climate change, which in turn has harmful impacts on industrial processes and world economy. This chapter will explain the evolution of power generation and shares of natural resources used in the world. Furthermore, climate change and its causes are explained.

2.1 Energy consumption and emissions

Power systems consist of power generation, power transmission and distribution and finally consumption of energy. This report will concentrate on the power generations environmental effects due to the fact that it is the largest contributor of environmental effects caused by the energy sector. /1/

2.1.1 Global and Europe's energy production and consumption

Energy consumption has increased during last decades evenly and largest share of it is produced with fossil fuels. Consumption of energy is also expected to rise with steady pace while the global economy is rising. From the worlds electricity supply 66,6 % was produced with fossil fuels in the year 2005. From total energy supply in the world, the share of fossil fuels was 82,8 % in year 2005. Figure 2.1 shows the evolution of electricity generation in the world from 1971 until 2005. / 2/

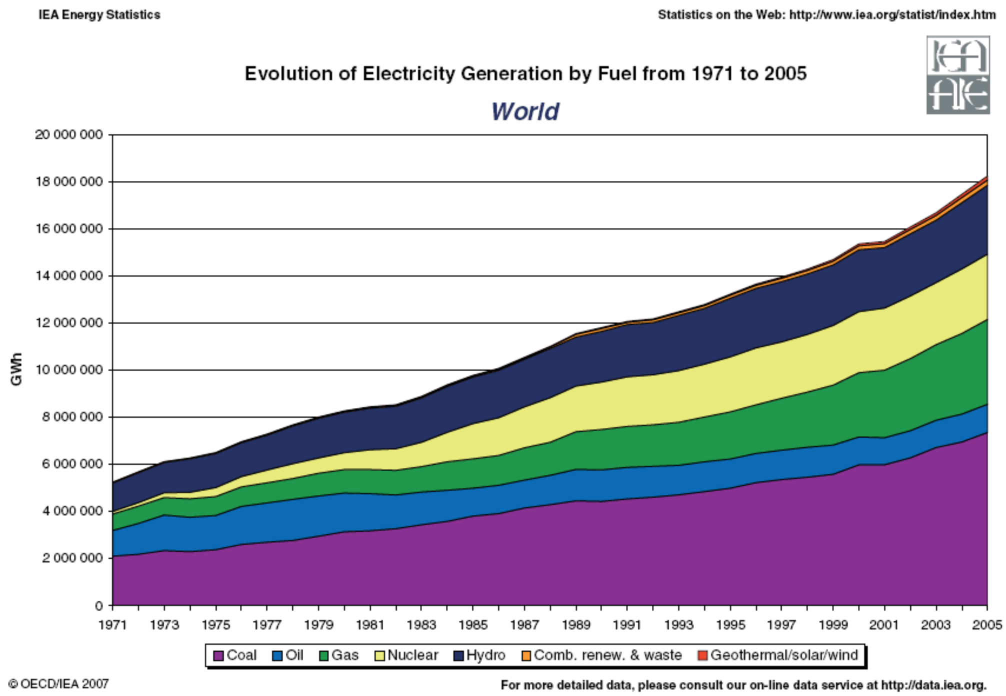

Figure 2.1 World electricity generation by fuel /2/

From final consumption of energy oil holds the largest share. Electricity's share of final consumption of energy was 16,3 % in 2005. Oil's share was 43,4 %. Figure 2.2 describes the evolution of world final consumption of energy from 1971 to 2005. /2/

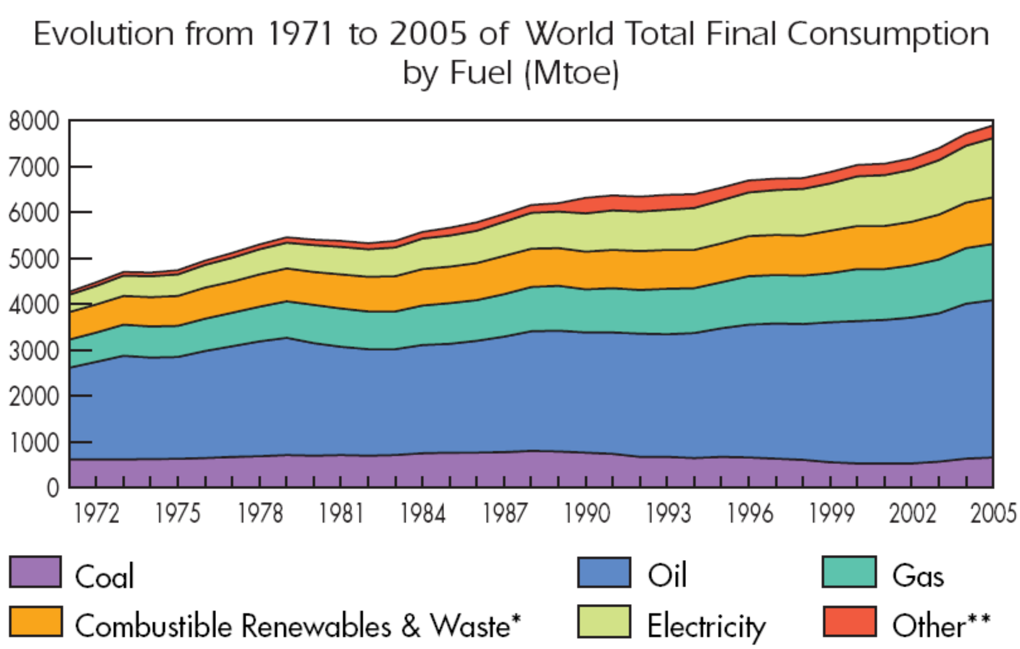

Figure 2.2 Worlds final consumption of energy /2/

2.1.2 Energy consumption in EU

Primary energy consumption in EU has been projected to grow during 1990 – 2010 by average of 1 % per year. Growth of consumption differs across the member countries. 75 % of EU's energy consumption was satisfied by energy from fossil fuels sources in 2007 and largest energy source was oil with 37 % share. Figure 2.3 represents the shares of energy sources used for energy in 2004. /3/

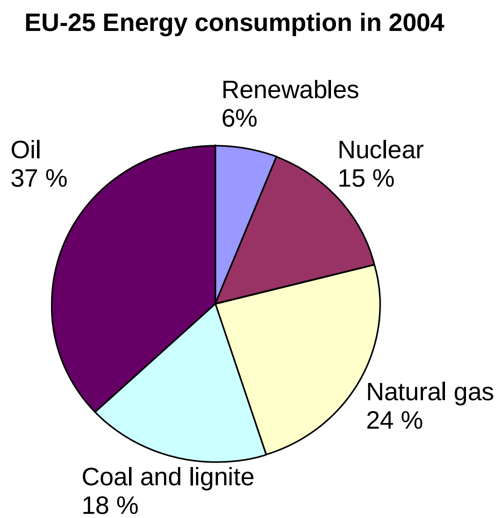

Figure 2.3 EU-25's energy consumption in 2004 /3/

Energy sources used for electricity production in EU are shown on figure 2.4. Furthermore, some projections for future production are shown. Largest single source is nuclear power with share of 31 % and fossil fuels cover 53,9 % from total energy produced. /3/

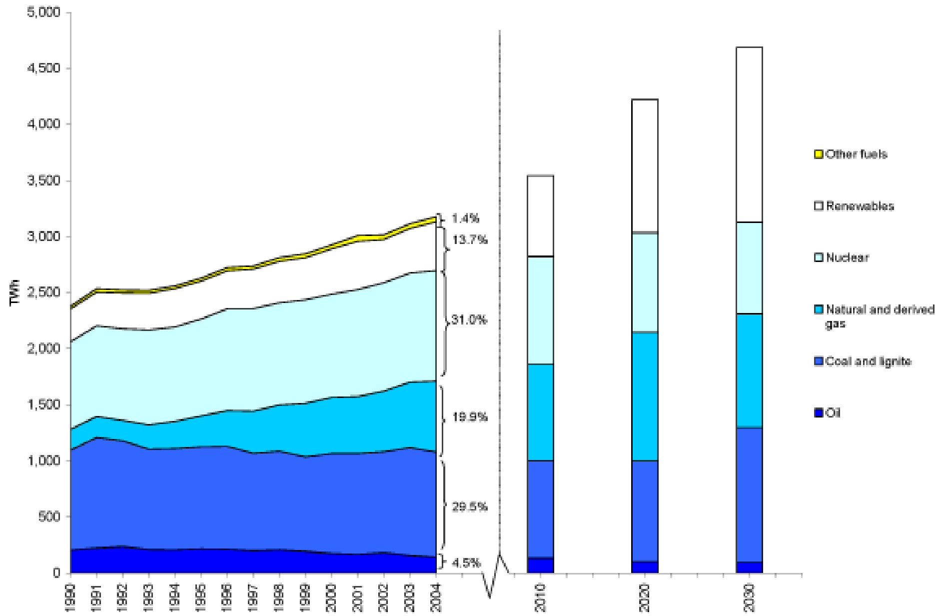

Figure 2.4 EU-25 electricity production from 1990 – 2004 and projections for 2010, 2020 and 2030 /3//4/

CO_2 emissions from electricity production in EU are mainly coming from coal-condensing power plants. CO_2 emissions coming from electricity and heat production are 31,8 % of total CO_2 emission in EU. Table 2.1 describes the greenhouse gas emission in EU are and share of emissions from electricity and heat production in year 2005. /5/

Table 2.1 EU electricity sector emissions in 2005 /5/

	Total emissions [Mt CO_2 eq]	% of total GHG emissions	Emissions from electricity and heat generation [Mt CO_2 eq]	% of total emissions from electricity and heat generation	% of emissions from electricity and heat generation out of total
CO_2	4259	82,5	1354	98,9	31,8
CH_4	418	8,1	1	0,1	
N_2O	415	8	14	1	3,4
HFCs	57	1,1			
PFCs	6	0,1			
SF6	9	0,2			
	5144	100	1369	100	

2.2 Climate change

Water vapour and some compounds, like carbon dioxide, which occur in small concentrations in the atmosphere, are disrupting heat leaving from earth, thereby increasing earth's temperature. This natural greenhouse effect occurs in periods of time and it can increase earth's temperature by over 30 degrees of Celsius. /6/

Human activities such as using fossil fuels as energy source, has increased the amount of greenhouse gases, thereby making the greenhouse effect stronger than normal. Studies show that pre-industrial levels of carbon dioxide was about 280 ppm (parts per million), and in year 2000 same level was 368 ppm, and growing approximately 1,5 ppm annually. In methane's case, the concentration in the atmosphere has doubled. According to Intergovernmental Panel on Climate Change, Greenhouse effect, caused by greenhouse gas concentration in atmosphere, has been calculated to raise earths average temperature by 1,4 – 5,8 °C by the year 2100. Effects from the temperature increase are estimated to raise oceans water level by 0,1 – 0,9 m causing storms and hurricanes and changing considerably earth's humidity levels of soil, courses of ocean currents and the precipitation. Figure 2.5 describes the deviation of temperature from year 1890 until 1990 and the change of CO_2 concentration in atmosphere in parts per million (ppm). /7/

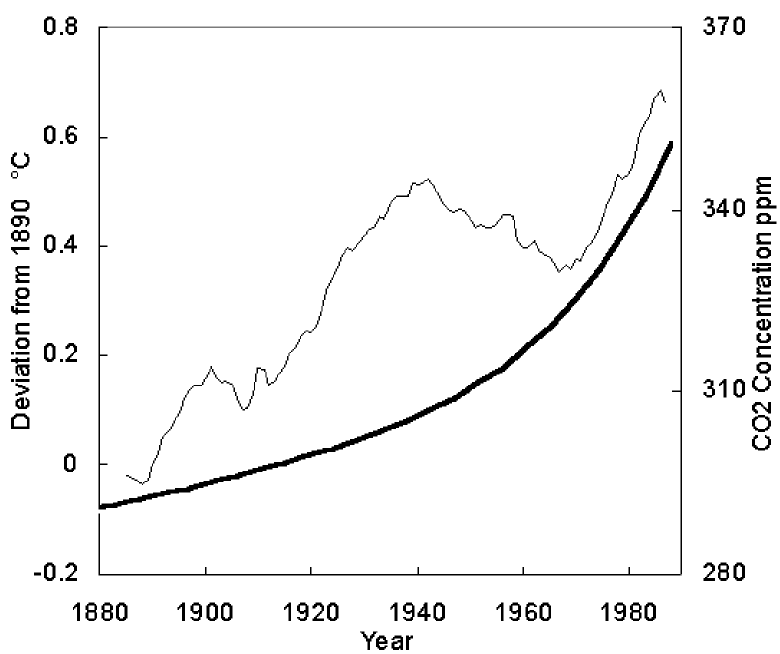

Figure 2.5 Graph showing deviation of temperature from 1890 (thin line) and CO_2 concentration (thick line) /7/

2.3 Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). Its constituency is made of /7/:

- The governments: the IPCC is open to all member countries of WMO and UNEP. Governments participate in plenary Sessions of the IPCC where the main decisions about the IPCC work programme are taken and reports are accepted, adopted and approved. They also participate on reviewing of IPCC Reports.
- The scientists: hundreds of scientists all over the world contribute to the work of the IPCC as authors, contributors and reviewers.
- The people: as United Nations body, the IPCC work aims at the promotion of the United Nations human development goals.

The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. "The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation" /7/. IPCC reports are supposed to be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage. /7/

2.4 Greenhouse gases

In nature occurs temperature and climate changing in periods naturally, but this change seems to have been accelerated to un-natural speed after industrialization of the world. Main reason for this acceleration is caused by greenhouse gas (GHG) emissions, of which carbon dioxide is largest single greenhouse gas. Approximately 75 % of all carbon dioxide emissions are created from combustion process of fossil fuels (lignite, coal, oil and natural gas). Also peat is considered as fossil fuel due to its long formation time, approximately 2000 – 3000 years. Destruction of rainforests also causes large amount of carbon dioxide emissions. Methane emissions caused by human activities comes from waste dumps, animal husbandry, production of fuel and cultivation of rice. Causes for nitrous oxide emissions are nitrogenous eutrophication, production of nitric acid and combustion processes. Nearly two-thirds of emissions in the world are coming from the activities associated with electricity production and the transport sector. Electricity generation alone accounts for third of over all global emissions. /6/

Greenhouse gases (GHG) are mostly natural part of nature, but there are also gases which results of human activities. Naturally occurring GHG are /8/:

- Carbon dioxide ($C0_2$)
- Methane (CH_4)
- Nitrous oxide (N_2O)

Un-naturally occurring, from industry processes emitted GHG are /8/:

- Hydro-fluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6),

IPCC has formulised a way to calculate the effects of different GHG. The Global Warming Potential (GWP) is the measure of the ability of a gas to affect climate change compared to a reference gas, which is CO_2. The atmospheric lifetime of gases differs highly e.g. methane stays in atmosphere for 20 years and nitrous oxide stays for over 100 years. Therefore, the results are integrated over different time intervals. Table 2.2 shows GWP values that have been calculated with 100 year time horizon. /7/

Table 2.2 Gases and their GWP values compared to CO_2 /7/

Gas type	GWP values
Carbon dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous Oxide (N_2O)	296
Sulphur hexafluoride (SF_6)	22.200
Tetrafluoromethane (CF_4)	6.500
Hydrofluorocarbons (HFCs)	1.300
Chlorofluorocarbons (CFCs)	9.300
Hydrochlorofluorocarbons (HCFCs)	1.700

Calculations of emissions in this thesis have been made with multiplying emissions from all other than CO_2 gases with the GWP value to make them comparable. All emissions are then summed up together as CO_2 equivalents. Figure 2.6 shows the change of $CO_{2,eq}$ in the world from 1970 until 2004. /7/

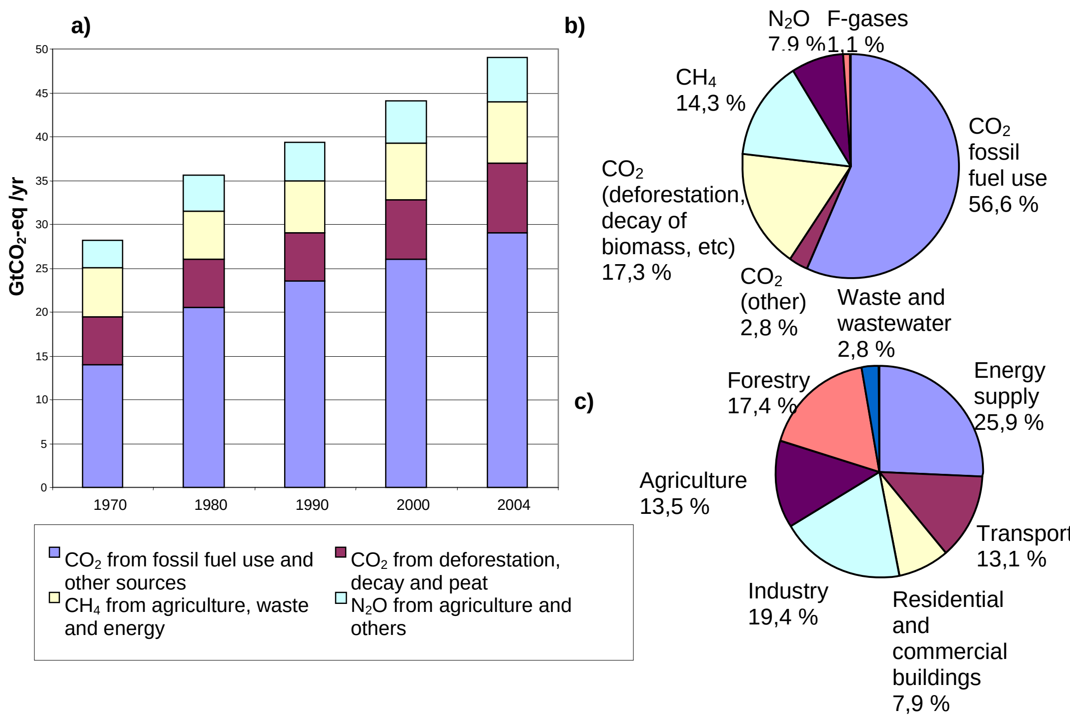

Figure 2.6 Global anthropogenic GHG emissions /7/ a) Global annual emissions for anthropogenic GHGs from 1970 – 2004, b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of $CO_{2\text{-}eq}$, c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2 e.g. forest includes deforestation

As the climate problem is global, solution for the problem has to be found in global level and continued down with the pyramid to state and consumer level. Following chapters will explain more of conventions and framework in different scales to counter and minimize the effects of electricity industry.

3 Environmental policies

Environmental legislations and regulations have a huge impact on the electricity industry and the price of electricity and fuel. These rules and regulations set up framework, in which electricity industry has to operate. These laws come from both international and domestic front and their instruments for environmental framework can be divided into legislative and non-legislative instruments, depending on the nature of the legal acts. Some are meant to be strict laws when others are voluntary agreements to motivate industry to lower their emissions.

3.1 International climate conventions

This Chapter will describe how the power industry is affecting specific environmental areas and describes the legislations and regulations for these areas mostly inside EU. List of all directives and decision effecting energy industry in EU can be found in Annex I. /9/

3.1.1 United Nations Framework Convention on Climate Change

United Nations Framework Convention on Climate Change (UNFCCC), international treaty, was set up on 21 March 1994, to set up overall framework to cope with climate change challenges. Essentially convention sees that global climate has been and is being affected by emissions of GHGs and the responsibility for this has to be shared. Convention has members from 192 States. /10/

Under the Convention, governments are to /10/:

- gather and share information on greenhouse gas emissions, national policies and best practices
- launch national strategies for addressing greenhouse emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries
- cooperate in preparing for adaptation to the impacts of climate change

3.1.2 The Kyoto Protocol

Member states of UNFCCC saw that their commitments were not adequate enough to slow down the climate change, so governments decided that stronger and more detailed commitments had to be made. Kyoto Protocol, self-standing agreement negotiated within the member states of UNFCCC was adopted at Conference of Parties (COP) 3 in Kyoto, Japan, on 11 December 1997. /10/

Requirements of the Protocol states that developed countries have to reduce their GHG emissions (CO_2, N_2O, CH_4, SF_6, PFC and HFC) within a five-year timeframe between 2008 and 2012, by at least 5,2 % against the baseline of 1990 level. Burden of emissions cuts are shared by all countries, though heavier burden is placed upon developed countries, for they have historically contributed more to the problem compared with developing countries. To European Union the commitment to reduce GHG emissions were 8 % during the target period 2008 to 2012. Table 3.1 shows the share of world emissions contributed by single countries in the year 1990. /10/

Table 3.1 Share of emissions in year 1990 /9/

Country	Emissions [%]	Country	Emissions [%]	Country	Emissions [%]
Australia	2,1	Greece	0,6	Netherlands	1,2
Austria	0,4	Hungary	0,5	New Zealand	0,2
Belgium	0,8	Iceland	0,0	Norway	0,3
Bulgaria	0,6	Ireland	0,2	Poland	3,0
Canada	3,3	Italy	3,1	Portugal	0,3
Czech Republic	1,2	Japan	8,5	Russian Federation	17,4
Denmark	0,4	Latvia	0,2	Slovakia	0,4
Estonia	0,3	Lichtenstein	0,0	Spain	1,9
Finland	0,4	Romania	1,2	Sweden	0,4
France	2,7	Luxembourg	0,1	Switzerland	0,3
Germany	7,4	Monaco	0,0	UK	4,3
				USA	36,1

Kyoto protocol affects all major sectors of the economy and for that reason it is considered the most far-reaching agreement on environment, but which many countries, especially developing countries like India and China, are hesitant to ratify. Some countries chose not to ratify it and only agreed with it. The Kyoto agreement entered into force on 16 February 2005. The Kyoto Protocol entered into force when 55 countries ratified it. Table 3.2 describes the emission targets set to EU and other countries. /10/

Table 3.2 Emissions targets from the Kyoto Protocol /11/

Parties	Emissions target (expressed in relation to emission in the base year or period) [%]
Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland	- 8
United States of America	- 7
Canada, Hungary, Japan, Poland	- 6
Croatia	- 5
New Zealand, Russian Federation, Ukraine	0
Norway	+ 1
Australia	+ 8
Iceland	+ 10

Countries reductions of GHG emissions are to be from the baseline from their 1990 levels, in exception countries with economics in transition, which may choose different baseline. Moreover, countries may choose a baseline of 1990 or 1995 for its emissions of HFC, PFC and SF_6. Table 3.3 describes more in detail the emission targets from the EU member countries between the years 2008 and 2012. These burdens were later followed by requirements for renewable energy source share in each member state in EU. EUs Renewable Energy Roadmap is described later in chapter 3.5.1. /12/

Table 3.3 EU15 burden sharing for achievement of EU 8 % emissions reductions /12/

Member state	Change-% compared to year 1990. Emissions between years 2008 – 2012 [%]
Luxembourg	-28
Denmark	-21
Germany	-21
Austria	-13
Great-Britain	-12,5
Belgium	-7,5
Italy	-6,5
Netherlands	-6
Finland	0
France	0
Sweden	+4
Ireland	+13
Spain	+15
Greece	+25
Portugal	+27

According to UNFCCC rough estimate the total amount of emissions should be decreased by 60 % by the year 2100 from its levels in the beginning of century for stopping the concentration of GHG in the atmosphere on safe levels. For this estimation to happen there should be stricter emission constrictions. Stabilization of the atmospheric concentration will take at least 100 due to rapid growth of global population and consumption, slow changes in economies and energy technologies and slow removal of atmospheric substances from the atmosphere. /10/

Changing of the countries allowed emissions is done by trading Kyoto Protocol units, which are called *Kyoto mechanisms* /13/:

- Emissions trading
- Joint Implementation
- Clean Development Mechanism

Units attained from other country are added to the countries assigned amount where as transferred unit amount will be subtracted from the assigned amount. The mechanisms allow developed counties to earn and trade emissions credits from projects implemented domestically or in foreign country. /13/

3.1.3 European Climate Change Programme

Introduction of response measures has been active in EU, at domestic level. May 2002 Kyoto Protocol was ratified as a body by EU followed by the adoption of a decision on burden sharing between EU15. /13/

After initial addressing of climate change in 1991 with limitation of CO_2 emission levels and improvement of energy efficiency, EU adopted European Climate Change Programme (ECCP I) in 2000. Objective was to formulate strategies within EU for achieving 8 % GHG emission reductions, specified by Kyoto Protocol. Second phase of the ECCP (ECCP II) was launched on 24 October 2005, and its concentration points are; ECCP I review, aviation, CO_2 and cars, Carbon capture and storage, adaptation, EU emission trading scheme review. /13/

3.1.4 Emissions trading and Kyoto mechanisms

The ECCP set Directive that set in place “cap and trade” framework for the emissions, by focussing initially on CO_2 for selected industrial sectors (Pulp and paper, glass, cement and ceramics, iron and steel, energy). In the directive “cap” stands for the overall quantity of allowances that can be distributed by the state for their industry in trading sector and the specific installation. /13/

Kyoto mechanisms are /13/:

Joint implementation Joint implementation refers to measures through which a country can achieve emission reductions in another country which is defined as an economy in transition. In this way, countries can agree on the transfer of emission reduction units (ERU) from one country to another. The ERUs are removed from the emission rights of the economy in transition in question and transferred to the account of the other country which implements the joint implementation project in the economy in transition.

Clean development Clean development mechanism (CDM) is similar to joint implementation, but the emission reduction takes place in a country for which no emission goal has been defined in the Kyoto Protocol (normally in developing countries). Emission reduction units achieved through CDM projects are referred to as CER (certified emission reduction).

Emission trading Emissions trading is a mechanism through which states can trade in emission rights. It can be expected that especially Russia, the Ukraine and Poland can sell their excess emission allowances to those countries which find it hard to achieve their emission goals.

3.1.5 Renewable energy roadmap of EU

At present EU is importing 50 % of its energy and fuel for it. With current developments in the economic growth and population increase the corresponding figure will be 70 % during next 20 - 30 years, if changes are not made to the energy policy in EU. EU gas imports are expected to be 80 % in 25 years from total consumption. In the world energy demand and emissions are expected to grow 60 % until year 2030. By then and world's oil-consumption will have increased by 20 % from 1994 and it will continue to increase by 1,6 % annually. In addition according to IPCC greenhouse gases will have increased worlds temperature by 0,6°C, and it will further rise by 1,4 - 5,8°C by the turn of the century. Table 3.5 describes the requirements of the green paper for member states' share in renewable energy sources by the year 2020. /14a/

Table 3.4 Requirements of shares of renewable energy for member countries /14b/

Member State	Share of renewable in 2005 [%]	Share required by 2020 [%]
Austria	23.3	34
Belgium	2.2	13
Bulgaria	9.4	16
Cyprus	2.9	13
Czech Republic	6.1	13
Denmark	17	30
Estonia	18	25
Finland	28.5	38
France	10.3	23
Germany	5.8	18
Greece	6.9	18
Hungary	4.3	13
Ireland	3.1	16
Italy	5.2	17
Latvia	34.9	42
Lithuania	15	23
Luxembourg	0.9	11
Malta	0	10
The Netherlands	2.4	14
Poland	7.2	15
Portugal	20.5	31
Romania	17.8	24
Slovak Republic	6.7	14
Slovenia	16	25
Spain	8.7	20
Sweden	39.8	49
United Kingdom	1.3	15

With Commissions Renewable Energy Roadmap EU decided to make legally binding agreement to increase share of renewable energies to target 20 % of EU total energy consumption by year 2020 from current 5,5 % (2005) share. EU will miss the previous target of 12 % by year 2010, exceeding about 10 %. Targets also included 20 % decrease of GHG emissions and 20 % increase of efficiency by year 2020. Achievement of target 20 % lower emissions will reduce CO_2 emissions in range of 600 – 900 Mt in 2020. With CO_2-price of 25 €/tonne, the additional total CO_2 benefit can be calculated at a range of 150 - 200 billion €. /14a/

3.2 Environmental issue areas

Number of specific environmental issue areas can be specified for the power industry. Those areas are air, climate change, water and waste and residues. This chapter describes environmental issue areas and how EU legislation affects energy industry through these issues.

3.2.1 Air

Power industry's harmful impact on air quality is mostly caused by the emissions from thermal power plants. Environmental problems caused by the main emission SO_2, NO_x and dust, include acidification, eutrophication and harm to public health. Key directive for air pollution is Directive 2001/80EC that regulates emissions in air, by limiting emissions of certain pollutants from large combustion plants. The Directive is also referred to as the LCP Directive, Large Combustion Plant Directive (LCPD). The Emission Limit Values (ELV) are prescribed for individual plant commissioned before 27 November 2002. Furthermore, for all existing plants commissioned before 1 July 1987 has been formulated national emissions reductions. For SO_2 the target was 70 % reduction in 2003 in comparison to 1980 emissions. For NO_x, 40% reduction in 1998 compared to the emissions in the same reference year. In 2016, the emission limit for the NO_x of solid fuels will become even stricter for plants of more than 500 MW. Table 3.6 describes the ELV for SO_2 and NO_x from plants to be built after 2003. /9/

Table 3.5 ELVs for SO_2 and NO_x for plants to be built after 2003 /15/

Plant size [MW]	SO_2 [mg/m^3]			NO_x [mg/m^3]		
	50 - 100	**100 - 300**	**> 300**	**50 - 100**	**100 - 300**	**> 300**
Solid fuels	850	200	200	400	200	200
Liquid fuels	850	400-200	200	400	200	200
Biomass	200	200	200	400	300	200
Natural gas	35	35	35	150	150	100

Other directives for Air /15/:

- Directive 1992/32/EC: Reduction of sulphur content of heavy fuel oil of 1,00 % by mass and gas oils of 0,02 % as of 1 July 2000 and 0,1 % as of 1 January 2008.
- Directive 96/61/EC: Provides the structure for air quality management in the EU, also known as Air Quality Framework Directive (AQFWD)
- Directive 2001/81/EC: National emission ceilings for certain atmospheric pollutants (NECD), limits national emissions of SO_2, NO_x, VOC and NH_3.

3.2.2 Water

Hydropower has been used for a long time for the production of electricity and with current trends in energy policies it plays a vital role in GHG reductions as a power source and regulation power for e.g. wind power. Thus, damming rivers and making artificial lakes for the hydropower has negative impact on environment, in spite of its GHG emission free power production principles. Lakes and rivers are also used in cooling systems of thermal and nuclear power plants, which may lead to release of substances in the water causing possible environmental impact on the ecosystem /15/. Environmental permissions also state how warm water is allowed to be released back to the watercourse. Cause of this is that during warm seasons power plants may have to lower their production so the released water is not too warm /14c/.

Water protection policy in EU is governed by Directive 2000/60/EC, also known as Water Framework Directive (WFD). Objectives of WFD are: "An environmental objective stipulating that by 2015 all surface waters shall have reached (at least) good ecological and chemical status and ground waters to have reached (at least) good quantitative and chemical status; and, secondly, to streamline EU water legislation by repealing old directives." /15/

3.2.3 Waste and residues

Power industry produces by its activities wastes of non-hazardous and hazardous nature. Recovering and disposing these wastes through whole chain of activity fields (generation, transmission and distribution) cause inevitably environmental impacts and economic costs.

Directives for waste and residues /15/:

- Directive 75/442/EEC: European framework on waste management
- Directive 91/689/EEC: Hazardous waste from electricity industry
- Council Regulation 259/93/EC: Supervision and control of shipments of waste within, into and out of European Community
- Directive 99/31/EC: Disposal of waste, landfill of waste
- Directive 96/59/EC: Disposal of PCBs/PCTs, (Polychlorinated Biphenyls / Polychlorinated Terphenyls) requirements for electricity industry to dispose of equipment containing more than 5 litres of PCB
- Directive 2000/76/EC:ncineration of waste

3.2.4 Other issues

Biodiversity protection and its Directive 92/43/EEC, on the conservation of natural habitats and of wild fauna and flora, has also role in power industries regulation. The directives aim to ensure biodiversity and conservation of specific natural habitats is managed by the EU member state, which is required to designate Natura 2000 areas. /15/

Natura 2000 areas may raise a number of concerns for the power industries. Building in these areas is prohibited and emissions caused by installations in the vicinity of those areas may have consequences. For example building hydropower plant or an artificial lake for hydropower, may prove to be impossible due to Natura 2000. /15/

Small note can be made because of environmental noise and the Directive 2002/49/EC relating to the assessment and management of environmental noise. Noise caused by electricity production (e.g. wind power) may have impact on the environment and its inhabitants, at least humans. /15/

3.3 Environmental management

In addition for the environmental legislation there has to exist a working method for managing of the environmental impact with proper structured and systematic framework. To monitor the management there has to be monitoring and verifications system. This section will describe some measures to manage environmental policy within a state or individual company.

3.3.1 Environmental Management systems

Environmental Management systems (EMS) can be registered by electricity companies for two available international standards: ISO 14001 or EMAS. Distinctive feature of an EMS is that it is voluntary, though it has been implemented in fair number of electricity companies. Intention of EMS is to help companies to manage requirements posed by environmental legislations. Differences between EMAS and ISO 14001 standards are described in Annex II. /9/

3.3.2 Environmental Impact Assessment

Environmental impact assessment (EIA) procedure is to ensure that environmental aspects and concerns are taken into account during the planning and before the execution of power industrial projects. EIA gives possibility to identify and assess environmental consequences and take in to account the public opinion before authorisation is given. /9/

Directives concerning EIA:

- Directive 85/337/EEC: Assessment of the effects of certain public and private projects on the environment
- Directive 2001/42/EC: Assessment of the effects of certain plans and programmes on the environment

Voluntary environmental agreements made between operators and lawmakers can provide flexible alternative to legislative measures for achievement of environmental objectives. For the time being agreements in electricity industry does not exist, although e.g. car manufactures have reached agreements in EU Member States. Inclusion of more environmental characteristics and provisions in the technical *standardisation* process could simplify environmental legislation. /9/

3.3.3 Green certificates

Green certificates are market-based approach for supporting renewable electricity. Demand for the certificates can be voluntary or through requiring the power suppliers to have a certain percentage of renewable electricity in their portfolio. Through these ways, these tradable certificates can be received by investing in renewable energy or by acquiring them from other market participant. /15/

3.3.4 Eco-labelling

Eco-labelling and its subset *environmental product declaration* can be defined as energy markings of the products in general. In power industries case, question is about electricity. The ISO standard ISO 14020 recognises three types of eco-labels;

- Type I (third-party certified labels)
- Type II (self-declarations)
- Type III (third-party certified environmental product declarations)

On an EU level, there exists the Type I eco-label "the EU flower" (established through Regulation 880/92 and amended through Regulation 1980/2000). Whilst this label system does not have criteria for electricity (i.e. it is not applicable to electricity), there are national systems that do have. Proposed Directive concerning common rules for the internal market in electricity and natural gas proposes provisions for disclosure of some environmental aspects of electricity production, even though it is yet unclear what the final requirements will be. Some electricity companies have developed Type III environmental product declarations where the environmental impacts of the entire electricity production chain are presented based on a life-cycle approach. /9/

3.3.5 Feed-in tariff

Feed-in tariff is measure for states internal market, which has also effects on international markets in case open electricity markets. Feed-in tariffs purpose is to promote renewable energy with a tariff, which would ensure the renewable power producer with base price, which the producer would get for the electricity fed-in to the power system, even though the market price would be less than the base price. /9/

There are Electricity feed laws, feed-in tariffs (FITs) and Advanced Renewable Tariffs (ARTs) which differ in the way the tariffs are set. Tariffs are different depending on the technology used (wind power, solar PV, biomass) and also within technologies with project size or productivity in certain area. Countries such as Germany, Denmark and Spain have boosted their wind power production by using FITs and many other have done similar with wind power and other renewable energy sources, countries are: Australia, Austria, Canada, China, Czech Republic, Great Britain, France, Greece, Ireland, Italy, New Zealand, Netherlands, Portugal, South Africa, Turkey, some states of USA. /16/

3.4 Environmental protection and permitting

Environmental permitting and protection falls under larger directive package Directive 96/61/EC concerning integrated pollution prevention and control (IPPC). Below IPPC are environmental controls e.g. Strategic Environmental assessment, Environmental Impact Assessment, Seveso Directive and the Environmental Management and Audit System (EMAS). Some elements of IPPC /15/:

- Both new and existing combustion plants with thermal capacity exceeding 50MW requires permit for operation
- The permits must be based on “Best Available Technique” (BAT) (i.e. technology and methods of operation must be effective and advanced to minimize all significant plant emissions)
- Encourages for use of Reference Emissions Values (REV) to minimize transfer of pollutants from one

3.5 Fiscal measures and instruments

Fiscal instruments are mainly taxation or levy of taxes on e.g. certain fuels falls on individual states authorities. Under EU legislation is mentioned that fiscal matters will not be EU matter if they interfere with the Internal Markets. Nevertheless, in European states there has become large range of different fiscal instruments including; Taxes on sulphur content in fuels, charges on certain emissions and taxes on water use. With large variety of these instruments the influence on power industry is eminent. /15/

One exception on EU energy taxation is EU taxation regime, which was adapted on 1 January 2004 and it states that taxation levels will amount to 0,5 EUR/MWh electricity for business use and 1.0 EUR/MWh for non-business use. /15/

4 Energy production technologies

This chapter will describe the main technologies and their characteristics that are used in energy industry for power generation. Furthermore, technologies that can be used to improve the older technologies by minimizing the impact of power generation on the environment are described.

4.1 Principles of power production

Energy production is conversion process where primary energy sources are converted into electricity and heat. Three main conversion types can be specified /17/:

- Transforming mechanical energy into electricity; i.e. thermal, wind and hydro power plants
- Conversion of solar radiation into electricity; i.e. solar power plant/photo voltaic
- Electrochemical conversion; i.e. Fuel cells

Power production technologies that use these main energy conversion processes can be separated into three main categories /18/:

- Fossil-fuel fired condensing power plants
- Nuclear power plant
- Renewable energy power plants

In addition can be specified number of technologies producing power in “small-scale”. Those are: Internal combustion engines, Fuel cells, micro gas turbines and Stirling engines. /18/

Share of certain power production types in use within states and regions depends on following factors /19/:

- Time alternation of consumption
- Supply of energy source (fuel, water, sun etc.)
- Heat loads in use
- Cost structure of the power plants

Production categories

Power supply is divided into different categories depending on how they are used. Method of application for these supplies comes from their operational principles. Those categories are /19/:

- Base power supply: Supply with big capacity, typically large investment and production operation time long: > 6000 h
- Intermediate-power supply: Supply with medium or small capacity, used also as distributed generation, operation time: ~ 2000 … 6000 h
- Peak load and reserve power supply: Simple and small stations with fast power output and usually expensive operating costs, fairly short operating time: < 2000 h
- Regulating power supply: Power supply with fast changeable power output that can be used fast

Some power generation types can be utilized in many different categories, though they may be in optimal use only in one category. On the other hand, optimal use of supplies is sometimes not possible when certain supply is not available enough or available at all (e.g. hydro). In the case of Finland where base supply is produced with nuclear, hydro and combined heat and power (CHP), and conventional condensing power stations and gas-turbine plants are used to cover extra-power needs and peak-loads. Nordic power systems power regulation is mainly done by hydropower in each country and all the countries take part in the regulation operations via interconnection lines. Figure 4.1 illustrates the price formation during high and low demand. /19/

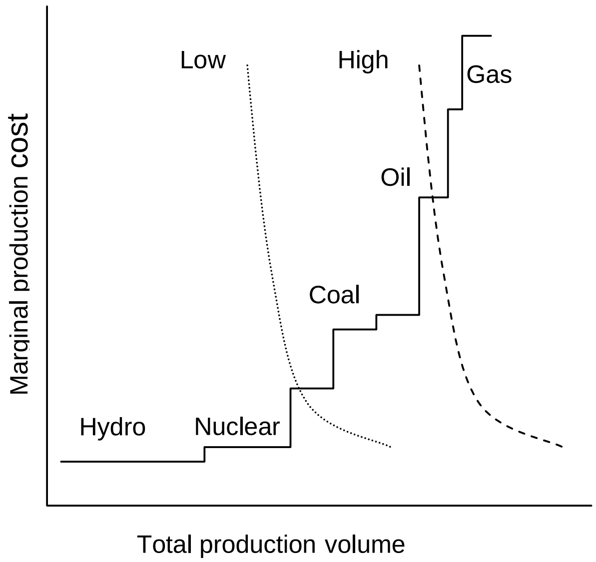

Figure 4.1 Schematic supply-stack with two demand curves for low and high demand /20/

Figure 4.1 has schematic supply stack and on it are two demand curves superimposed. The price of electricity is not volatile for price changes while the stack in low demand is flat, but on high demand even a small increase in consumption can raise the prices dramatically. /20/

<u>Electricity as a commodity and different energy sources</u>

The main difference between electricity and normal bulk commodity production is that the supply and consumption of electricity must be balanced at each point in time. And also it should be understood that various energy production options bring about completely and genuinely different types of impacts, such as greenhouse gas effects and hypothetical accidents or long-term potential radiological impacts of nuclear waste disposal. The aggregation or comparison of these types of impacts is unavoidably involved with significant uncertainties that may raise many differences in the ways people value certain impacts i.e. degradation of environment, own health. /21/

Power supply's effects on environment are mostly due to their fuel source. Following chapter will explain more about conventional power generation technologies and following list explains the main energy carriers (fuels) they use for power production /17/:

- Coal and lignite
- Crude Oil and Natural Gas liquids
- Oil Shale
- natural Bitumen and Extra-Heavy Oil
- Natural Gas
- Uranium / Nuclear power
- Hydro power
- Peat
- Solar
- Geothermal
- Wind
- Tidal
- Wave

4.2 Conventional condensing power plants

Conventional condensing power plant is usually fossil-fuel fired, but there are also plants for e.g. peat. Typically condensing plants uses coal as fuel and it can be made as power plant supplying base power or intermediate-power depending on the unit size. Condensing coal-fired power plant can also use other, more expensive and easier firing-up like heavy oil or gas, fuels as reserve fuel. /19/

Today's steam cycle power plants have efficiency or roughly 43 %. Main reason for the "low" efficiency rate is due to the alloys ability to withstand heat and pressure in the steam cycle. Raising the currently used 560 °C to 700 °C could raise efficiency rate to 52 % and lower the emissions of CO_2 by 35 %. /18/

Fuel consumption of single boiler may be estimated from the amount of actual heat transferred to the process, the thermal efficiency of one unit and annual operating hours. Following equation is fuel consumption of steam boilers /22/:

$$e_{\mathrm{F}} = \dot{m} \cdot c_{\mathrm{h}} \left(h_{\mathrm{i}} - h_{0}\right) \cdot \frac{100}{\eta} \cdot \frac{t_{0}}{8760} \cdot g_{\mathrm{c}} \tag{4.1}$$

Where,

e_F rate of fuel consumption expressed as an energy flow rate and based on the higher heating value of the gas (GJ/y),

m mass flow rate of the process fluid being heated (kg/s),

c_h specific heat capacity of the process fluid (kJ/kg · C),

h_i inlet enthalpie of the process water/steam (kJ/kg),

h_o outlet enthalpie of the process water/steam (kJ/kg),

η thermal efficiency of the heater or boiler (percent),

t_O annual operating hours (h), and

g_c factor to convert from units of kJ/s to GJ/y, = 31.536

Fuel consumption is an estimate based on the actual heat transferred to the process. For calculation of energy production and efficiencies of total process, all the enthalpies of each process fazes and efficiencies of all pumps, turbines, generators etc. has to be taken to account. Figure 4.2 illustrates condensing power plants steam cycle process.

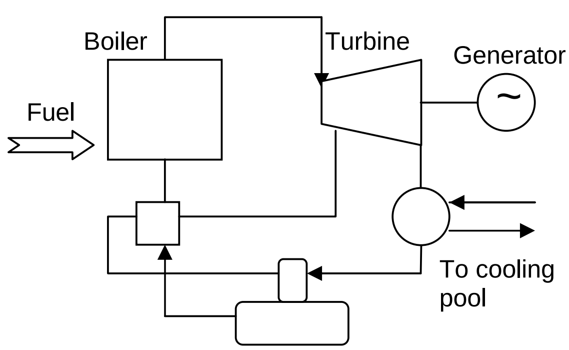

Figure 4.2 Condensing power plants process /19/

4.2.1 Back-pressure power generation

Back-pressure power (BPP) generation is utilized for high heat load either for industrial processes (pulp and paper, metal) or for district heating. BPP can be produced with almost any kind of fuel. Most conventional fuels are coal, peat, gas and heavy oil. Further more, in industrial applications also process-gases and black lye can be used. BPP produces both electricity and heat with factor 0,3 - 0,5 and its efficiency rate can go up to 90 %. Figure 4.3 illustrates back-pressure power plants steam cycle process. /19/

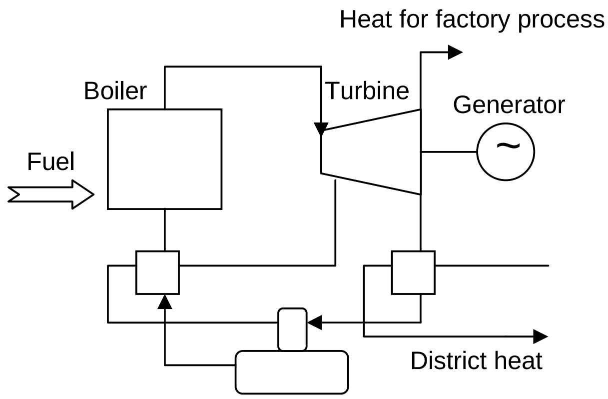

Figure 4.3 BPP plants process /19/

4.2.2 Gas-Turbine generation

Gas-turbine power plants use as fuel natural gas and oil. These types of power plants are usually made to be small and simple in design to suit its purpose as reserve and peak load power stations in power systems. Without the utilisation of the heated exhaust gases, the efficiency of these power plants remain quite low ~20 %. Figure 4.4 describes gas-turbine power plants steam process. /19/

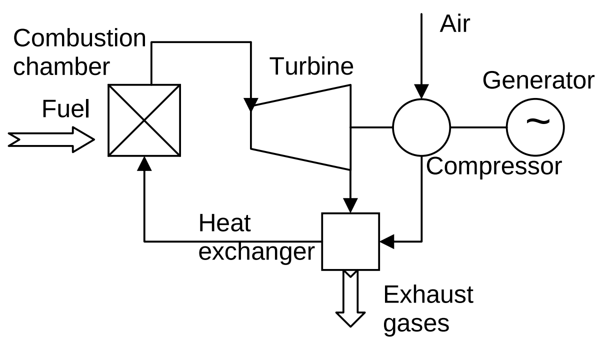

Figure 4.4 Gas-turbine power plants process /19/

4.2.3 Combined Heat and Power

Combined heat and power (CHP) is based on back-pressure power generation, but with the difference that the share of electricity from the output is lifted. This is done with combination of Gas turbine process and back-pressure process. Higher share of electricity production lowers the efficiency from back-pressure, though the combined cycle gas turbines (CCGT) conversion process is the most efficient thermal conversion process with efficiencies reaching up to 57 % /19/. In addition, as for back-pressure process, efficiencies and energy savings can be achieved by presence of stable heat load whole year long. In figure 4.5 can be seen combined-cycle process for combined power and heat production. /18/

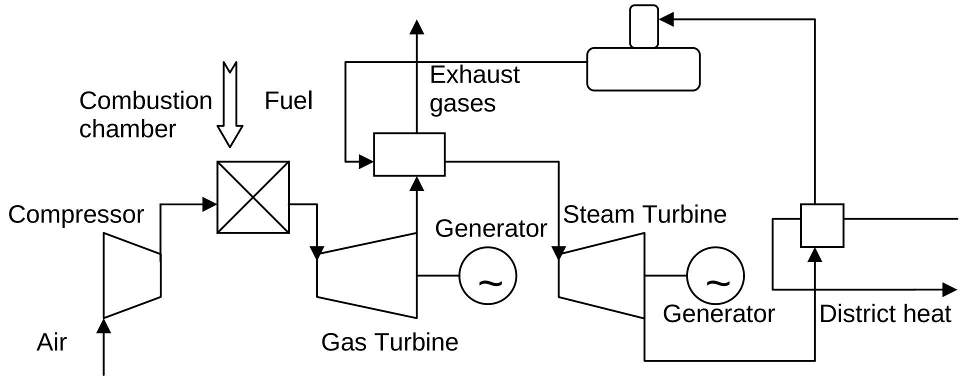

Figure 4.5 Combined-cycle-process for combined power and heat production /19/

4.3 Nuclear power

Nuclear power plant is basically a condensing power plant where the heat energy is created in nuclear reactor. Conventional reactor uses as fuel Uranium's isotope U^{235} which is located in fuel rods inside the reactor. Nuclear reaction inside the reactor heats up the coolant/moderator surrounding the fuel rods and the coolant is directed to thermal exchanger. Heated steam from the thermal exchanger leads to turbines connected to electric generators /19/. Following equations describe the fission reaction inside the reactor /23/:

$$n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \tag{4.2}$$

$${}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3n + 177\,MeV \tag{4.3}$$

Where, n are neutrons, U Uranium, Ba is Barium, Kr is Krypton.

Neutron are slowed by moderator (normal or heavy water) so they are more likely to cause further fission reactions or be captured by control rods. Each second or third neutron must be captured for keeping the reaction stable. /23/

There are light and heavy water reactors. Terms come from the moderating water surrounding the fuel rods. Most nuclear reactors in the world are light water reactors. Most common light water reactors are Pressure Water Reactor (PWR) and Boiling Water Reactor (BWR) being 68 % of all reactors in the world in 2003. Heavy water reactor, e.g. Canadian Deuterium Uranium reactor CANDU, uses heavy deuterium water as moderator and as fuel it uses natural uranium. Natural uranium is 99,3 % U^{238} and 0,7 % U^{235} and CANDU reactor converts the U^{238} to useful Pu^{239}. /24/

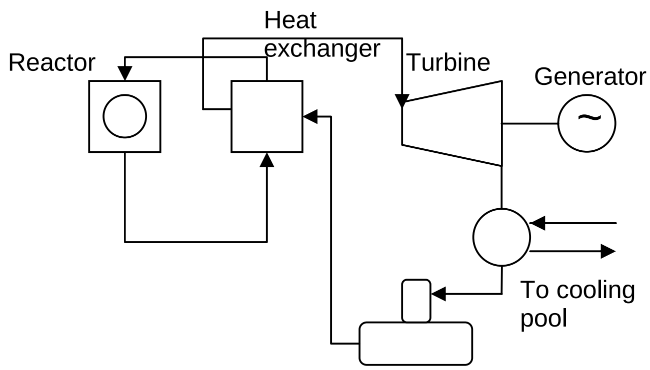

Figure 4.6 PWR-nuclear power plant process /19/

Nuclear power plants are built to be base power supplying plants. Characteristics of Nuclear power plants are big capacity (biggest under construction is 1600 MW), and long service time, 40-60 years. Moreover, in construction of nuclear power plant is included large investment and due to the long building time (7 – 9 years) just the interest expenses during construction are circa 12 % from total fixed costs. Extra expenses rise also from additional security systems, plant decommissioning and handling of nuclear waste and spent fuel. Benefits can be realized from stable price of the fuel, low energy production costs and zero emission from production. /24/

Beneficial factor for nuclear power is the un-fluctuating price of its fuel. Price of Uranium has been moderately stable, specially compared to other non-renewable energy fuels. But if the price of the fuel would suddenly go up, this would not have major effect on the energy price of nuclear power due to nuclear power plants cost structure presented on figure 4.7. Share of capital costs for nuclear power plants are 60 % when the same percentage for gas or coal are circa 20 % and 30 %. Share of fuel price from nuclear energy are 15 %, from which the price of uranium is about third. Share of fuel price from the price of produced energy with natural gas or coal are 70 % and 40 %, which makes the energy price easily fluctuating with the changes in the fuel market price. In nuclear powers case, if the price of uranium goes double, the price of produced energy rises about 5 %. /24/

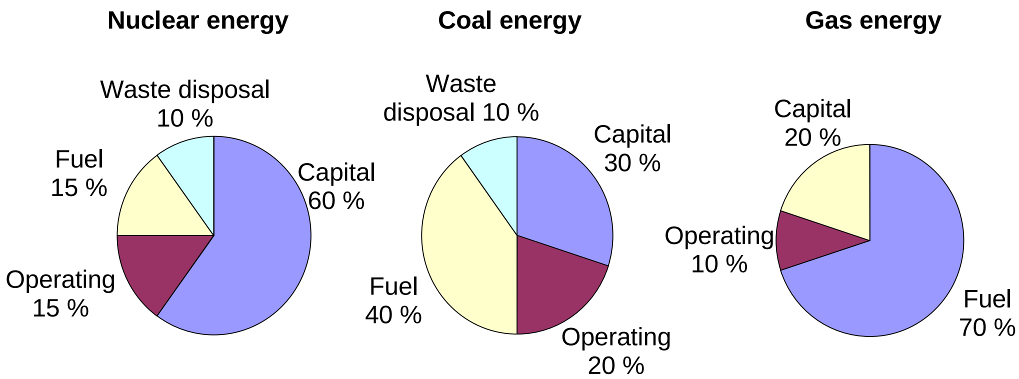

Figure 4.7 Structure of costs for nuclear, coal and gas energy /24/

Efficiency rate of nuclear power plant is moderate 35 - 45 %, depending on the reactor, and it is mainly used only to produce electricity. There are no technological obstacles to use nuclear power for production of CHP, and thereby for district heating, and only difference between conventional condensing power plant and nuclear power plant exist in the turbine system. This would raise nuclear power efficiency rate to over 60 % and also lower GHG emission in the air caused by fossil-fuel use for creating heat. Main issue is to build the nuclear power plant near the residential areas. Otherwise building a long distance district heat transmission line would not be the most cost-effective way to reduce emissions in heating. In Europe there exists some nuclear power plants used for heat production also, in countries like Russia, Bulgaria and Switzerland. /24/

4.4 Renewable energy

Renewable energy sources (RES) are those energy sources which are recurrent in the world. Those are hydro, biomass, wind, solar thermal, solar photovoltaic, geothermal, wave and tidal energy. Renewable energy has become biggest energy trend in 21st century in electricity generation. Investments on renewable energy have multiplied and it will continue while countries are struggling to lower their emissions and to transform their production mix more sustainable for fossil-fuel free world.

4.4.1 Hydropower

Hydropower plants are usually situated in the rivers, main river-beds and on the banks of rivers. Conventional hydropower plant uses waters potential energy for electricity production. Water is directed from watercourses main lake to water turbines and the turbines uses the kinetic energy of the water for electricity production with generator. Following equation is the general formula for any hydro system's power output /25/:

$$P_W = \eta \cdot \rho \cdot g \cdot Q \cdot H \qquad (4.4)$$

Where,

P_W	Mechanical power produced at the turbine shaft, W
η	Hydraulic efficiency of the turbine, kg/m^3
g	Acceleration due to gravity,~ 9.81 m/s^2
Q	Volume flow rate passing through the turbine, m^3/s
H	Effective pressure head of water across the turbine, m

Hydropower is the most reliable part of electricity power system and it is used mostly for electricity power systems regulation purposes i.e. for keeping the balance between demand and supply of electricity. Power regulation possibilities with other forms of electricity generation are eminently worse, resulting from used alloys temperature changing speeds restrictions. Set backs from hydro power may arise from water resources seasonal essence. With low water supply season hydropower has to be replaced with some other, more expensive means. /19/

Costs from hydropower plants are nearly fully from investment costs from plants and possible artificial lakes constructions. Operation time is long with hydropower plants are usually long, ~ 40 years. Fuel for the plant is free and operating costs are minimal due to automation and remote control. Operation costs are mostly dissipation from transmission of electricity, due to long distance transmission. /19/

Largest share of RES energy is produced with hydropower in the world. Beneficial characteristics are: free fuel, emissions free production and high efficiency rates, between 75 and 90 % of the energy input can be converted into electricity. Unfortunately increase of capacity in OECD countries is for environmental reasons no longer possible in larger scale. All potential places have been harvested for use already. Capacity increase maybe possible still through replacing technology in older power plants for newer more efficient machinery. Figure 4.8 is a schematic picture of hydroelectric dam. /18/

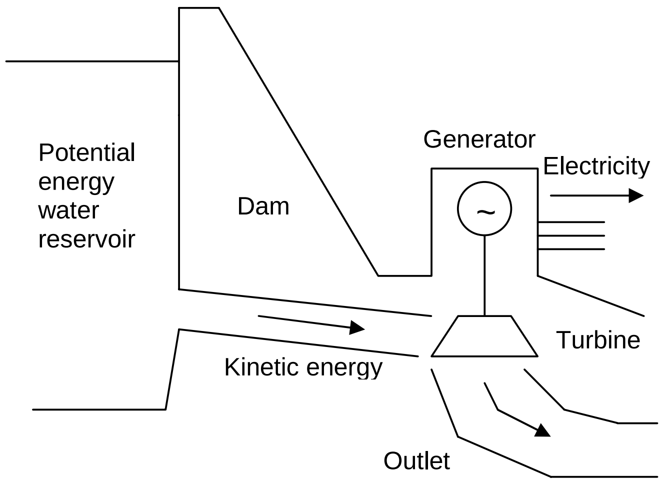

Figure 4.8 Hydroelectric dam schematic picture

4.4.2 Wind power

Energy from wind is harvested by using onshore or offshore wind turbines individually or with several units consisting wind farms. Energy of wind rotates turbines from where the power is transferred to generator, which transforms the energy into electricity. Capacity of single wind turbine is now days usually 1 – 3 MW and its efficiency factors are 43 – 44 %. However, capacity factor range from 20 – 40 %, at the upper end of the range in favourable sites. Following equation is the general formula for calculating power from a single wind turbine /26/:

$$P_W = 0{,}5 \cdot \rho \cdot A \cdot c_p \cdot v^3 \eta_g \cdot \eta_b \qquad (4.5)$$

Where,

P_W	Power produced, W
ρ	Density of air, kg/m^3
c_p	Coefficient of performance, (0,59 Betz limit, 0,35 for a good design)
v	Wind speed, m/s
η_g	Efficiency of generator
η_b	Efficiency of gearbox/bearings

Wind energy production has increased the most from all RES supplies. World wide capacity in the end of 2007 was 93,7 GW with 19,7 GW added in 2007 /27/. Wind power is one of the most attractive RES supplies with its abundant energy source and zero emissions. Wind turbines operation time is 15 to 25 years. /25/

Even with large benefits and strong support for wind energy, there are many factors against large scale wind energy production. Due to unpredictability of wind appears also possibility of that wind power is not operational at all. This means that almost total amount of wind power installed to the power gird needs the same amount of regulating power due to the fact that wind power has hardly any substitution capacity, the more wind capacity, the less it compensates other capacity. Wind power requires fast regulating power. For instance, in Germany during Christmas 2004 from the network of E.On Netz dropped wind power capacity from 6000 MW to 40 MW in 2 days. The fall was at some point even 1000 MW per hour. Capacity loss of this magnitude requires large amount of regulating backup power. /28/

4.4.3 Biomass energy

Biomass is organic material such as wood, crops, waste, landfill methane gas, alcohol fuels and energy is released by combustion. Electricity sector is the second largest secondary transformation of biomass after charcoal production. Process industries such as sugar, wood and chemical pulping use their by-products for producing CHP with biomass for their own uses and feeding surplus electricity to the power grid. Used bio-fuels are: corn, sugar canes, pellets, wood chips, straws, black liquor, bagasse, landfill methane, anaerobic digestors, vegetable oils etc. Energy is harvested or converted to another fuel from biomass by /18/:

- Burning
- Fermenting in zero-oxygen space to produce bio-gas
- By manufacturing ethanol from biomass

Most common biomass energy conversion process is direct combustion, which brings out some problems with certain biomass fuels. Only external combustion technologies can be used because biomass may contain elements harmful for engines. Efficiency is a vital issue with energy. At present efficiencies are relatively low, around 32 %, with CHP use up to 45 %. Big issue also comes if biomass is used to create bio-fuels. Then energy consumed by the conversion process maybe close to equal to the energy the bio-fuel could create, or less. /18/

4.4.4 Other renewable energy sources

As other RES supplies can be mentioned solar thermal, solar photovoltaic, geothermal, wave and tidal energy /17/. Significance of these supplies will grow in future, but for now they are not technologically or economically mature to be eminent part of Europe's power generation mix. Locally, e.g. photo voltaic in household scale might have significant savings in electricity consumption and installed solar energy collectors can pay themselves back in 1 – 3 years. /29/

Solar energy systems are mainly beneficial for household applications to lower yearly energy consumption from the grid. Photo voltaic (PV) systems are characterized as capital-intensive with zero fuel costs and very small operating costs. Furthermore, it has zero GHG emissions from its energy production. PV systems have very low efficiency (< 15 %) and its capacity factor also really low. In Germany capacity factor can reach up to 10 %, which is considered to be favourable for Europe. In California, USA, where should be more favourable sites for PV systems, the capacity factor reaches up to 22 % /30/. Due to these efficiencies and small capacities, PV systems are not mature enough technologies for large scale production in Europe. On the other hand Australia has invested on larger scale PV system for electricity production for 45.000 homes needs. Generation capacity of the solar power station is 154 MW. /31/

Although at present geothermal energy has been exploited mainly only in couple of regions where there is volcanic activity, in the future technology will present possibilities to exploit it economically also in regions which are not known to be so warm. Geothermal power plants operate continuously and it can be categorized as base load power plant. Geothermal production is renewable energy source with a lot of potential in future electricity production, although now it is mainly used for heat production. Energy generating capacity of geothermal energy and heat recovered by ground source heat pumps is estimated to be more than 100 GW. Even though geothermal energy is RES, dry steam and flash steam plants emit low levels of CO_2, NO_2, and S, although ~ 5 % of the levels emitted by fossil fuel-fired power plants. Some geothermal power plants have been equipped control systems which inject GHG emissions back into earth. /17/

Wave power is energy harvested from the ocean surface waves. This technology is not efficient or economically competitive yet for larger scale power production. Challenges lie in wave power slow motion for electric generators, corrosion and damage salt water, high cost of electricity produced. /17/

Tidal power uses two possible principles of exploiting tidal energy. Possibilities are to exploit the movement of water cause by the tidal currents or rise and fall of sea level caused by the tides. Motion of the water is converted to electricity by turbines connected to generators. Wave and tidal power are RES and could be used as part of solution for carbon free electricity generation though they are not technologically or economically ready. /17/

4.5 Carbon Capture and Storage

While fossil fuel based energy production is and will probably remain for decades as the most important source of energy, it is important to minimize emissions from power plants using fossil fuels. Furthermore, as long as coal prices remain low enough and coal resources are sufficient for next century it is not economically reasonable to abandon coal as source of energy. Energy sector produces > 60 % of world's total CO_2 emissions and from that power generation is 40 % from energy sectors CO_2 emissions. Due to these emissions it is important to start using different technologies to minimize these emissions. One of these technologies is Carbon Capture and Storage. /1/

4.5.1 Carbon capture

Carbon capture and storage (CCS) technologies are used to take away CO_2 during the energy production process and storing the extracted carbon. There are three main technologies and their principles depend upon when the carbon is extracted from the energy production process; in the beginning, in the middle or in the end. These technologies are /1/:

- Pre-combustion capture
- Oxy-fuelling
- Post-combustion capture

Figure 4.9 describes as schematic diagram the three main CCS technologies.

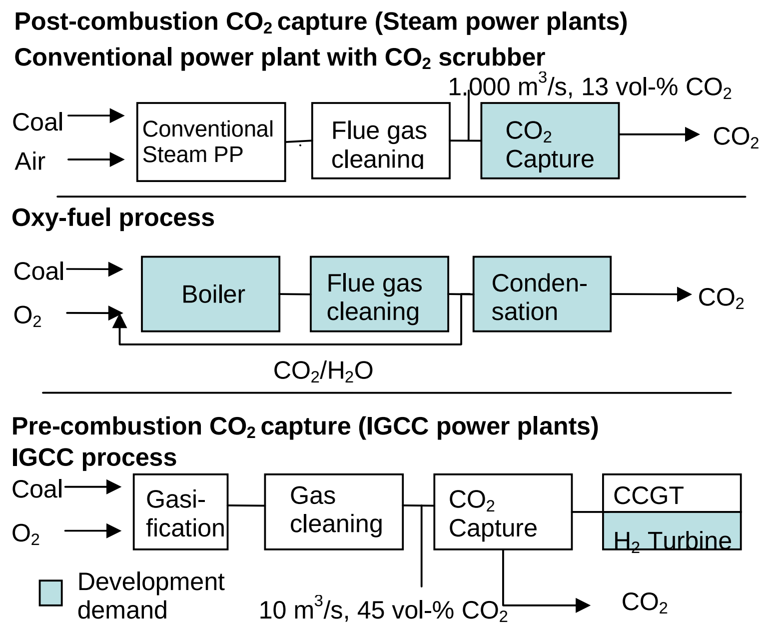

Figure 4.9 Schematic diagram of tree main CCS technologies /32/

Pre-combustion utilizes gasification of coal into synthetic gaseous mixture of hydrogen and CO ("syngas") before combustion. CO_2 and additional hydrogen are then produced from the syngas by reacting the carbon monoxide with additional steam. CO_2 is extracted from the syngas by absorption by liquid solvent of solid absorbent and CO_2 can be released either by heating or reducing pressure. The remaining hydrogen is combusted in Integrated Gasification Combined Cycle (IGCC) plant, in which coal (or any other solid or liquid fuel) is gasified, without emissions of CO_2. Syngas also can be used as feedstock for liquid fuels or chemical manufacturing. Applications of pre-combustion capture used in industries such as ammonia and hydrogen production. /1/

With Oxy-fuelling fossil fuel is combusted in pure oxygen rather than air. Flue gas, or rather mainly water vapour, resulting from this the flue gas has a very high CO_2 concentration (greater than 80 % by volume), which makes it easy to be extracted. Water vapour is removed by cooling and compressing the gas. Oxy-fuel-systems are being developed on small scale, in laboratory or in pilot projects. /1/

In Post-combustion method CO_2 is captured from the exhaust gases produced by combustion of fuel (coal, natural gas, oil or biomass) at end-of-pipe. There are various options for extraction depending on the volume and composition of the flue gases. One way is to capture CO_2 with liquid solvent. CO_2 is then released from the liquid with heat. Same technology is used in food and beverage industry and in fertilizer manufacturing. /18/

The three methods differ from one another in some ways. For instance pre-combustion compared with post-combustion processes, the CO_2 concentration in the former method is higher which allows CO_2 capture in lower temperatures. Furthermore, pre-combustion processes CO_2 capture involves production of syngas and hydrogen, which makes it more complicated, although additional benefits are realised from these gases. /1/

Type of method used is influenced highly by the fossil fuel used in the combustion, although all methods have similar disadvantage of requiring additional energy, between 10 – 40 %, according to estimates, which also depend on plant type. It is also estimated that this energy penalty will drop efficiency rates of power plants by 5 to 12 %. Emissions of CO_2 can be lowered using these technologies by 70 - 90 %. Due to lack of experience and knowledge on CCS using it in power plant may increase costs of electricity generation by 50 % or more. CCS has not been applied on large scale fossil-fuel power plant, although pilot projects on capture and storage are under way. First large scale power plants equipped with carbon capture technologies are estimated to be ready by 2015 – 2020. /1/

4.5.2 Carbon storage

Captured CO_2 is transported for storage. Retaining CO_2 so that it will not reach atmosphere is one of the big issues in CCS. Means of storing CO_2 are geological, ocean storage, mineral carbonation and use or re-use of CO_2. Geological storage is already in use and being tested. /1/

Geological storage involves injection of CO_2 in dense form rock formations below the Earths surface. Injection of CO_2 is already been implemented into gas and oil reservoirs, deep saline formations or un-minable coal beds. Other possibilities for CO_2 geological storage lies in basalts, oil or gas shales, salt caverns and abandoned mines. According to

IEA Greenhouse Gas R&D Programme, depleted oil and gas fields could accommodate 0,92 trillion tonnes of CO_2, which is 45 % of expected emissions between years 2000 – 2050 in the world. Furthermore, storage space in saline reservoirs could be up to 10 trillion tonnes. Figure 4.10 shows the principle of carbon storage. /1/

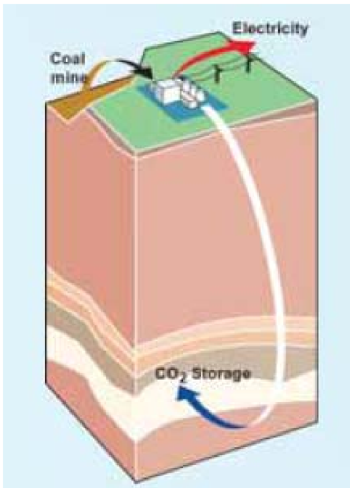

Figure 4.10 Principle of carbon capture and storage /32/

Ocean storage has been studied for many years but no pilot or demonstration programmes have been implemented. Ocean storages principles are to inject CO_2 deep in to the ocean, depths greater than 1000 meters. Another possibility for CO_2 storage is mineral carbonation, which have been researched and demonstrated for a while. Method is to fix the CO_2 in silicate rocks. This method is not yet ready for commercial deployment due to its energy intensive procedure and its need for transportation in scale. Use and re-use of CO_2 is already being carried in applications in industries such as urea and methanol production, in horticulture, refridgerating, food packing, welding, beverage production and fire extinguishers. /1/

As well as carbon capture still is in the beginning of its development process, so is storing the captured CO_2. There are no long term data storing and the projects for it are in first stages of implementation or have not started yet. Concerns about technical integrity of the storage and the potential health risks involved need to be addressed. Sudden or gradual leakages may occur and the effects on people and animals through groundwater reservoirs or soil are not known. Also potential danger lies to marine ecosystem and organisms. These potential risks require development of monitoring techniques. Table 4.1 describes the projected costs of storage of CO_2 four different storage technologies. /1/

Table 4.1 Costs of storage of CO_2 /1/

Storage Option	Cost range [€*/Tonne CO_2]	Notes
Geological storage	0,31 - 0,50 – net injected	Excluding revenues from enhanced oil recovery or enhanced coal-bed methane
Geological storage: Monitoring and Verification	0,06 - 0,19 – net injected	Covers pre-injection, injection and post-injection monitoring and depends on regulatory requirements
Ocean storage	3 - 19 – net injected	Including offshore transportation of 100-500 km, excluding monitoring and verification
Mineral carbonation	31 - 63 – net mineralised	Range for the best case studied. Includes additional energy use for carbonation

*converted to Euros with currency rate of 24.4.2008, EUR-USD 1,57

4.5.3 Policies

Regulatory framework is one of the key issues for CCS deployment in large scale. CCS is energy intensive and expensive, but according to IPCC, CCS could deliver up to 15 - 55 % to the mitigation effort of lowering CO_2 emissions worldwide until year 2100. There are several governmental incentives to make CCS more favourable technology /1/:

- Taxation of emissions: Making storage of CO_2 cheaper
- Development of cap-and-trade emissions programmes: For recognizing stored CO_2 as non-emitted; absolving the requirement of units for CO_2 generated in storing of CO_2
- Recognizing CCS as a mechanism for emissions reduction
- Offering of financial incentives for generation using CCS; feed-in tariffs.
- Mandate the use of CCS for certain sources or subsidies for CCS installation costs

4.6 Discussion on power plant characteristics

Essentially in different countries resources have been channelled for construction of power generating plants which results in the lowest possible energy costs, taking in to account the investment, operating and maintenance costs. In generation mix it is best to utilize all different generation types to make flexible power system to cope with different overall load patterns. Furthermore, power system which uses wide range of fuels is not so sensitive for fluctuating fuel prices, when single fuel is not dominant. Temptation of constructing especially coal-fired condensing power plants has been great in the past, due to cheap price of coal, good heat value, nuclear powers bad reputation and availability of other competitive energy source. With Kyoto protocol and EU's renewable energy share targets comes the burden to change the existing infrastructure, at least in some countries which are heavily dependent on imports of gas, oil and coal.

Table 4.2 Role of different electricity generation methods

	Capacity and delivery surety	**Regulation capability**	**GHG emissions**	**Renew-able**	**Cost-effective-ness**	**Availability of additional capacity**
CHP	+	0	+	(+)	+	(+)
Nuclear	++	0	++	0	+	++
Condensing	++	+	0	0	0	++
Hydro	++	++	++	++	+	+
Wind	0	-	++	++	-	++
Energy efficiency	+	(+)	++	+	+	+

With new era of investing mainly on low-carbon technology or renewable energy sources, availability of energy sources is again one of the main issues. Even with the desire of changing the power system for more sustainable and low-carbon supply, some technologies can not be used in some geographical regions:

- OECD countries hydropower possibilities are used
- Wind power is not suited for low average wind speed areas
- Solar power needs long term light regions
- Cultivation of energy crops may lead to higher food prices

Some plants are suitable for base-load operation, while others are used for peak production. Plants with intermittent source of operation need backup capacity. In electricity generation systems, plants with different operational characteristics are included. Figure 8.1 describes the investment costs of power plants and projected investment costs in the future.

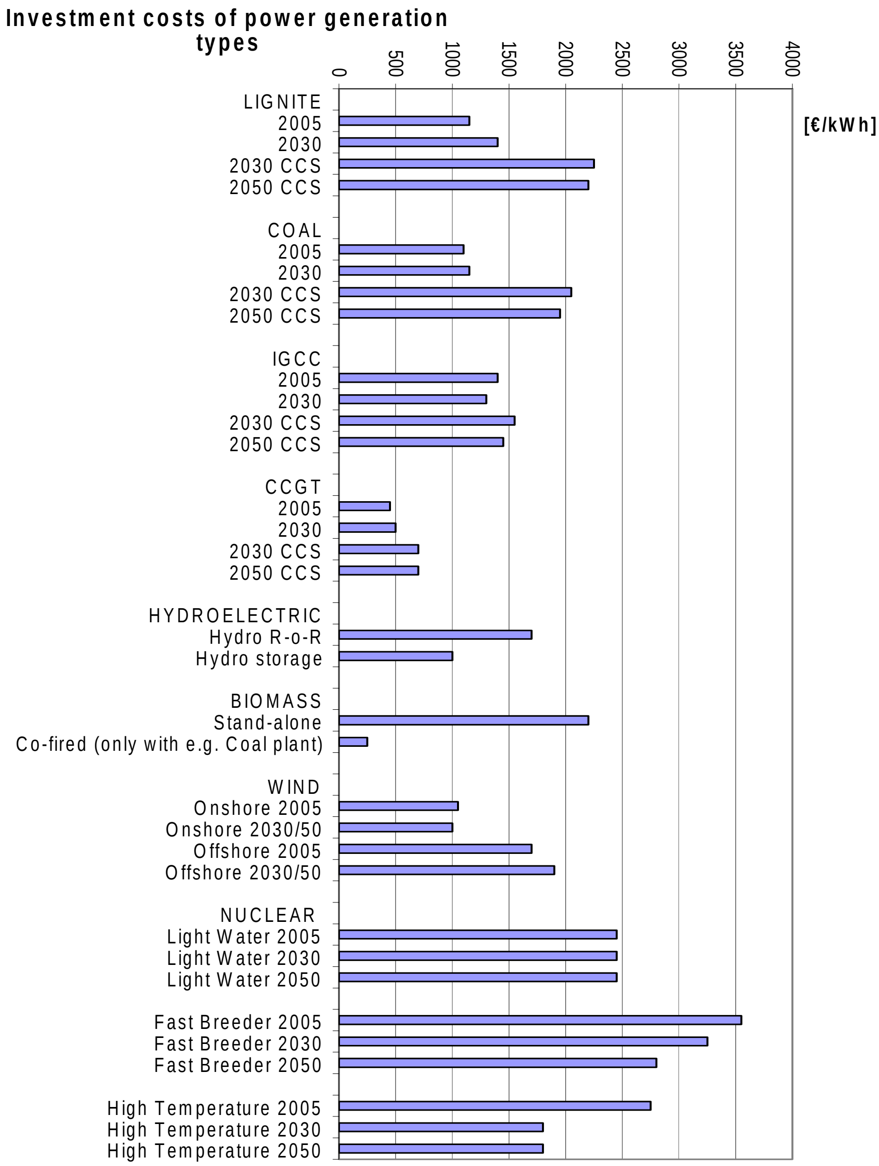

Figure 4.111 Investment costs of different generation types /!8/

The system characteristics play an important role in making decisions on new plant investment. The grid capacity, existing backup arrangements, type of loads and several other factors all need to be taken into account. In some cases, combined production of power and heat may be feasible. In open electricity markets, the cost of alternative supply is important.

Characteristics of the measures to be taken for reducing environmental impacts tend to be expensive and the actions themselves will not bring extra profit, excluding the benefits from improving the efficiency in different parts of power generation process, which will bring benefits through energy savings. Investing on technology for reducing emissions such as CCS will bring benefit by reduction of costs from carbon taxes and through decreasing need to purchase carbon allowances, though energy penalty resulting from the use of technology like CCS must be noted.

5 Power generations effects on environment

All types of power generation create harmful effects on environment, to the general public and the workers and the ways to impact are numerous and some times it is hard to define the overall effects of them. There are no single ways to estimate scale of total effects when the effecting ways are so dissimilar. It was defined in 1970 that main factors causing environmental effects are caused by use of fossil fuels causing NO_x and SO_2 fallouts into the environment. These sour fallouts produce environmental effects such as loss of fishes, forestry damage and corrosion on buildings. In the air these emissions can travel thousands of kilometres and cause further damage on health and environment. /6/

Acidification

Acidification is caused by sulphur oxide and nitrogenous oxide emissions. Effects are starting to show when pH value of watercourses or rainwater decreases below pH 5. Acidification causes in water fish kills and in nature worsening of tree condition or even death. Furthermore, water that has sulphate dissolved in it, washes away important nutrients from form the topsoil and acidification of ground water leads to dissolving of aluminium, which is toxic to the plants. /6/

Particulate matter and concern for heath

The term particulate matter (PM) is equivalent to the term atmospheric aerosol and defines a suspension of airborne solid particles. Size and chemical composition are regarded as the most important characteristics of such particles, while surface area and possibly particle number may also be important. A single particle usually contains a mixture of chemical and physical (solid, liquid) constituents. The PM_{10} concentration is the mass per volume unit ($\mu g/m^3$) of particles with an diameter smaller than 10 micro-metres (µm). The larger particles contained in the PM_{10} size fraction reach the upper part of the lung. The smaller particles of this size fraction (in particular $PM_{2.5}$ and $PM_{1.0}$, with diameters smaller than 2.5 and 1.0 µm) penetrate more deeply into the lung and reach the alveolar region. PM is often differentiated by chemical constituents (e.g., sulphates, heavy metals and organics), as well as by source-related constituents (e.g., diesel soot). Today, it has become common practice to denote the $PM_{2.5}$ as the “fine fraction” and particles with diameters between 2.5 and 10 µm ($PM_{2.5\text{-}10}$) as the “coarse fraction”. /22/

Large and very small particles have a limited residence time in the atmosphere. Particles in the size range between approximately 0.1 and a few µm remain in the atmosphere much longer (typically several days to a week) and can consequently be transported over long distances (1,000 kilometres or more). PM is emitted directly from "primary" sources (primary PM) and is also formed in the atmosphere by the reaction of precursor gases (secondary PM). Other common distinctions are natural/anthropogenic sources and combustion/non-combustion sources. The emission estimates from non-combustion sources have a high degree of uncertainty. /22/

Primary PMs are e.g. /6/:

- Soot formed from combustion, consisting from carbon
- chemical compounds, which are in gas form in burning temperatures, but return to solid from after cooling

Secondary PMs are e.g. /6/:

- Sulphur oxides conversion to sulphuric acid
- Nitrous oxides conversion to nitric acid

<u>Emissions from combustion</u>

During combustion process with fossil or carbon based fuel combustion gases are released. These exhaust gas compounds of oxygen with sulphur, nitrogen, carbon etc. depending on the quality of the fuel. Combustion with coal produces the most greenhouse gases compared with other fossil fuels and natural gases CO_2 emissions are third less than oil and coal. The level and mixture of pollutants depend on the fuel and the technology used. The emission level is different at different power levels and weather the plant takes part in the frequency regulating, where as in steady-state operation and in transient-state emissions levels differ. /22/

Estimation of emissions for some combustion processes can be relatively easy, but for some it can be made only roughly. Relatively good estimates can be made of CO_2, NO_x, SO_2, thermal emissions and solid waste. There are measurements and estimates of total dust and PM_{10} emissions, but this is less true for the finer fractions, $PM_{2.5}$, PM_1 and nano-particles. The impacts of these emissions depend on the location, recipient and scale of the operation. The impacts, for example, of thermal releases into the sea are different from those into an inland water body. The impacts of poor air quality in sparsely populated areas differ from those in urban areas or other area with higher population intensity. /22/

Determination of amount of specific pollutant *i* can be determined with following equation /22/:

$$E_{ii} = 10^{-6} \cdot e_{F_i} \cdot EF \cdot \left(1 - \frac{EC_i}{100}\right) \qquad (5.1)$$

Where,

e_{Fi}	Estimated fuel consumption (GJ/y for gas or L/y for liquid fuels) by combustion device i,
E_i	Emissions of pollutant I form specified source (t/y)
EF_i	Factor for emissions of pollutant I from specified type of source (GJ/y for gas or L/y for liquid fuels),
EC_i	Efficiency of control equipment for reaction of emissions of pollutant i, %

Harmful impacts of power generation start already from the beginning of energy production chain and that is acquiring of the fuel. Using of natural resources is already environmental impact, as are changing of landscape and nature for the plant and power lines. Effects come also from the refining and production of fuel, which also include waste management. The effects have to be measured from the whole production chain of energy which will add up to the differences of effecting ways. Simplest way may be to measure only effects which happen in large quantities like pollutant concentration in the air or water and acidification of soil. /6/

From table 5.1, it can be seen that the most harmful types of energy production are coal, oil and gas and from two sources which are considered renewable burning wood and peat have also harmful side-effects.

Table 5.1 Environmental effects in scale from different energy supplies /6/

Harmful impacts	**Fuels for energy production**							
	Coal	**Oil**	**Gas**	**Peat**	**Wood**	**Nuclear power**	**Hydro-power**	**Wind power**
Using of non-renewable sources	X	X	X	X		X		
Landscape				X	X		X	X
Watercourses regulation				X			X	
Watercourses heating	X	X	X	X	X	X		
Noise								X
Radiation						X		
Air quality	X	X	X	X	X			
Acidification	X	X	X	X	X			
Eutrophication	X	X	X	X	X			
Climate change	X	X	X	X	X			

Quantitative measurements of certain environmental effects are often dependent on human valuation. Especially in case of health concerns coming from different energy forms is especially hard to calculate. Division of environmental effects to residue effects and economically relevant external costs is particularly hard when they are essentially dependent on society's sense of moral. Valuation of effects has been done to climate change by number of studies, The Stern Review as most renowned of them. Due to the nature of Climate change being an environmental effect of global extent it has been put forward as main environmental issue recently. The amount of environmental effects, emissions and other, are influenced by numerous factors. These factors are e.g. technology used (age, efficiency, type), fuel characteristics, location, transportation of fuel and equipment, regulations etc. Following chapters will describe the effects from different production types and the parameters involved in them. /33/

5.1 Effects from solid fuels

Power generation chain begins with procurement of fuel. Extraction of the fuel causes environmental effects due to the emissions coming from the machines extracting it, and also extracting of the fuel can be harmful for the landscape. Extraction of peat may cause changes in currents of watercourses due to the organic material and minerals from soil that get into the watercourse. /6/

When solid fuels are used in combustion plants they emit large quantities of pollutants such as SO_2, NO_x, CO_2 and particles. Also these plants usually use coolant water from near by river of watercourse and then they dump the cooling water back. This will rise the temperature in the water course causing eutrophication when the vegetation of the watercourse gets too much sun also during winter. Wood chips as a fuel doesn't produce SO_2 emissions. /6/

Combustion process of carbon and other solid fuels produces bottom ashes and fly ashes which contain heavy metals and radioactive substances. Those are extracted with filters, but they have to be disposed of as problem-waste. Biomass ashes may be used also in production of fertilizer and building material. /34/

Solid fuels' main factors influencing GHG emissions /35/:

- Fuel characteristics; carbon content and caloric value; e.g. washing coal for improved caloric value
- Type of mine and location
- Fuels extraction way; methane releases, recovering and transportation needs involved
- Feedstock characteristics; moisture content and heating value of used fuel
- Fuel mix for electricity and power needs in fuel supply and plant construction and decommissioning
- Type of technology; e.g. combined cycle operation
- Energy used for feedstock: growth (biomass), harvesting (biomass) and transport
- Technology of the plant; efficiency is of essence with biomass power production while it is currently quite low.
- Assumed lifetime of installation

CO_2 emission factor for biomass is neutral i.e. carbon releases from the burning of biomass is equal to the biogenic uptake during plant growth. So it releases same amount as it takes in during its growth. /35/

Emission formation

Three main chemical reactions in combustion reactions are /36/:

$$C + O_2 \rightarrow CO_2 \quad (5.1)$$

$$H_2 + O_2 \rightarrow 2H_2O \quad (5.2)$$

$$S + O_2 \rightarrow SO_2 \quad (5.3)$$

Presence of sulphur with the true fuel materials, carbon and hydrogen, is cause of the latter reaction. Furthermore, if the combustion temperature is too high, following disassociation reactions occur /36/:

$$N_2 + O_2 \rightarrow 2 \cdot NO \quad (5.4)$$

$$N_2 + 2 \cdot O_2 \rightarrow 2 \cdot NO_2 \quad (5.5)$$

$$2 \cdot CO_2 \rightarrow 2 \cdot CO + O_2 \quad (5.6)$$

All of these reactions are endothermic, and result in pollutants NO_x and CO.

5.2 Effects from fossil fuels

Obtaining oil and gas cause landscape impacts onshore and offshore, bigger issues are the methane emissions during the procurement and transportation of the fuels. It must also be noted that methane is far more dangerous and effective GHG than CO_2. Also on the surfaces of the transfer pipes gather some natural radioactive substances, which results in that the tube lines have to be handled as problem-waste. /35/

Combustion of oil and gas produces GHG emission and the coolant water eutrophication. Problem with the warm coolant water is partly solved with back-pressure and CHP plants where the warm coolant water is directed for heating purposes which increases the efficiency of the plant also. /6/

Fossil fuels' main factors influencing GHG emissions /35/:

- Fuels extraction way; methane releases, recovering and transportation needs involved
- Transmission loses for natural gas; also methane leakages
- Conversion efficiency
- Type of technology; e.g. combined cycle operation
- Fuel mix for electricity and power needs in fuel supply and plant construction and decommissioning

- Assumed lifetime of installation

Emissions formation is similar with oil and gas as with other solid fuel combustion.

5.3 Nuclear power

Construction of the plant and the procurement of the fuel with waste disposal are the main indirect way that nuclear power produces GHG emission. Land use and ecological effects on the environment are minimal compared to the amount of power produced. Table 5.2 describes an example of nuclear fuel chains taxonomy.

Table 5.2 Example of nuclear fuel chains taxonomy /33/

Fuel chain processes	Effecting factors	Effects
Mining and enrichment	- Particles in air - NO_x in air - Emissions of radioactive substances	- Radiological health effects
Refining of fuel	- Emissions of radioactive substances - Heavy metal wastes - Energy needs for rectifying - U^{235} waste	- Radiological health effects
Construction of plant	- CO_2, SO_2, NO_x, - Particles - Dust - Noise	- Landscape effects - Need of space
Plant operation	- Emissions of radioactive substances - Warm water emissions - Waste waters - CO_2, SO_2, NO_x, - Particles - Low-and middle-active substances - Conventional wastes	- Radiological health effects - Curable cancers - Serious hereditary effects - Effects on nature
Decommissioning of plant	- Discharging wastes	
Handling of low-and middle-active substances	- Emissions of radioactive substances	- Radiological health effects
Final location of high active wastes	- Emissions of radioactive substances	- Radiological health effects
Transportation	- Emissions of radioactive substances - CO_2, SO_2, NO_x, - Particles	- Radiological health effects
Accidents	- Emissions of radioactive substances	- Radiological health effects

During production nuclear power emits radiation, which causes very small addition to the total amount of radiation been directed to a person. Human gets radiation in the world by average 2,8 m Sievert in a year, nuclear production causes 0,0002 mSv of that. Large amounts of waste are produced during ore mining and enrichment of the fuel ore. These wastes coming from the production and decommissioning have to be treated and put to final location for minimising the radiation effects. The final resting place for the used fuel of nuclear power is usually in deep caves of under bed-rock where it can't harm the environment. /6/ Table 5.3 describes the dose estimates for public and workers from major fuel cycle stages. Figure 5.1 radiation exposures during different stages of nuclear fuel cycle.

Table 5.3 Dose estimates for the public and workers from major fuel cycle stages of nuclear power /21/

Fuel Cycle Stage	**Public (generic calculations)**			**Workers (operational data)**	
	Collective dose truncated at 500 (manSv/GWa)		**Average annual dose to the critical group (mSv/a)**	**Annual collective dose (manSv/GWa)**	
	Once-through	**Reprocessing**		**Once through**	**Reprocessing**
Mining and Milling	1,0	0,8	0,30-0,50	0,02-0,18	0,016-0,14
Fuel conversion and enrichment	0,0009		0,020	0,008-0,02	0,006-0,016
Fuel Fabrication				0,007	0,094
Power generation	0,6	0,6	0,000-0,0008	1,0-2,7	1,0-2,7
Reprocessing vitrification	Not applicable	1,2	0,40	Not applicable	0,014
Transportation	Trivial	Trivial	Trivial	0,005-0,02	0,005-0,03
Disposal	(*)	(*)	(*)	Trivial	Trivial
Total	**1,6**	**2,6**	**Not applicable**	**1,04-2,93**	**1,14-2,99**

(*) No releases during the first 500 a

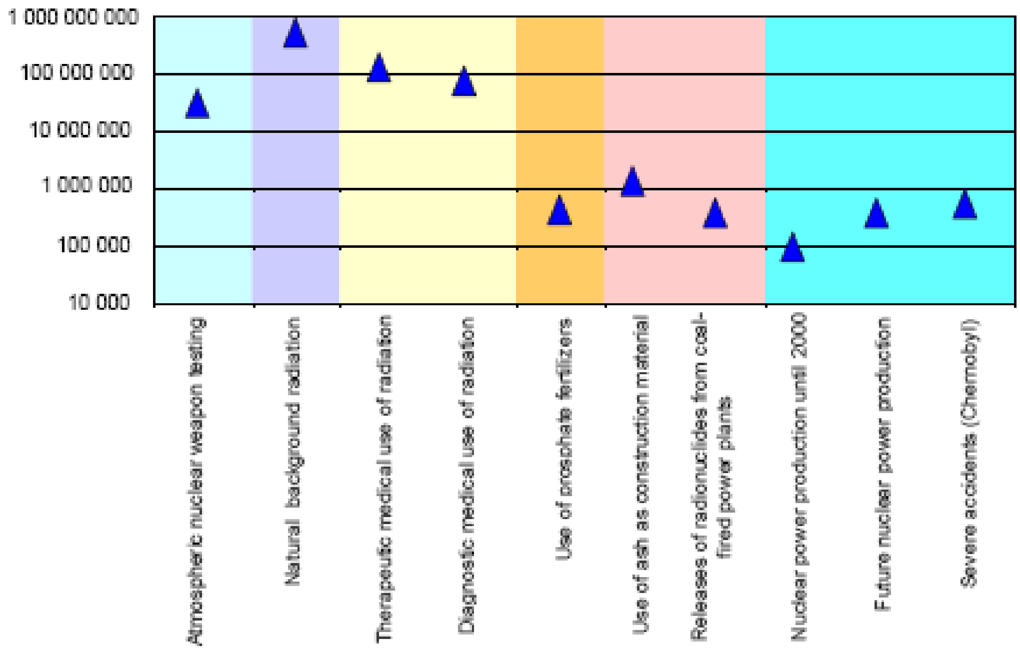

Figure 5.1 Radiological effects from nuclear power /21/

Nuclear powers main factors influencing GHG emissions /35/:

- Energy use during fuel extraction, enrichment, conversion and construction and decommissioning (plus materials)
  - Fuel enrichment method; enrichment by gas diffusion is far more energy intensive process and causes more GHG emission compared with enrichment with centrifuge
  - Enrichment location; GHG emission from enrichment stage depend on the country where it is done due to different fuel mixes
  - Fuel reprocessing; binding process done with uranium. Binding uranium with oxide as uranium oxide or mixed oxide can account for 10 % to 15 % of total GHG emissions from nuclear power.
- Assumed lifetime of installation

5.4 Hydropower

Hydropower is renewable energy which does not produce any emissions or use any natural resource which could be depleted. Emissions caused by hydropower occur mostly during the construction of the power plant. Even though hydropower production does not emit GHG gases, may be that the basin behind the dam causes significant amounts of GHG emissions, especially in the tropical regions. All the organic material left under the reservoir lake will start to decompose in anaerobic conditions, which will produce methane and CO_2. Although the amounts of methane may be high and its effects to the environment are larger that those of CO_2, methane emissions are always left out of the calculations of emissions from hydropower. Mentionable effects from hydropower occur also to the fish base of the river. /35/

Evaluation of environmental effects caused by hydropower must be done on single project and location bases. Effect variables from hydropower can be following factors: Hydrology, Flood damages and soaking of shores, Recreational use of watercourses, Aquatic life, Quality of water, Fish base and fishing, Socio-cultural effects and Energy economics. Table 5.4 describes an example of effects during construction of hydropower plant and during the operation due to the rising of water level. /33/

Table 5.4 Effects from hydropower during construction and operation /33/

Faze of life-cycle	Object of effects	Effects
Construction: Construction of shore protection/Working site traffic	- Inhabitants	- Noise - Accidents - Emissions effects on health
	- Air quality	- Emissions from vehicles
	- CO_2 levels and Climate Change	- Emissions from vehicles
Operation: Rise of water level	- Hydrology	- Rising of water level - Diminishing of change in water level - Increase of energy production
	- Energy economics	- Loss of land area
	- Farming and Forestry	- Soaking - Change in habitat (deeper water)
	- Vegetation	- Diminishing of change in water level
	- Fish base	- Loss of flow-areas - Deterioration of nutrient resources - Improvement in recreational possibilities
	- Inhabitants	- Improvement in landscape - Improvement in waterborne traffic - Improvement in fishing

5.5 Wind power

Wind power production is emission free and it does not deplete any natural resource. Emissions and wastes coming from wind power are due to the fabrication of the wind turbines and their installation. Emission caused by the construction of the plant are still not so small, due to the energy intensive process of making the alloys used in the wind turbines. Also the installation GHG burden can grow if they are installed in region with possible earthquakes, due to making of heavy foundations, which can increase GHG emissions. Table 5.5 describes the stages of wind turbine life curve and environmental factors and effects caused by them. /35/

Table 5.5 Stages and effects from wind power /33/

Fazes of life cycle	Effecting factors	Environmental effects
- Construction and setting up	- Emissions in air	- Health problems from emissions
- Operation and maintenance	- Noise - Electromagnetic disturbances - Effects on animals and plants - Effects on appearance	- Noise level - Fluctuating light effects - Worsening of TV-and radio-signal - Changes in animal and plant life - Effects on natural experiences - Horizontal landscape effect
- Decommissioning	- Emissions in air	- Health problems from emissions

One of the environmental effects caused by wind power is noise which comes mainly from the aerodynamic noise from blades and some additional noise is produced by individual parts of the electricity producing machinery i.e. gearing, generator and cooling systems. Intensity of the noise leaving from the turbine is about 100 – 110 dB in the immediate vicinity, but it goes down to 40 dB in range of 200 – 300 m. Table 5.6 shows an example of possible GHG emissions coming form wind turbine construction and maintenance. Must be noted that these are highly state oriented and emissions are mostly due to fuel mix used for the energy needs of production. /33/

Table 5.6 Example on emissions from 500 kW wind turbine from Denmark /33/

Faze \ Emission	CO_2 [g/kWh]	SO_2 [g/kWh]	NO_x [g/kWh]
Construction of Wind turbine	12,1	0,05	0,04
Manufacturing of the material needed in operation	2,07 – 5,26	0,01 – 0,02	0,01 – 0,02

Additional environmental effects occur from the wind power due to bird and bat deaths caused by the wind turbines onshore. Offshore wind turbines cause harmful effect on the marine life. Also esthetical effects occur when wind farms are mainly situated on places with clear view without obstacles. Those locations are hills, coasts and on the sea. /33/

Wind powers main factors influencing GHG emissions /35/:

- Energy use for blade manufacturing and building of installation; tower and foundation
- Electricity production mix and construction regulations; highly country- and site-specific e.g. onshore of offshore
- Capacity factor or annual yield; intermittence and penetration factor i.e. sites average wind speed (50 % more wind → 200 % annual yield)
- Assumed lifetime of installation

5.6 Solar power, photo voltaic

Photo voltaic has no fuel costs and modest operating costs. Furthermore, it does not produce GHG emissions from it energy production. Manufacturing and installation processes are the only cause for photo voltaic GHG emission, which are the highest from all RES production methods as seen from the figure 5.2. Manufacturing cost can be reduced through using modern and more developed technology for production of cells. In table 5.7 can be seen an example of emissions from PV construction. /35/

Table 5.7 Example of Solar PV emissions during whole life-cycle /33/

	Multi-crystal silicon	**Single-crystal silicon**	**Unit**
Primary energy use	129.011	56.222	**[MJ]**
CO_2	4.902	2.203	**[kg]**
NMVOC	4,3	2	**[kg]**
NO_x	14	6	**[kg]**
Particles	2,3	1	**[kg]**
SO_x	29,7	13,7	**[kg]**

Solar powers main factors influencing GHG emissions /35/:

- Quality and grade of silicon in cell production
- Type of technology; amorphous or crystalline
- Type, site and of installation; rooftop or facade and which country, due to high differences of light amounts during year
- Fuel mix used in for productions electricity needs
- Annual yield
- Assumed lifetime of installation

5.7 Assessment of total environmental effects

Power generation has environmental effect throughout its production chain and none of them can be discarded. In fossil fuels case emissions are sum of stack emissions from combustion and other releases from up- and downstream activities. Typically 1 % of total emissions can be attributed to the plant construction and decommissioning in case of fossil fuel power plants. Key factor for hydro, solar and wind power are size and type of the plant. Furthermore, geographical location and local construction regulative framework have strong influence on the emission rate. /35/

Commonly used method for analysing the environmental impacts is Life-Cycle Analysis (LCA). This method takes into account each mass and energy flows at each step of the process chain for creating a product. Some times LCA is completed by an Input-Output Analysis (IOA) which takes into account the indirect emissions from other economic sectors attributing for the product creation e.g. electricity used in processing. Effect of these indirect emissions can be significant, contributing for example 30 % higher emission for fossil fuel power plants. GHG emissions of nuclear power can even double when indirect emissions are taken into account. Ignoring up- and downstream activities for the fossil fuel cycles would underestimate the total GHG emission rate between 5 % and 25 %. In case of nuclear power and most renewable sources there are no GHG releases from the generation, but there are emissions during fuel mining, preparation and transport, plant construction and decommissioning, manufacturing of equipment and decay of organic matter. Emission levels are influenced highly by the technology and geographical location of the power plant. Furthermore, due to need of backup (secondary) power for intermittent technologies, i.e. wind, solar and seasonal hydropower, question rises whether to include backup in the calculations. Advantages of calculating primary and secondary power separately are: Emissions for the primary system are determined on the use of given technology, influence of annual yield (operation hours) can be clearly ascertained, permitting of comparison between backup options. IAEA used in their study Full Energy Chain (FENCH), which considers all the steps from "cradle to crave". Figure 5.2 represents the results from IAEA study. /35/

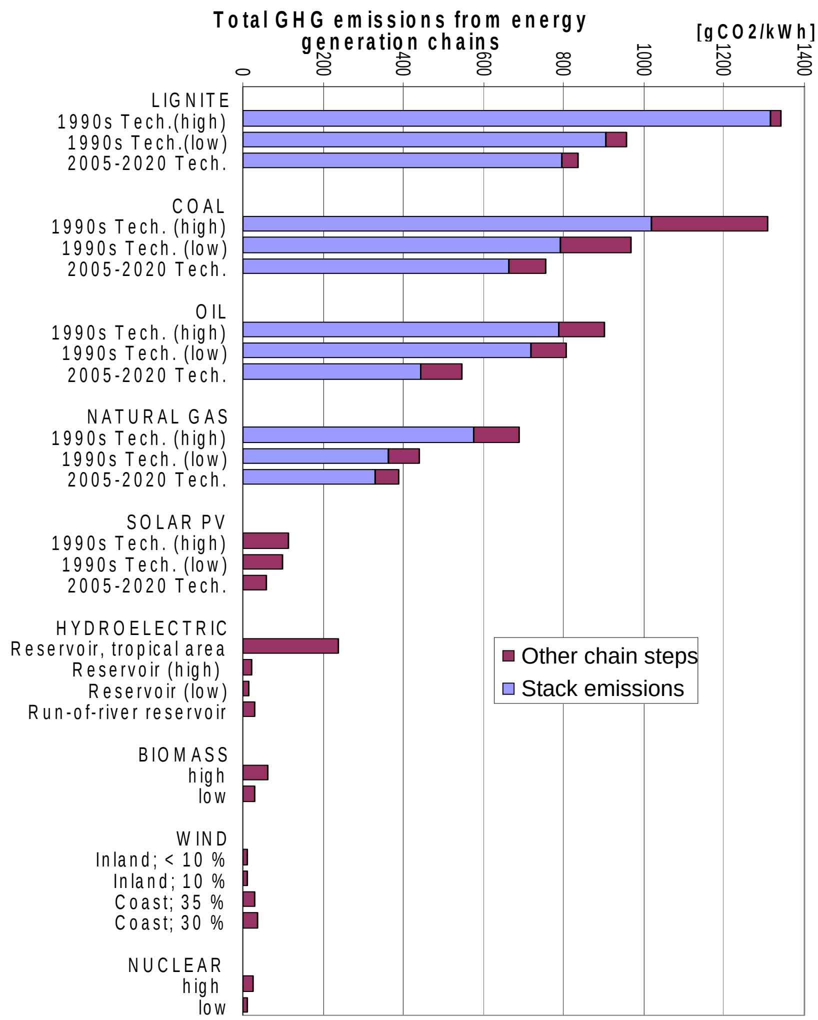

Figure 5.2 Total GHG emission generated by power production chains $CO_{2,eq}$ /35/

The International Atom Energy Association (IAEA) research was made as part of their Comparative Assessment of Energy Sources, which involved 6 specialist conferences between years 1994 and 1998, for reviewing the GHG emission from the process chains related to the production of electricity using: lignite, coal, oil, gas, nuclear, biomass, hydro, wind and solar photovoltaic. Fossil fuels have the highest emission factors from which natural gas emits half as much as coal or lignite and two-thirds of the estimate for fuel oil. Lowest emissions come from nuclear and hydropower with 50 to 100 times lower emissions than coal. /35/

5.8 Measures for environmental effect reductions

Measures for minimizing the environmental effects can be categorized into technical measures and legislative measures. Technical measures are measures that can improve the energy production processes during the whole process chain and new technologies that can be used for minimising the effects or new ways to produce energy. Legislative measures are for making better framework for use of low-carbon technologies and for supporting new technologies for making it beneficial to lower the emissions.

Technical measures for minimizing environmental impacts can be categorized as follows:

- Utilising only energy production methods that are characterized as low-carbon technologies i.e. nuclear power, renewable energy sources (Bio-energy, wind power, hydro power, solar etc.)
- Apply technologies to increase energy efficiency in the production, industry, transportation etc.
- Increasing efficiency factor in energy production with e.g. by expanding CHP production, rising process temperature and pressure with new alloys
- Transition between fossil fuels to less emitting ones e.g. change from use of coal to gas
- Utilizing technologies which can filter or extract harmful pollutants from the power generation process or fuels e.g. CCS, coal-to-liquid etc.
- Development of control centres for market information, i.e. electricity price, CO_2 price, congestion on transmission lines, water reservoirs, and creating mechanism and technologies to help market participants to receive the information in real time
- Availability and utilization of distributed generation during peak-load hours e.g. solar power, wind power etc.

Legislative and economical measures for minimizing environmental impacts can be categorized as follows:

- Taxation of emissions: emissions produced are cost for the industry, making it cost-effective to reduce emissions
- Development of cap-and-trade emissions programmes

- Recognizing technical investments for emissions reduction as a mechanism for emissions reduction e.g. CCS, filter systems, monitoring, coal-to-liquids
- Development of financial incentives e.g. feed-in-tariff, green certificates, for plants producing low minor emissions of zero-emissions where it is sensible e.g. CCS, renewable energy sources
- Mandate the use of emissions reducing technologies for certain sources or subsidies for installation costs of the technologies
- Development of market-oriented approaches
- Progressing with pan-European electricity and CO_2 market integration to create common markets for all Europe, also market integration with CIS EPC (Electricity Power Council of the Commonwealth of Independent Countries) and European systems

6 Economical aspects

The relation between the environment and energy industry is clear through the impacts the energy industry makes by its activities. Studies have been made on the relation between environment and economics. This chapter will explain about that relation and also about most known review on the economics of climate change, the Stern Review.

6.1 Relation between environment and economics

There are indications in which U-shaped relationship between emissions or concentrations of GHG and income per head, the so-called 'environmental Kuznet's curve' exists. Simon Kuznet's theory was originally about income per capita and inequality. Economic inequality increases over time, but after critical average income is attained, it starts to decrease. /37/

The evidences show that while the income per head grows, eventually emission level saturates and then starts to decrease. Stern in his report finds that such a decrease is unlikely globally, at least not until the emissions the GHG concentrations have risen to destructive levels /37/. Environmental Kuznet's Curve hypothesis can be formulated in IPAT framework. In IPAT, an environmental impact is expressed with factors of population, "affluence" (GDP per capita) and technology /38/:

$$I = P \cdot A \cdot T \qquad (6.1)$$

Where,

I	Environmental impact
P	Population
A	GDP per capita, €
T	Technology

In empirical studies of environmental Kuznet's curve hypothesis, a specific impact indicator is chosen e.g. SO_2 emissions could be chosen to represent environmental impact I. Technology factor T is estimated by dividing I by GDP, and regression is performed on a quadratic functional form /38/:

$$\ln(T(A)) = a + b \cdot \ln(A) + c \cdot \ln^2(A) \qquad (6.2)$$

Where,

$$a = \ln(T_{\max}) + \frac{1}{2}\varepsilon_{\text{low}} \cdot \varepsilon_{\text{high}} \cdot \ln^2 \cdot A_{\max} \tag{6.3}$$

$$b = \varepsilon_{\text{low}} \cdot \varepsilon_{\text{high}} \cdot \ln A_{\max} \tag{6.4}$$

$$c = -\frac{1}{2}\varepsilon_{\text{low}} \cdot \varepsilon_{\text{high}} \tag{6.5}$$

Where,

T_{maz}	maximum value of T
A_{maz}	income where T reaches T_{max}
ε_{low}	income elasticity of T at low incomes
ε_{high}	income elasticity of T at high incomes

Illustrative picture of Kutznet's curve can be seen on figure 6.1

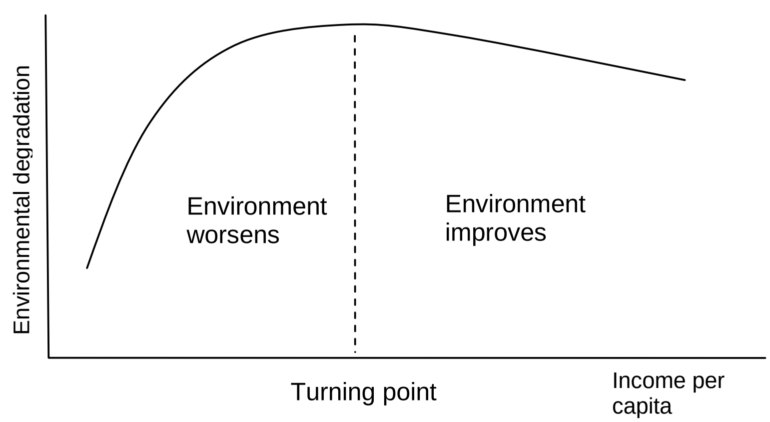

Figure 6.1 Environmental Kuznet's curve /37/

When societies get richer, new technology will substitute the old technology, which can lead to emissions decrease from single society. But the problems comes from the fact that concentration levels in atmosphere are global and it will take very long time for developing countries to be in level that the emissions would start to fall. Therefore, single societies cannot change the course of the concentration level on earth. /37/

On single society level the environmental Kuznet's may be valid. Curves appearance may be also culture-oriented and incidental due to different fuel mixes and standards of living in different states. In Europe's level also can be stated that during time period 1990 – 2000

EU-25 GDP of area grew 25 % also the electricity production grew 20 % whilst CO_2 emissions reduced 2,3 % in absolute terms. /18/

Figure 6.2 illustrates the relationship between per capita GDP, energy use and emissions in four countries; the United Kingdom, United States, Australia and Sweden. It reveals significant differences in the relationship between GDP and energy use. United Kingdom has the lowest energy intensity of the four, according to the figure. However, there are much more dramatic differences in emissions. Australia and Sweden, for instance, have almost identical per capita energy consumption, but Australia's per capita emissions are almost three times Sweden's. Thus while energy intensity may play a part in "de-coupling", the most dramatic gains are likely to be made in addressing the carbon intensity of the fuel mix. De- coupling can be understood as disconnection of relation between GDP and energy consumption or intensity. /39/

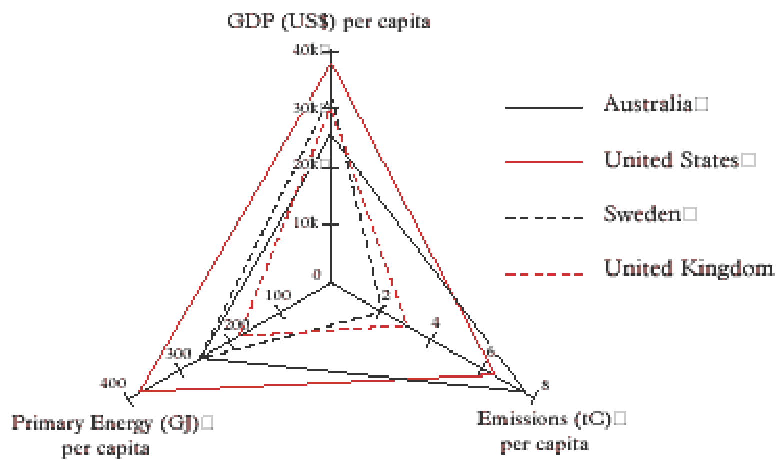

Figure 6.2 De-coupling: the relationship between GDP, emissions and energy consumption in 2002 /39/

6.2 Effects of Climate Change

As the chapter 5.9 explains the expensiveness of the possible measures for minimizing GHG emissions and other impacts, this chapter explains about researches about the costs for not doing anything. There are a lot of studies about the economic bases for climate policies, but the most known and debated is The Review on the Economics of Climate Change by economist Sir Nicolas Stern for the British government. Next chapters will go through its main content and some criticism toward it.

6.2.1 The Stern Review

The Economics of Climate Change: The Stern Review was fabricated by Sir Nicholas Stern and his 23 people work group. The Stern review is not the only one of its kind to estimate possible costs of climate change, but it is by far the largest. Special note is that the report doesn't bring out any new knowledge or scientific facts for the climate change or its impact on the societies instead it is review or summary of all previous researches, although the conclusions differ from the previous studies. /40/

The Stern Review bases its analysis on the studies in which under business-as-usual scenario shows what will happen if immediate measures are not taken to stabilize concentration on safe level. Scenario states that the GHG concentration in the atmosphere could be more than treble of the pre-industrial levels (greater than 850 ppm $CO_{2\text{-eq}}$) by the end of century. Trebling of the amount by year 2100 would give 50 % risk of temperatures exceeding 5°C above pre-industrial levels. Knowledge is limited on environments or human societies responding for to increases in temperature, but studies that The Review gathered presented that the impact of climate change across multiple dimensions are likely to be highly arched and the marginal damages increases exponentially as temperature rises. Risks and damages are based on the assumption that the temperature will rise 5°C. Damages of the climate change were explained on chapter 2.2 of this report. /37/

In principle the Review is cost-benefit analysis with aim to estimate the costs of inaction and the benefits of action to minimize the emissions. The results are given with percentages from global GDP value. Costs of inaction would bring a drop in global GDP by 5 % now and forever and with some more pessimistic estimate the drop could be even 20 % or more. On the other hand, with changing of energy policy with emission restrictions, the costs of stabilizing the concentration at 450 – 550 ppm CO_{2eq}, thus bringing down the risks of climate change, would cost about 1 % per year. /37/

The Review also discusses the policy instruments, such as promoting mitigation, adaptation approaches and the international framework, on second half of the report. Further discussion involves three strands of policy intervention – correcting the market failure on GHG, technology policy and change of perspectives toward more responsible behaviour. Importance of tax, trading and regulation in creation of a carbon price has been brought up. /37/

Policy instruments effectiveness to bring GHG reductions, efficiency and working capital available are key factors for desired effect. Moreover, for different states and different sectors, different approaches will be appropriate and effective e.g. several EU countries have posed high fuel taxes, whereas USA have seen more important vehicle efficiency standardization. /35/

Emission trading was shown in the review to be efficient and bringing across country boundaries. Ambitious targets and heavy restrictions on emissions with support of effective mechanisms is driving private sector to invest on developing countries. Allowing use of the CDM in developing countries has potential to increase the use of carbon finance in poorer countries. /37/

The review also raises high importance on the support for the developing countries, so they avoid locking in new high-carbon infrastructure during the next few years, when substantial growth and investments is likely take place. /37/

6.2.2 Criticism on the Stern Review

The Stern review created considerably interest and debate. Even though the climate change is widely debated issue, criticism toward the review did not focus on that, instead more on the principles Stern used to calculate the costs of the climate change. The costs of climate change were considerably larger compared to previous studies, then again costs of cutting the emissions and slowing the change are considered cheap. Figure 6.3 illustrates Stern Review and previous studies estimates on costs of climate change. /40/

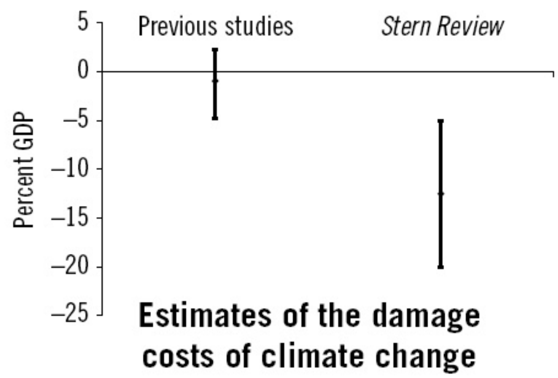

Figure 6.3 Estimates of Climate change costs /41/

Economical issues brought up were about the discount rates Stern used in his calculations for costs and benefits. Stern used as discount rates of 0,1 % and 1,3 % economic growth per year, these counts for 1,4 % market interest per year, which is fairly low compared to real market interest. /37/

Benefits from consumption are described by the size of the bar in 2007. Bigger the wealth in the future, less benefit comes from saving. Saving is submitting benefits from consumption, and investing on markets, where technology defines profit from investment. Profit means extra-consumption in year 2107. Figure 6.4 illustrates Ramsey's rule about saving. The submitted "benefit" from 2007 consumption is the same size as the "benefit" through saving from 2107. Former is grown with market growth and latter is corrected down with discount rate. /40/

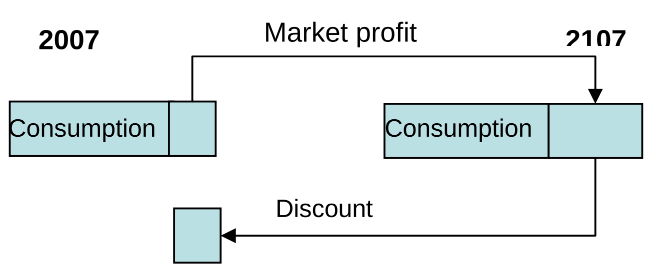

Figure 6.4 Ramsey's rule on saving /40/

By using Sterns discount rate (time preference) and estimation for economic rate with 1 % sacrifice on future to avoid 5 % GDP drop after 100 years we get as benefits compared to costs factor circa 4,5 with 1,4 % discount rate. But if the market interest is higher than 3,3 % per year factor of costs and benefits of environment policy are opposite.

For example, if GDP is 20.000 € per person in 2007, with 1,3 % GDP growth it will be 72.774 € in year 2107. 5 % drop of GDP in 2107 would be then 3639 €. In the year 2007, with 1,4 market interest, 3639 € would be in value of 2007, 903 €. Cost of 1 % per year is 200 € makes benefit – cost factor 4,5.

With the market interest of 3,3 %, GDP drop of 5 % in 2107 would be valued in 2007 127 € and factor would be 0,6. It would not be any more beneficial to invest 1 % of GDP today. Figure 6.5 illustrates the example.

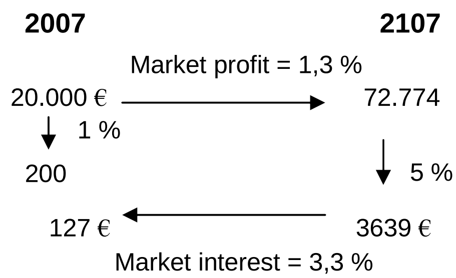

Figure 6.5 Example with possible market interest 3,3 % /40/

Formula for expected profit from saving can be written as follows if uncertainty is not included in consumption /40/:

$$r \approx \delta + \gamma \frac{c_1 - c_0}{c_0} \tag{6.6}$$

Where,

δ	Discount rate
γ	Flexibility of financial benefit
c_1	Consumption in time 1
c_0	Consumption in time 0

Often used figures for the parameters are δ=2 %, γ=2, $\frac{c_1 - c_0}{c_0}$=2 %, this would lead to market interest of 6 %. Stern reviews default values were δ=0,1 %, γ=1, $\frac{c_1 - c_0}{c_0}$=1,3 %, leading to market interest of 1,4 %. /40/

Furthermore, due to chosen time preference and property effect Stern comes to conclusions that action has to be taken now. This assumption has also risen several questions, when most studies suggest that it is best to take gradual steps. The schedule depends on market growth, costs and harms and in what amount are the harmful effects irrevocable. Professor of economics William Nordhaus from Yale University criticised discount rate assumption: "The Review's unambiguous conclusions about the need for extreme immediate action will not survive the substitution of discounting assumptions that are consistent with today's market place. So the central questions about global-warming policy — how much, how fast, and how costly — remain open. The Review informs but does not answer these fundamental questions". /42/

6.2.3 Reflection on Stern review

The Stern Review is extensive report on costs and benefits of environment policy. The economic contents are easily criticised due to the uncertainties climate change and its real effects. The review tries to be independent research on facts proven by studies, when in truth it is and political document /40/. Were the basis for the studies political agenda or desire research how we can justify environment policy today it seems to have been successful. Deliberately chosen rates show in full what are the full dangers if nothing is done to prevent climate change from continuing. Furthermore, the research did help to bring more debate on the issue. The fact that the climate change is happening and that something has to be done with it has not been criticised as much.

7 Scenario calculation on Finland energy production

As the Stern Review stated, states are forced to act now to the issue of sustainability of energy production and lowering of energy related GHG emissions. Question lies, which road to follow for lowering the emissions. Choices vary from full investment to renewable energy sources, combined resource channelling on RES and nuclear or continuation of coal-fired power production, but equipping them with CCS or other emissions lowering technology.

Following chapter will make an example calculation through different scenarios how the emissions levels change with different approaches on energy policy. Example will be for Finland and the calculations and the scenarios will be made with a program called GEMIS.

The scenario models follows partially research, estimations and assumptions made by consulting unit of Pöyry Energy Oy in their report /46/. Following chapters will first describe the GEMIS software used for Life-cycle analysis and then description of Finland's electricity production structure and assumptions of its development. In addition short description of Pöyry Energy's study methods are made.

7.1 About GEMIS and life-cycle analysis

Global Emissions Model for Integrated Systems (GEMIS) is a life-cycle analysis (LCA) program and database for energy, material and transport systems. With the consideration of variety of technologies in use as well as the diversity of environmental impacts, the environmental effects caused by energy systems are considerably complex. /43/

During resent decades the studies of environmental impacts has gone forward starting from energy carriers (fuels) air pollutant emissions in the early seventies, which was followed by nuclear specific impacts, heating systems and a focus of attention for above all SO_2 and NO_x. Release of GHG emissions and traffic sector started to be interesting in the end of eighties. Up until now not only direct environmental effects from energy production systems are regarded, but also the upstream processes. /43/

The origins of the program go to Germany, year 1987, where the first version 1.0 was released. GEMIS was made as a tool for comparative assessment of environmental effects of energy made by co-operation of Öko-Institut and Gesamthochschule Kassel (GhK). English translation for GEMIS was available since 1990 which was called TEMIS, Total Emissions Model for Integrate Systems. Between 1993 and 1995, EM (Environmental Manual for Power Development) was developed. EM is similar to TEMIS, but the database was specifically adjusted to developing countries, and new features for power planning were added. Furthermore, the "check for compliance with emission standards" is an original EM feature. The version of GEMIS used for the current report was 4.42 and it has all models integrated. /43/

GEMIS uses the Life Cycle Analysis or Life Cycle Assessment (LCA) where also the materials of construction of the processes are considered. "This integrated way of looking at energy and material flows puts up high standards to database and computer modelling and it cancels the distinction between "energy referred" environmental assessments and such in other sectors (e.g. consumer goods, traffic)" as Öko Institut says in their introduction for their program. /43/

7.1.1 The life cycle assessment method

LCA is a general method suitable for analysing products, processes or services regardless of their nature or extent. The objective of LCA is to describe and evaluate the overall environmental impacts of a certain action by analysing all stages of the entire process from raw materials supply, production, transportation and energy generation to recycling and disposal stages following actual use. LCAs should include all relevant physical-chemical activities, that are connected with the supply of an (energy)-service or a product. All relevant transports as well as the production of materials and auxiliary products should be considered, too /21/. Environmental impacts of the supply of an energy-carrier or material result from all processes should be involved. Auxiliary energies and the processes supplying them cause environmental effects through indirect impacts resulting partially from loops and other process chains. LCAs can not be calculated simply linear. The same applies to the fact, that materials preliminary work is included in LCAs, which extends data and modelling considerably. Besides energy flows, now also material flows have to be considered as well as connections between both. Extraction, transports, conversions etc. (with specific environmental impacts) have to be paid attention to in connection with material process chains, too. /43/

LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process or service, by /17/:

- Compiling an inventory of relevant energy and material inputs and the associated emissions to the environment;
- Evaluating the potential environmental impacts associated with identified inputs and emissions
- Interpreting the results to facilitate making a more informed decision.

Inputs may be divided into the following stages /17/:

- Raw materials
- Manufacturing
- Use/reuse/maintenance
- Recycle/waste management

Outputs may be listed as the following /17/:

- The products
- Atmospheric emissions
- Waterborne wastes
- Solid wastes
- Co-products
- Other releases

Life Cycle Analysis was used in The World Energy Councils (WEC) study of various energy production forms in 2002-2004 Studies Work Programme. The objective was to identify existing LCA studies, review them and prepare a compilation report. /17/

7.1.2 Stages of LCA

The LCA process is a systematic approach that consists of four stages /17/:

- Goal definition and scoping
- Inventory analysis
- Impact assessment
- Interpretation

The three mains stages (Goal definition and scoping, Inventory analysis, Impact assessment) are connected to interpretation. Stages of LCA are shown in Figure 7.1. /17/

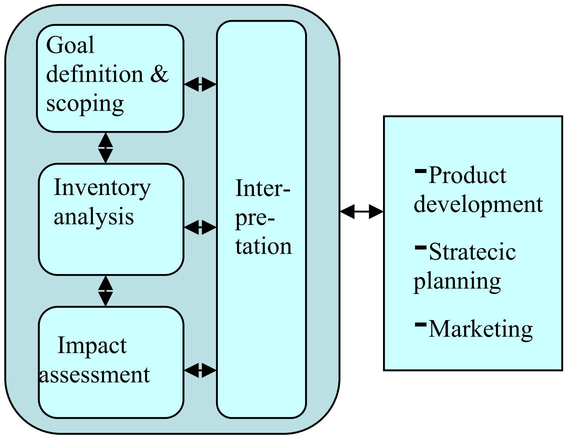

Figure 7.1 Stages of LCA /17/

Goal definition and scoping:

In this stage the purpose and method of including life-cycle environmental impacts in LCA are defined. The following six decisions should be made in the beginning of the LCA process /17/:

- Definition of goal(s)
- Determination of information types needed
- Determination of way the data should be organised and the results displayed
- Determination of what will or will not be in included
- Determination of required data accuracy
- Determination of ground rules for performing the analysis

Inventory analysis

Inventory analysis (LCI) is a process for quantifying the energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes and other releases for the entire life cycle of a product, process or activity. In this analysis all relevant data are collected and organized. The level of accuracy and detail of the collected data is reflected throughout the whole LCA process. The outcome of the inventory analysis is a list containing the quantities of pollutants released to the environment and the amount of energy and materials consumed in the life cycle of the product. /17/

Information for life cycle inventory is collected with following steps /17/:

- Development of a flow diagram of the processes being evaluated
- Development of data collection plan
- Collection of data
- Evaluation and reporting of results

In figure 7.2 displayed one *unit process* which is a single part of process flow which is series of interconnected unit processes.

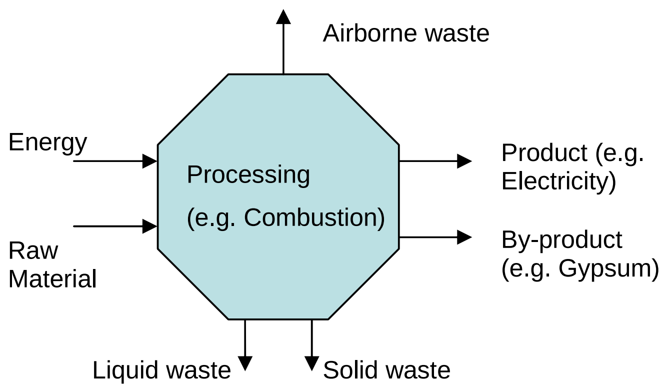

Figure 7.2 Single unit-process /17/

<u>Impact assessment</u>

Life-cycle impact assessments (LCIA) purpose is to determine and evaluate the potential human health and environmental impacts of the environmental resources and releases identified during the LCI process. Table 7.1 describes the common categories used from impact analysis. /17/

Table 7.1 Life cycle impact categories /17/

Impact Category	Scale	Relevant LCI Data	Common Characterisation Factor	Description of Characterisation Factor
Global Warming	Global	Carbon Dioxide (CO_2)	Global Warming Factor (GWP	Conversion of data in to (e.g. CO_2 equivalents)
		Nitrous Oxide (N_2O)		
		Methane (CH_4)		
		Chlorofluorocarbons (CFCs)		
		Hydrochluorofluorocarbons (HCFCs)		
		Methyl Bromide (CH_3Br)		
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs)	Ozone Depleting Potential	Conversion of data into trichlorofluoromethane (CFC-11) equivalents
		Hydrochluorofluorocarbons (HCFCs)		
		Halons		
		Methyl Bromide (CH_3Br)		
Acidification	Regional	Sulphur Oxides (SO_x)	Acidification Potential	Conversion of data in to hydrogen (H+) ion equivalents
	Local	Nitrous Oxide (N_2O)		
		Hydrochloric Acid (HCL)		
		Hydrofluoric Acid (HF)		
		Ammonia (NH_4)		
Eutrophication	Local	Photosphate (PO_4)	Eutrophication Potential	Conversion of data into phosphate (PO_4) equivalents
		Nitrogen Oxides (NO_x)		
		Nitrogen dioxide (NO_2)		
		Nitrates		
		Ammonia (NH_4)		
Photochemical Smog	Local	Non-methane volatile organic compounds (NMVOC)	Photochemical Oxidant Creation Potential	Conversion of data into ethane (C_4H_6) equivalents
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_5 date into equivalents
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_5 date into equivalents
Human Health	Global	Total releases to air, water and soil	LC_{50}	Converts LC_5 date into equivalents
	Regional			
	Local			
Resource Depletion	Global	Quantity of minerals used	Resource Depletion Potential	Converts data into ratio of quantity of resource versus quantity of resource left in reserve
	Regional	Quantity of fossil fuels used		
	Local			
Land Use	Global	Quantity disposed of in a landfill	Solid waste	Converts mass of solid waste into volume using and estimated density

An LCIA provides a systematic procedure for classifying and characterising different types of environmental effects, establishing a linkage between the product and processes and its potential environmental impact. For example, with LCIA all the compounds that may cause global warning are gathered and for each are determined GWP factor for determining their equivalent share of emissions. As a result it gives a checklist showing the relative differences in potential environmental impacts for each option. /17/

<u>Interpretation</u>

Interpretation is a systematic process to identify, quantify and evaluate the information from all the stages of LCA (goal definition and scoping, inventory analysis, impact assessment). Interpretation is the last phase of LCA process, but there has to be "communication" between the stages already. /17/

The International Organization for Standardisation (ISO) has defined the following two objectives of life cycle interpretation /44/:

- To analyse results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner
- To provide a readily understandable, complete and consistent presentation of the results of an LCA study in accordance with the goal and scope of the study

7.1.3 GEMIS and LCA process

GEMIS is a tool for LCA. GEMIS contains lot of information, data links and algorithms and it determines emission balances, environmental effect potentials and costs with the adequate data, but the most current data must be defined by the user. In the terms of LCA process stages Figure 7.3 shows where GEMIS fits.

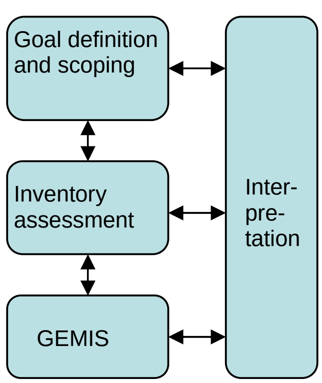

Figure 7.3 LCA process with GEMIS

LCA process with utilization of GEMIS starts normally with the stage of defining the goal(s) and scoping, for determination of objective of the projects. Inventory assessment is to determine which data has to be given for GEMIS. GEMIS has extensive database of processes and products, but even with the upgrades and extensions for the program, some data comes fast obsolete or the nature of the project requires special values. /43/ Figure 7.4 describes GEMIS data and category setting for the impact assessment.

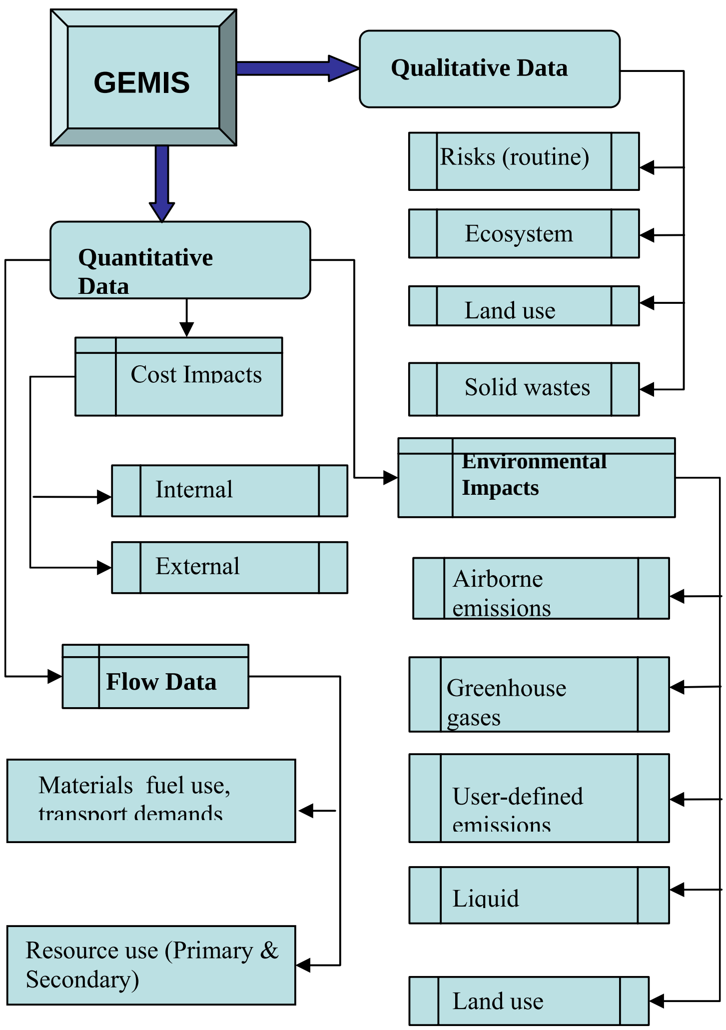

Figure 7.4 GEMIS and LCI and LCIA /45/

7.1.4 GEMIS database, processes, products and scenarios

The GEMIS database is supplied with information on energy carriers (process chains and fuel data) as well as different technologies for heat and electric power generation. /43/

The information includes /43/:

- Fossil fuels (hard coal, lignite, natural gas, oil), renewable, nuclear, biomass (residuals, and wood from short-rotation forestry, miscanthus, rape oil etc), household waste and hydrogen (including fuel composition, and upstream data)
- Processes for electricity and heat (various power plants, co-generators, fuel cells, etc.)
- Materials: raw and base materials, and especially those for construction, and auxiliaries (including upstream processes)
- Transports: airplanes, bicycles, buses, cars, pipelines, ships, trains, trucks (for diesel, gasoline, electricity, and bio-fuels) and freight transport (trucks, LDVs, train ships and pipelines)
- In addition processes for: waste treatment (disposal), monetary

The process data are given for a variety of different countries, and a special set of data refer to the situation in developing counties. Each and every data item can be adjusted for the work with the core database which covers more than 8000 processes in over 20 countries in the version 4.42, which was used in this report.

In the GEMIS *total life-cycle analysis* are included the impacts from "every step of the way" i.e. fuel delivery, materials used for construction, waste treatment, and transports/auxiliaries. For each process GEMIS database covers following details /43/:

- Efficiency, Power, Capacity factor, Lifetime
- Direct air pollutants: SO_2, NO_x, halogens, particles, CO, NMVOC
- greenhouse-gas emissions: CO_2, CH_4, N_2O, SF_6, all other GH gases defined by the Kyoto protocol
- Solid wastes: ashes, overburden, FGD residuals, process wastes
- Liquid pollutants: AOX, BOD_5, COD, N, P, inorganic salts
- Land use

Analyzing of costs is also included with the implemented data for fuels and energy systems. Further more, GEMIS allows to asses the results of computations of environmental and cost analyses by valuing the results as aggregated indicators /43/:

Resources into:

- CER (Cumulated Emission Requirement): indicator for energy systems and can be used as a "proxy check" in life-cycle analyses (LCA)
- CMR (Cumulated Material Requirement): A quantitative measure of the total amount of raw material needed to deliver a product or a service. In GEMIS, the CMR is the material complement to the CER

Greenhouse gases into:

- CO_2 equivalents: result of the aggregation of greenhouse gases which takes into account their respective global warming potentials (GWP, see chapter 2.4)

Air pollutants into:

- SO_2 equivalents: quantitative expression of the acidification potential based on the relative acidity of SO_2. In SO_2 equivalents, also the air emissions NO_2, HCl, HF, NH_3 and H_2S are included
- Ozone-precursor equivalents: Or tropospheric ozone precursor potential (TOPP) is the mass-based equivalent of the ozone formation rate from precursors, measured ozone precursor equivalents. The TOPP represents the potentially formation of near-ground (tropospheric) O_3 (ozone) which can cause summer smog.

In addition GEMIS calculates the external costs resulted by avoiding the emissions.

<u>Products of GEMIS</u>

Products in GEMIS represent the inputs and outputs of *processes* during the energy flow chain. Products are the lines between the energy conversion processes as shown in figure 7.5 below. Important products are energy carriers and materials serving to link *processes*. Products can be main products for the conversion or auxiliary products needed for the main conversion. An important sub-type of different energy carriers are *fuels* e.g. coal, oil, natural gas. /43/

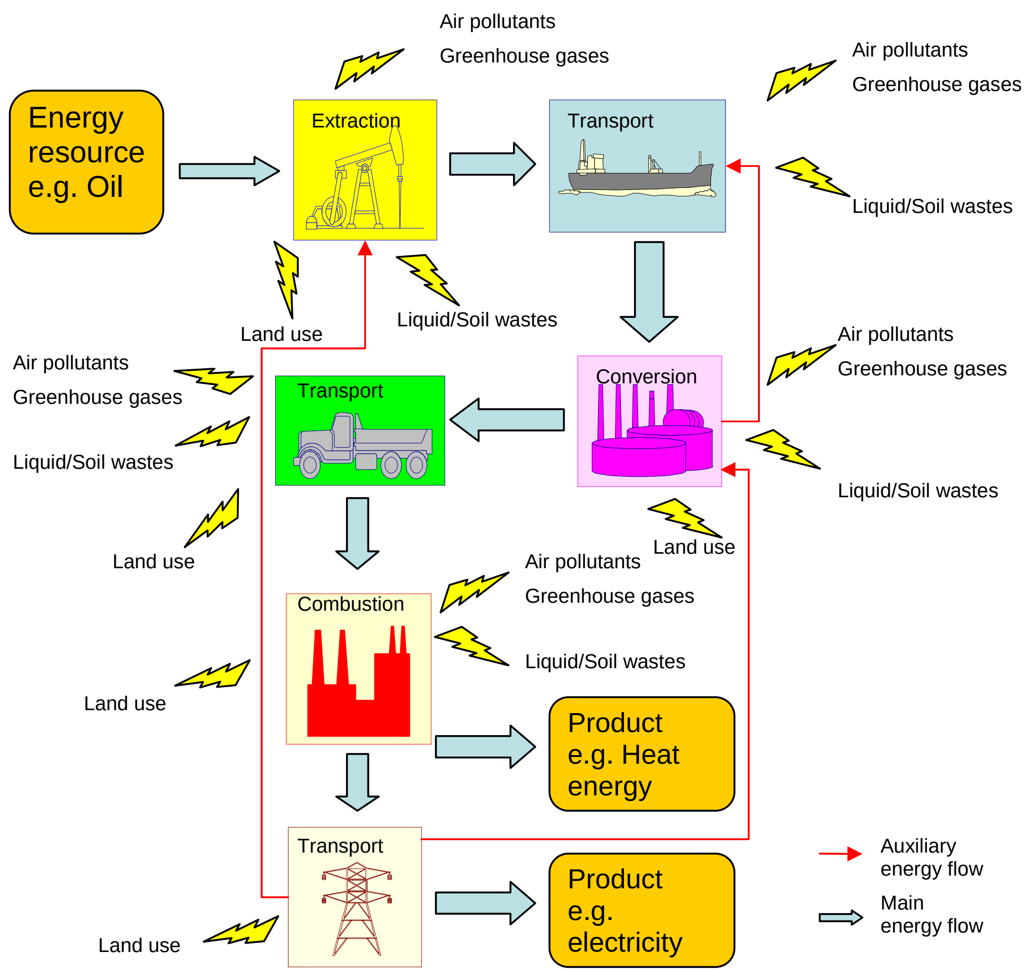

Figure 7.5 Energy production chain and effects caused during the processes /45/

All products have connected to them information which is needed to calculate costs and emission released from using these *fuels* /43/:

- Specified costs for materials and energy carriers (e.g. prices)
- fuel inventories of harmful substances

Processes

Processes represent an activity of converting a given energy or material input into another energy or material output or an activity of transport. Processes are also described in the figure 7.5 and as example of processes /43/:

- Power plants converting fuel (input) to electricity (output)
- Refineries converting fuel into another
- Steel works converting pig-iron to steel
- cars rendering person transport service

Processes usually also have secondary output in addition to the main output. These secondary outputs can be emissions, residues etc. and processes may need auxiliary products for the main activity to work. Auxiliary energy flows are also described in the figure 7.5 above. Figure 7.6 represents a process chain as it is shown in GEMIS. Processes are connected with product transport line to another process. Process chain of coal import to Europe is also shown. By selecting one of the processes it is possible to examine their data or process chains involved in each processes.

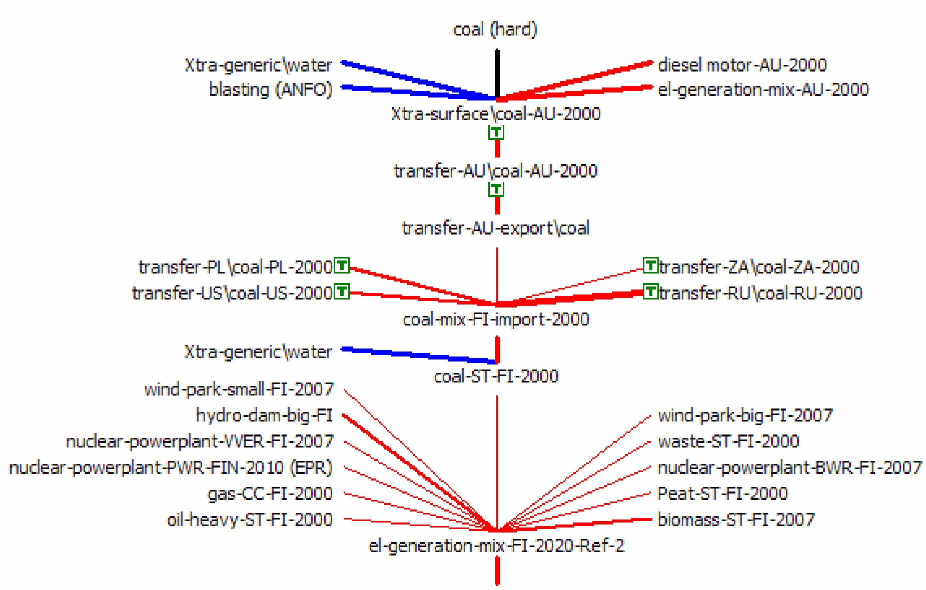

Figure 7.6 Process chain in GEMIS

<u>Scenarios</u>

Scenarios in GEMIS are collection of processes, or at least one for each option, that supply a certain demand e.g. energy, material, transport service, waste treatment. Each combination of processes represents one scenario option. After implementation of scenarios GEMIS can calculate the environmental effects and costs for the different scenarios and compare the results by displaying them in tables and graphs. /43/

The scenarios can be pure *energy-only-scenario* or *multiple-option-scenario*. With *multiple-options-scenario* it is possible to enter 6 different initial data about the processes: *Energy* amount, *Material* amount, *Person* transport distance, *Freight* transport distance, *Residue* amount, *Money* amount. In case of pure *energy-only-scenario* the demand can comprise needed electricity as well as thermal *generation*, the supplying processes can be added and their operating time can be determined. *Distribution system* can also be included with electricity and district heat and the demand is automatically increased by the transmission and distribution losses, if the lengths of transport are given. /43/

<u>Results</u>

Results can be calculated for the each process available individually, or the results are from fabricated scenarios. Individual results from GEMIS /43/:

- Greenhouse Gases - CO_2, CH_4, N_2O, HCF, PCF, SF_6
- Air Emissions - SO_2, NO_x, particulates, HCl, HF, CO, NMVOC, H_2S, NH_3
- Solid Wastes - ash, overburden etc.
- Liquid Effluents - AOX, BOD, COD etc.
- Resources Use: CEC, CER, and CMR
- Land Use - area affected by processes
- Costs - internal and external costs, and total costs (sum internal + external), for *energy-only-scenarios* also investment- and average costs
- Employment effects
- Fuel Balance - the amounts of fuels used
- Process Turnover - detailed representation of the energy, material, and transport turnover for all processes in each scenario option

GEMIS can show all of these results in tables and it is possible to compare different scenarios with each other. GEMIS can also show the results graphically for chosen results e.g. CO_2 equivalents from each scenario.

7.2 Research of Pöyry Energy Oy

Finnish electricity industry wanted to create a vision how the Finland's electricity production structure will evolve during following decades, when electricity industry is facing challenges set by aging production capacity, demands for competitive energy price, low-carbon emissions and delivery guarantee, emissions restrictions, demand for efficiency increase and targets of RES share in production. For these challenges to be met, all the potential RES and CHP possibilities have to be utilized and also other new production capacity.

The research generated scenarios for Finland's electricity production structure for the years 2015, 2020 and 2030 and gave as results /46/:

- The structure of Finland's electricity production capacity, MW_{eq}
- The structure of Finland's electricity generation, GWh_{eq}/a
- Emissions from electricity production, tCO_2/a

Scenarios were created with Pöyry's Boiler- and power plant-database and ELMO-electricity market model.

Boiler- and power plant-database

The Pöyry's Boiler- and power plant-database include circa 2000 boilers, which covers 98 % of Finland's energy productions fuel consumption. Coverage of boilers electricity production is 100 % and consumption of coal, gas, peat and wood based fuels is nearly 100 %. Data base includes among others boiler ownership, location, commission date, plant type, capacity, fuel consumption, production and emissions. /46/

The database includes in addition to current power plants also plants that are been constructed and those which are planned for later construction. Needs for new power plants are based on development of energy demand, competence of fuel sources and production type and older plants coming obsolete. The database can be used to analyse future energy production in Finland in different market situations e.g. effects of emissions trading, changes in energy taxation, fuel prices, electricity demand and electricity market price. /46/

ELMO-model

ELMO-electricity market model is developed by Pöyry Energy Oy for studying electricity production structure and costs and also for studying the effects on them coming from electricity market changes and from new plant investments. Modelling is done for each hour by counting the equilibrium of supply and demand on Nordic market area. For analysing future periods production structure is created. For each production unit is defined variable costs (fuel price, other variable costs, emission allowances), which defines the order in which they will operate, so that the cheapest will be first. Electricity price is defined by the most expensive production unit. Price formation of the ELMO-model is illustrated in figure 7.7. /46/

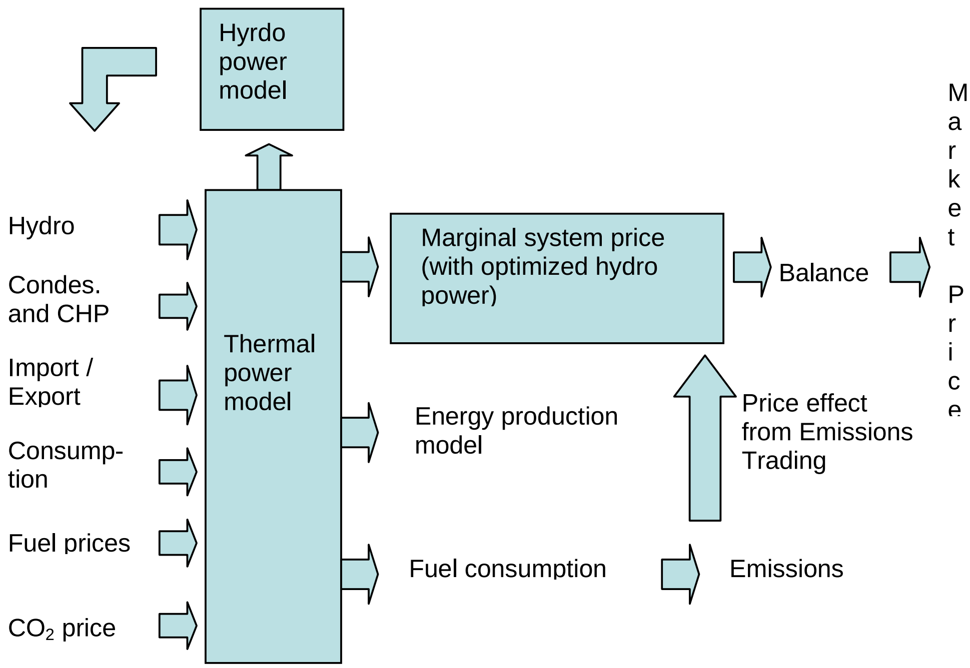

Figure 7.7 Price formation in ELMO-model /46/

7.3 Electricity production and demand predictions in Finland

Finland is energy intensive country due to its power intensive industrial structure and northern location. Sparsely populated and fairly large land area in EU standards makes the distances generally long, which has effect on transportation emissions and costs. Figure 7.8 shows the structure of Finland's electricity production in year 2007 by energy source and figure 7.9 describes the energy supply in 2007 through production types. Peak loads occur during winter on very low temperatures and when water reservoirs are low energy import is not available from Sweden or Norway.

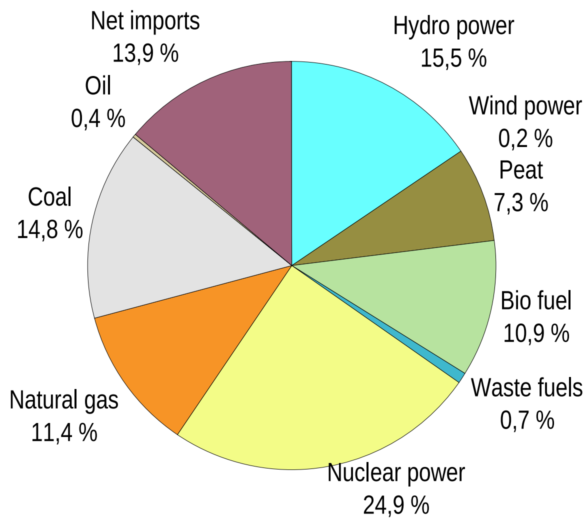

Figure 7.8 Electricity production divided by sources in 2007 /47/

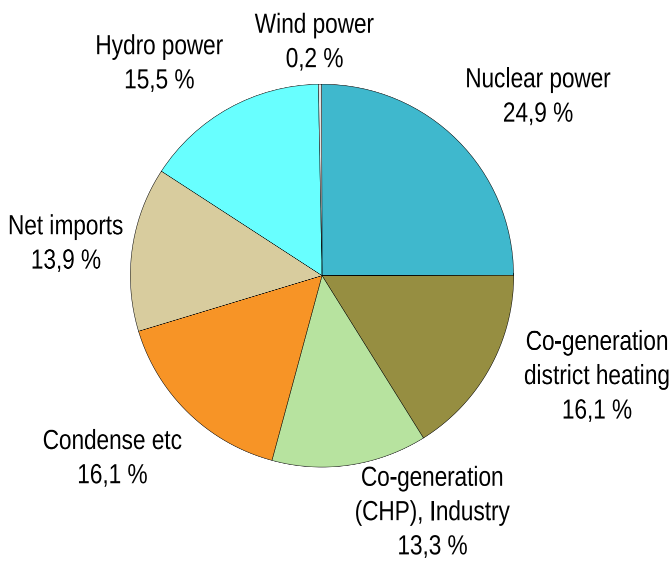

Figure 7.9 Finland's power supply in 2007/47/

Nordic countries form a fairly consistent electricity market area which electricity market price is determined in Nordic electricity power exchange Nord Pool. Congestion points still occur between border interconnection lines and longitudinal transmission within the countries of Finland, Sweden and Norway. Finland has also interconnection lines between Estonia and Russia. Table 7.2 shows the capacities of Finland's interconnection lines and planned ones.

Table 7.2 Interconnection capacities from Finland /48/

	Voltage [kV]	Capacity from Finland [MW]	Capacity to Finland [MW]
Sweden	220 400 400	1200	1600
	400	550	550
	110	80	80
Norway	100	100	100
Russia	110	-	100
	2X400 400	- -	1400
	110	-	60
Estonia	150	350	350
Total		3045	4240

During time of inspection there will be several power plants coming obsolete due to tightening environmental legislation and ageing of the power plants. Some estimates say that almost third of Finland’s power generating capacity will come obsolete by the year 2020, which would be 4000 MW. Pöyry Energy made the estimations of capacity and they were based on /46/:

- Estimates of the market participants
- Operation time defined by the LCP-directive (see chapter 3.1.6), for those plants for which it affects
- Other thermal plants on the bases of Pöyry’s own database
- Two nuclear power units are expected become obsolete during end of year 2027 and 2030

Figure 7.10 displays the estimated energy capacity from 2003 to 2030 including the expected energy demand curve.

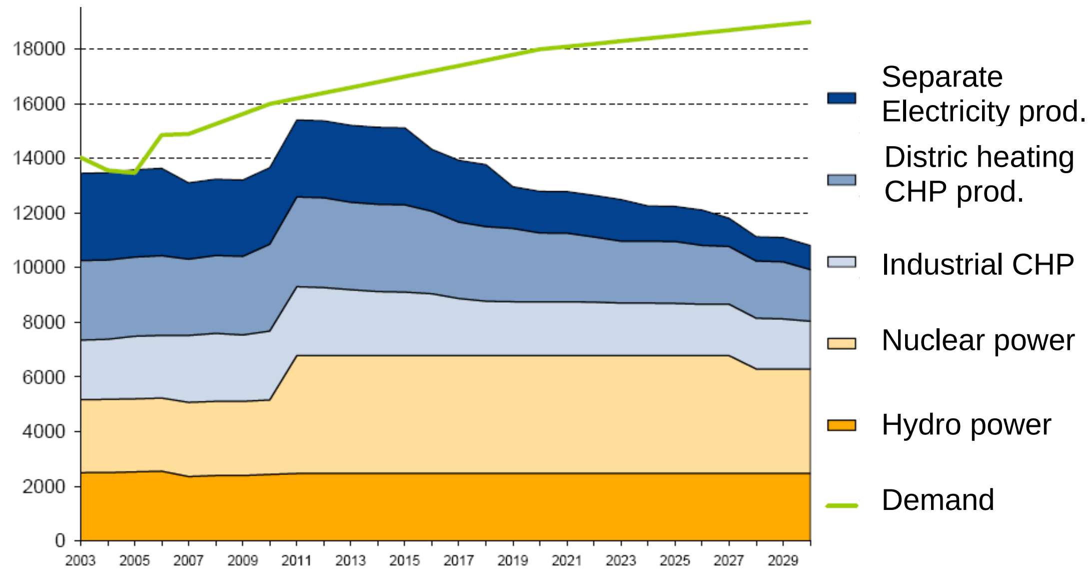

Figure 7.10 Peak-time capacity demand and available capacity in Finland from 2003 until 2030, separate el. prod. means condensing power supply /46/

The maximum capacity in the figure 7.10 does not show the importing capacities or the system reserves i.e. Gas-turbine plants for maintaining operational reliability and 90% of hydropower capacity reserved for frequency regulation and transient disturbances. Source for these statistical peak load capacity is the Finland's Transmission System Operator (TSO) Fingrid and the Finnish Electricity Market Authority. /46/

Finnish electricity demand is expected to rise due to favourable predictions on economic development and stable growth. Growth of the demand will slow down resulting from growing energy efficiency, technological development and partly political control. Figure 7.11 describes the expected energy consumptions in Finland. /46/

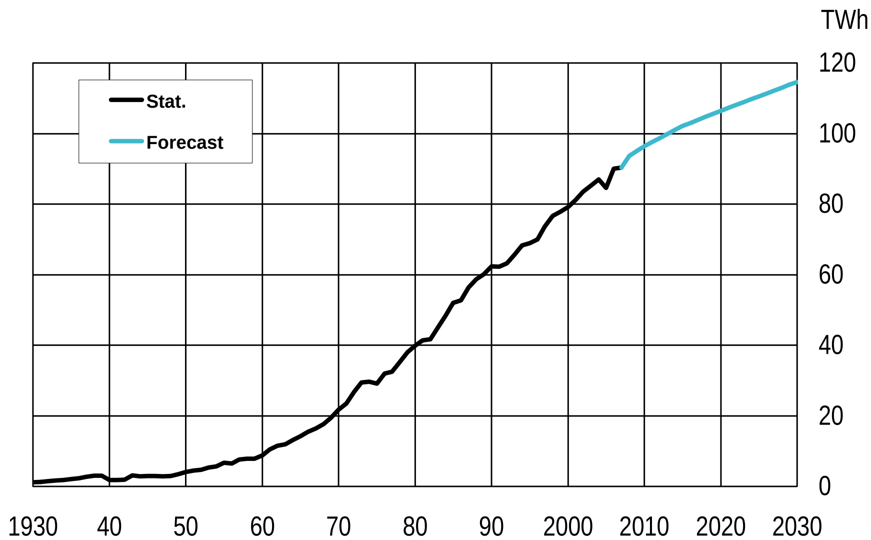

Figure 7.11 Finland's energy consumption and forecast /47/

7.4 Assumptions on electricity generation possibilities

Assumptions are made according to resent studies about the potential of Biomass, hydropower and wind power capacity addition in Finland. These generation types were chosen because of their restrictions for extra capacity possibilities.

7.4.1 Hydropower

Amount of hydropower is expected to rise in Finland and in other Nordic countries, which is of essence for Finland also. The rise of Finland's hydropower capacity is due to additional power plant capacity and estimations of production increase resulting from the climate change. Estimations and assumptions are based on research done by Vesirakentaja Oy in year 2007 and it was done for Finnish electricity industry. /49/

Result of the research was that in Finland there exists in total 1710 MW, in energy 6,7 TWh/a, un-built hydropower potential, which is about half of hydropower operational currently. Hydropower suitable for electricity systems regulation needs could be built 470 MW, in energy 1,3 TWh/a, by the year 2020. Fourth of this capacity would be implemented as change of plant machineries in already existing plants. For many of the potential sites from hydropower exists environmental regulations and decisions which could without re-evaluation prevent the projects implementation. Major possibilities exist in Ounas- and Ii-river where exists sites for 460 MW extra capacity, in energy 1,6 TWh/a. Both of these water courses are protected areas. Small hydropower plants are possible to build for the amount of 63 MW, 223 GWh/a which are expected to be realized before year 2020, unless the state subsidy policy changes for support of hydropower. The rest of the potential hydropower sites are protected areas which means the border-rivers which have hydropower potential of 502 MW, 2872 GWh/a, but construction of hydropower in these areas is not realistic. These rivers are part of Natura 2000 (see chapter 3.1.9) and these rivers are important part of fishing industry. In addition building on border-rivers is not possible only on Finland's decision. /49/

In total hydropower economically and technically eminent potential is 9834 MW, 2976 GWh/a from which hydropower which are not protected and raise of power output from old plants 367 MW, 639 GWh/a. Hydropower potential in protected areas totals on amount 569 MW, 2337 GWh/a. Protection legislations on state level are special protection law on Ounas-river and protection of rapids are the rest. Vuotos-river is partly Natura-2000 area. /49/

Pöyry Energy used in their calculations growth of hydropower capacity 450 MW, 1,5 TWh/a, until year 2020 and total of 900 MW, 3,0 TWh/a until year 2030 which are fully capable for regulation purposes. According to ILMAVA-review medium water-reservoir year hydropower production would increase 7 – 12 % from years 1961 – 1990 until years 2021 – 2050 due to raining and excessive penetration caused by the climate change. In the research was used figures 0,5 TWh until year 2020 and total of 1,0 TWh until year 2030 for increase of hydropower production. Table 7.3 describes the hydropower production estimates in Nordic countries. /46/

Table 7.3 Hydropower production estimates from three Nordic countries used in Pöyry Energy research /46/

	Implemented [TWh]	**2010 [TWh]**	**2020 [TWh]**	**2030 [TWh]**
Finland	13	14	15,5	15,5 (17)
Sweden	65	66	68	70
Norway	119	122	123	125
Total	197	201	206	212

7.4.2 Wind power

Wind power predictions are described on table 7.4. Estimations and assumptions are based on the research which was had done by Finnish Energy Industries and the research was done by Greenstream Network Oyj.

In the end of year 2007 there was 107 wind turbines in Finland which totalled in 110 MW in capacity. Total wind energy in year 2007 was 190 GWh which was 0,2 % of Finland total electricity produced. Potential sites for wind energy protection exist in Finland near the coast, on the sea and on mountains in Lapland. Research done by Greenstream Networks Oyj showed that wind energy production in Finland could be 4,5 TWh, 1500 MW by the year 2020 and 7,5 TWh, 2500 MW by the year 2030. These figures were used in the Pöyry Energy scenarios. Wind power production estimates are described on table 7.4. /50/

Table 7.4 Wind power production /46/

	2007 [TWh]	2015 [TWh]	2020 [TWh]	2030 [TWh]
Wind energy production	0,2	2,0	4,5	7,5

7.4.3 Biomass

Finland's biomass potential exist in use of biomass coming from wood product. Largest fuel source are black liquor which is used in forest industrial processes and solid wood products which are both side products from forest industry, those are; powder, bark, wood chips and so called forest fuels i.e. forest chips and stomps.

Use of black liquor is expected to rise 15 % from the medium of year 2000 from circa 40 TWh. Energy amount coming from wood bases fuels was about 28 TWh in 2006, from which 6 TWh was from forest fuels. Use of solid wood products is expected to rise from the part of forest fuels and the total energy from wood based products is expected to be circa 35 TWh by the year 2020. /46/

7.4.4 Nuclear power

Finland two nuclear units are expected to be decommissioned in years 2027 and 2030. Currently in Finland there is one nuclear unit under construction with capacity of 1600

MW and it is expected to be operational during the year 2011. There are applications on way for building 1-3 new units in Finland during the years 2010 – 2030 but no decisions have been made further from environmental mapping. In scenarios are used new nuclear units with the same capacity as the new unit in production. /46/

7.4.5 Condensing power plants and CCS

Further condensing power plants are expected to be built after the base load requirements are filled with nuclear, hydro and CHP production and in addition all potential wind extra-power. Choices for condensing power plants are to use coal-fired, peat, natural-gas and oil-fired gas turbines. Coal-fired power plants are expected to be realized. Use of CCS is expected to be possible by commercially ready for larger power plants by the years 2015 – 2020, thus the first condensing plants are expected to be equipped with CCS added after 2020. /1/

7.5 The task and targets of the review

Following review introduces scenarios of Finland's electricity production structure for years 2015, 2020, and 3 scenarios for year 2030. Scenario calculations were done with GEMIS. Basis for the scenarios were the demand of peak-load and the remaining capacity in the year 2030 after obsolete power plants. The remaining capacity was filled with using all potential RES, CHP and nuclear.

Results form the scenarios are:

- The structure of Finland's electricity generation for 2007, 2015, 2020 and 3 scenarios for 2030, GWh_{eq}/a
- The structure of Finland's electricity production capacity, MW_{eq}
- GHG Emissions from electricity production and from the fuel production chain for each model of energy production , $CO_{2,eq}/a$
- Airborne Emissions from electricity production and from the fuel production chain for each model of energy production , $SO_{2,eq}/a$
- Costs of electricity production, €/MWh

Emissions and costs are calculated with program GEMIS which uses Life-Cycle Analysis (LCA) for calculating emissions and costs coming from beginning (fuel mining) to end (decommissioning) of power production chains life-curve.

7.6 Modelling Finland energy production structure with GEMIS

Finland's energy production in year 2007 will be used as reference for the calculations for the following years. Energy models for years 2015 and 2020 will be made in accordance with planned power plant decommissions and power plant construction plans. For 2020 model will be made also in accordance with Finland's commitment to increase the share of renewable energy source use to 38 % (see table 3.4) by the year 2020, and assumptions are made in that respect. For the energy model for 2030 there are 3 scenarios made with different possibilities to meet the energy demand when more previous capacity has become obsolete. Share of electricity import is assumed to drop due to the growing demand for electricity and tightening capacity situation in St. Petersburg area as well as Finland's desire to be less dependent on imports.

7.6.1 Energy models for Finland

Following models represents energy production in Finland in 2007, 2015, 2020 and tree scenarios for 2030. 2007 model is reference model taken from actual shares of energy source use according to the Finnish Energy Industries. /47/

2007

Finland's energy production by energy source in 2007 is described on table 7.5.

Table 7.5 Finland's energy production in year 2007 by energy sources

	2007		Without Import	
	[TWh]	[%]	[%]	[TWh]
Waste	0,63	0,7	0,81	0,63
Biomass	9,84	10,9	12,66	9,84
Peat	6,59	7,3	8,48	6,59
Natural Gas	10,29	11,4	13,24	10,29
Oil	0,36	0,4	0,46	0,36
Coal	13,36	14,8	17,19	13,36
Hydro	14,00	15,5	18,00	14,00
Wind	0,18	0,2	0,23	0,18
Nuclear	22,48	24,9	28,92	22,48
Imports	12,55	13,9		
Total	90,3	100	100	77,75

Nuclear power was one quarter of whole energy consumption with the biggest share followed by hydropower and mostly condensing power and heat production with Coal. Share of electricity import was noticeably large with 13,9 % and 12,6 TWh. Share of import is expected to increase.

<u>2015</u>

In table 7.6 can be seen the energy production in year 2015 with it the estimate shares and energy amounts.

Table 7.6 Finland's energy production in year 2015 by energy sources

Difference to 2007 [TWh]	2015 Demand 101 TWh	[TWh]	[%]
0	Waste	0,64	0,67
2	Biomass	12	12,53
0	Peat	6,8	7,10
-0,3	Natural Gas	10	10,44
0	Oil	0,4	0,42
0	Coal	13,4	14,00
0,5	Hydro	14,5	15,15
1,8	Wind	2	2,09
13,5	Nuclear	36	37,60
	Total	95,74	100
	Imports	5,26	

Main changes in 2015 are the additional capacity from new nuclear power reactor of 1600 MW. Share of biomass, hydropower and wind power have also increased as described in chapters 7.5.1, 7.5.2 and 7.5.3 with energy amounts of 2, 0,5 and 1,8 TWh. 0,3 TWh of gas power has decreased due to substitution with nuclear power. It is assumed that it would not be possible to build a new nuclear reactor until 2015 due to long construction time (at least 6 with the new reactor) and long process of state approval for construction.

<u>2020</u>

In table 7.7 can be seen the energy production in year 2020 with it the estimate shares and energy amounts.

Table 7.7 Finland's energy production in year 2020 by energy sources

Difference to 2015 [TWh]	2020 Demand 106,5 TWh	[TWh]	[%]	Share of Renewables [%]
0	Waste	0,64	0,64	38,22
6	Biomass	18,5	18,36	
0	Peat	6,8	6,75	
-3	Natural Gas	7	6,95	
0	Oil	0,4	0,40	
-4	Coal	11,4	11,32	
1	Hydro	15,5	15,39	
2,5	Wind	4,5	4,47	
0	Nuclear	36	35,74	
	Total	100,74	100	
	Imports	5,76		

Finland's undertake on EU's targets on renewable energy shares are the main issue in changes in energy production in 2020. Further more approximately 7 TWh of energy will be decreased due to decommissioning of old condensing power plants. Hydropower and wind power amount has increased with 1 and 2,5 TWh as described in chapters 7.5.1 and 7.5.2. In hydropower's case, it is the limit of additional capacity unless the environmental laws in Finland are changed. Wind power is also reaching for limits unless there regulating power is installed into the power system. Because of these reasons the production of biomass, mainly wood products, has to increase by 6 TWh, in case that the import level is assumed to be approximately the same as in 2015, if Finland is to achieve the target of 38 % share of renewable resources in power production mix. It would be possible that a new nuclear power plant would also be available by year 2020 if the state policy would be favourable during years 2008 – 2013. It is still assumed that new reactor would not be ready by this time due to long building process and unfavourable pro-longings in the building process of new nuclear reactor. If a new reactor would be made by the year 2020 it would not still change the necessity of increasing power production from RES, and the new reactor would only substitute fossil-fuel power plants. Situation is different if energy import is yet again increased to 2007 level.

<u>2030</u>

In table 7.8 can be seen the base energy production in year 2030 with it the estimate shares and energy amounts.

Table 7.8 Base for Finland's energy production in year 2030 by energy sources

Difference to 2020 [TWh]	2030 Demand 114,6 TWh Base Model	[TWh]	[%]
0	Waste	0,64	0,71
0	Biomass	18,5	20,62
0	Peat	6,8	7,58
-1	Natural Gas	6	6,69
0	Oil	0,4	0,45
-2	Coal	9,4	10,47
0	Hydro	15,5	17,27
0	Wind	4,5	5,01
-8	Nuclear	28	31,20
	Total	89,74	100
	Open positon	24,86	

In year 2030 two nuclear reactors has been shut down in Loviisa, and the amout of energy is decreased by 8 TWh from 2020 power level. Furthermore, 3 TWh of condensing and CHP production has been decommissioned during last 10 year. Open position between the power production capacity and the projected power demand is 24,86 TWh. This amount should be filled with new power generation capacity between years 2020 and 2030. Table 7.9 describes 3 possible models from the year 2030 and table 7.10 energy source shares in the models.

Table 7.9 Finland's energy production in year 2030 scenarios by energy sources

Base difference	Nuclear Model	[TWh]	Base difference	Nuclear + RES model	[TWh]	Base difference	Combination Model	[TWh]
0	Waste	0,64	0	Waste	0,64	0	Waste	0,64
0	Biomass	18,5	2,5	Biomass	21	2	Biomass	20,5
-3	Peat	3,8	0	Peat	6,8	0	Peat	6,8
-5	Natural Gas	1	-3	Natural Gas	3	3	Natural Gas	9
0	Oil	0,4	0	Oil	0,4	0	Oil	0,4
-8,4	Coal	1	-7	Coal	2,4	2,7	Coal	12,1
0	Hydro	15,5	1,5	Hydro	17	0	Hydro	15,5
0	Wind	4,5	3	Wind	7,5	3	Wind	7,5
40,5	Nuclear	68,5	27	Nuclear	55	13,5	Nuclear	41,5
		113,84			113,74			113,94
	Import	0,76		Import	0,86		Import	0,66

Table 7.10 Shares of energy sources in model scenarios of 2030

	Nuclear model [%]		Nuclear and RES model [%]		Combination model [%]	
Waste	0,56	Reneable share	0,56	Renewable share	0,56	Renewable share
Biomass	16,25	%	18,46	%	17,99	%
Peat	3,34	33,82	5,98	40,00	5,97	38,18
Natural Gas	0,88		2,64		7,90	
Oil	0,35		0,35		0,35	
Coal	0,88	Low or no emissions	2,11	Low or no emissions	10,62	Low or no emissions
Hydro	13,62	%	14,95	%	13,60	%
Wind	3,95	94,00	6,59	88,36	6,58	74,60
Nuclear	60,17		48,36		36,42	
Total	100		100		100	

Nuclear Model

In Nuclear Model the base assumption was that there will be 3 new nuclear reactors which have the same capacity as the reactor installed in 2011 to the power system, 1600 MW, 13500 TWh. The total added power will be 40,5 TWh, which is more than the open position left by the decommissioned power plants. With this surplus of energy would be possible to start exporting power to neighbouring countries, but in this scenario it is assumed that fossil-fuel power plants will be less in use. In this scenario the share of RES would come down circa 5 % from 2020 but the share of energy production from low- or zero-carbon releasing power would go up to 94 %. Power production from peat could also be lowered. Peat is not still RES by EU standards do to its long recurrence time.

Nuclear and RES model

In Nuclear and RES models it is assumed that the open position would be delivered with 2 new nuclear power reactors for the amount of 27 TWh and with RES in total of 7 TWh (Biomass 2,5 TWh, Hydro 1,5 TWh, Wind 3 TWh). For these RES increases to happen the environmental laws would need to be changed in case of hydro power. In case of wind power, the increase of hydropower would be desirable, if not mandatory. Share of RES in power production would increase to 40 % compared with the share of RES in 2020.

<u>Combination model</u>

In Combination model only one new nuclear reactor is built by the year 2030 with amount 13,5 TWh in a year. This still leaves a open position of 11,4 TWh. It is assumed that new hydro power will not be built due to the existing environmental laws in place for the possible hydropower sites. Wind power has been increased by 3 TWh according to estimates by Greenstream /50/. This amount needs regulating power which can be supplied by the interconnections and new fast gas turbines. Biomass production has also been increased by 2 TWh, though in addition of biomass power production also, especially wood product bio-fuels, starts coming limits. Forest would need to be cleared just for energy production, thus influencing the forest industries material needs. Additional RES will not still be enough to satisfy the demand, if the amount of import is to be kept in minimum. There would have to be more fossil fired CHP plants and condensing power plants. Coal condensing has been increased by 2,7 TWh, so by one 600 MW condensing power plant or IGCC power plant and with 3 TWh, two 250 MW CCGT natural gas power plants

7.6.2 Results

Amount of energy produced by the energy production models are ascending as is the demand. Further increase is explained by the lower amount of imported amount. Figure 7.12 shows the amount of energy produced in different models. Open position is filled with energy import.

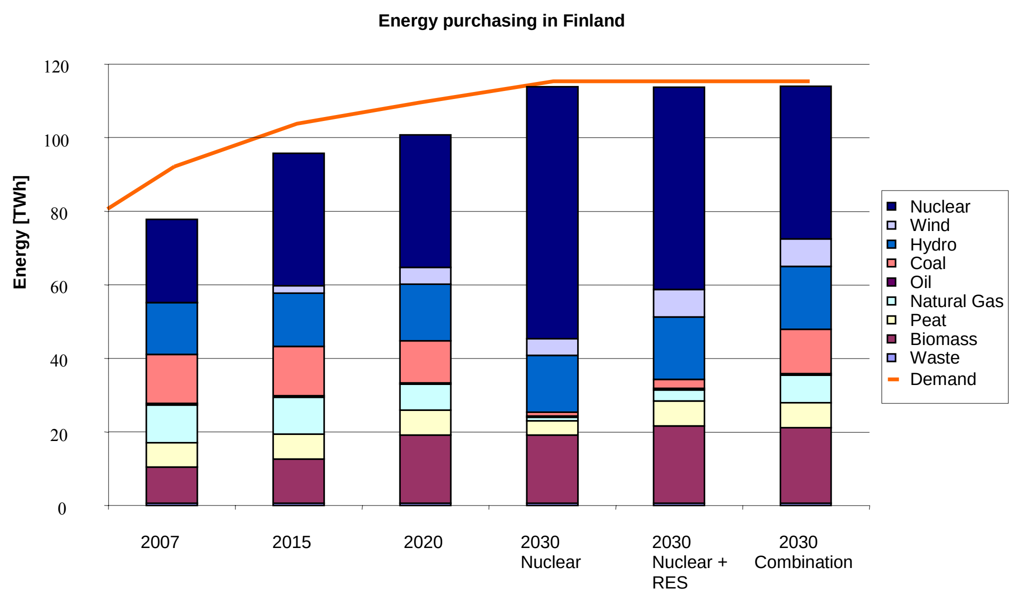

Figure 7.12 Demand and supply in Finland in years 2007, 2015, 2020 and 2030, open position is filled with imported energy

Biggest differences between the models come from the production of nuclear power and it can seen in the three energy sources of the 3 scenarios from 2030 how in the combination model that the energy production with coal has said the same without second nuclear reactor. This is because of need for base power which is produced mainly with coal-condensing power plants and nuclear power.

7.6.3 Environmental effects

Table 7.11 and 7.12 below describe the results from GEMIS for GHG emissions from the different energy production models. Difference between the results in the tables comes from different method of calculating the emissions. Table 7.11 shows the emissions from whole life-cycle i.e. in the calculation has been included emissions coming from waste treatment, mobile transports and construction of the facilities. Table 7.12 describes the emissions coming mostly from the production of energy.

Table 7.11 Greenhouse gases from the models calculated by GEMIS including waste treatment, mobile transport and construction

GHG emissions						
Option	**CO2 equivalent [kg]**	**CO2 [kg]**	**CH4 [kg]**	**N2O [kg]**	**Perfluoro-methane [kg]**	**Perfluoro-ethane [kg]**
2007	2,10E+10	1,95E+10	4,91E+07	1,19E+06	19,58	2,46
2015	2,18E+10	2,03E+10	4,97E+07	1,26E+06	21,12	2,65
2020	1,80E+10	1,67E+10	3,91E+07	1,18E+06	18,47	2,32
2030 Nuclear	4,82E+09	4,44E+09	9,57E+06	5,34E+05	6,08	0,76
2030 Nuclear + RES	7,36E+09	6,75E+09	1,70E+07	7,37E+05	8,37	1,05
2030 Combination	1,94E+10	1,80E+10	4,47E+07	1,28E+06	19,90	2,50

In tables 7.11 and 7.12, it can be seen that CO_2 emissions from 2007 to 2015 increase due to the increase of power produced with biomass and stable production of power with fossil-fuels. Worth of noticing is also that the power production increased between years 2007 and 2015 about 18 TWh.

Table 7.12 Greenhouse gases from the models calculated by GEMIS excluding waste treatment, mobile transport and construction

GHG emissions						
Option	**CO2 equivalent [kg]**	**CO2 [kg]**	**CH4 [kg]**	**N2O [kg]**	**Perfluoro-methane [kg]**	**Perfluoro-ethane [kg]**
2007	1,92E+10	1,79E+10	4,50E+07	1,15E+06	16,12	2,02
2015	1,98E+10	1,84E+10	4,52E+07	1,21E+06	17,06	2,14
2020	1,59E+10	1,48E+10	3,44E+07	1,14E+06	13,76	1,73
2030 Nuclear	3,47E+09	3,18E+09	6,17E+06	5,06E+05	1,46	0,18
2030 Nuclear + RES	5,69E+09	5,19E+09	1,29E+07	7,02E+05	3,07	0,39
2030 Combination	1,72E+10	1,59E+10	3,97E+07	1,23E+06	14,60	1,83

Difference of the two calculation methods, whether the upstream and down stream processes emissions are included, are e.g. 2007 1,8 million tonnes of CO_2 equivalents. That is about 9,4 percent rise from the emission level of only production emissions. Figure 7.13 shows the results from in graph form from the table 7.11.

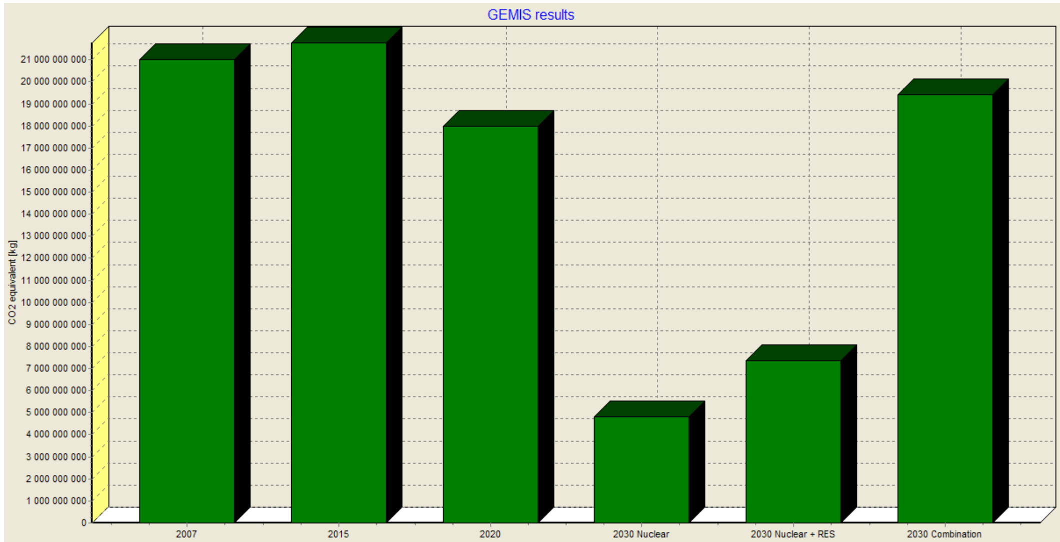

Figure 7.13 Results of CO_2 equivalent calculations from GEMIS when waste treatment, mobile transport and construction are included

Regardless of the calculation method similarities can be seen in the scale of emissions from the 2030 scenarios. Nuclear and Nuclear + RES models prove to be the least GHG emitting models, thought the Combination models GHG emissions exceeds the emissions from 2020. Tables 7.13 and 7.14 describe the airborne emission from the power generation models.

Table 7.13 Airborne emissions from the models calculated by GEMIS including waste treatment, mobile transport and construction

Option	TOPP equivalent [kg]	SO2 equivalent [kg]	SO2 [kg]	NOx [kg]	HCl [kg]	Particulates [kg]	NMVOC [kg]
2007	6,20E+07	5,97E+07	2,52E+07	4,68E+07	1,88E+06	3,66E+06	2,16E+06
2015	6,57E+07	6,32E+07	2,66E+07	4,96E+07	2,02E+06	3,84E+06	2,24E+06
2020	6,81E+07	6,48E+07	2,65E+07	5,19E+07	2,24E+06	3,76E+06	2,13E+06
2030 Nuclear	4,43E+07	3,98E+07	1,46E+07	3,40E+07	1,56E+06	2,19E+06	1,22E+06
2030 Nuclear + RES	5,66E+07	4,98E+07	1,76E+07	4,34E+07	1,92E+06	2,56E+06	1,59E+06
2030 Combi-nation	7,27E+07	6,60E+07	2,53E+07	5,53E+07	2,24E+06	3,54E+06	2,31E+06

There are no differences between the calculation methods in the order of the models, but there are differences in the amount of emissions. For example, the difference between the two calculation methods in 2007 models are 9,1 thousand tonnes of $TOPP_{eq}$. With airborne emissions Nuclear and Nuclear + RES model are the least harmful gases emitting models and the Combination model exceeds all. Worth noticing is that 2007 airborne emissions are less than in 2015 and 2020 even with the difference of almost 10 % RES share, 2020 RES share 38 % compared with 2007 approximate 28 % share.

Table 7.14 Airborne emissions from the models calculated by GEMIS including waste treatment, mobile transport and construction

Option	TOPP equivalent [kg]	SO2 equivalent [kg]	SO2 [kg]	NOx [kg]	HCl [kg]	Particulates [kg]	NMVOC [kg]
2007	5,26E+07	4,82E+07	1,85E+07	4,02E+07	1,66E+06	2,14E+06	1,67E+06
2015	5,53E+07	5,08E+07	1,95E+07	4,25E+07	1,78E+06	2,20E+06	1,70E+06
2020	5,76E+07	5,33E+07	2,02E+07	4,47E+07	2,05E+06	2,18E+06	1,55E+06
2030 Nuclear	3,80E+07	3,50E+07	1,26E+07	3,00E+07	1,53E+06	1,34E+06	8,40E+05
2030 Nuclear + RES	4,86E+07	4,33E+07	1,48E+07	3,83E+07	1,87E+06	1,50E+06	1,10E+06
2030 Combi-nation	6,12E+07	5,36E+07	1,85E+07	4,75E+07	2,04E+06	1,83E+06	1,67E+06

Figure 7.14 displays the airborne emissions as SO_2 equivalent from the energy models with waste treatment, mobile transport and construction included.

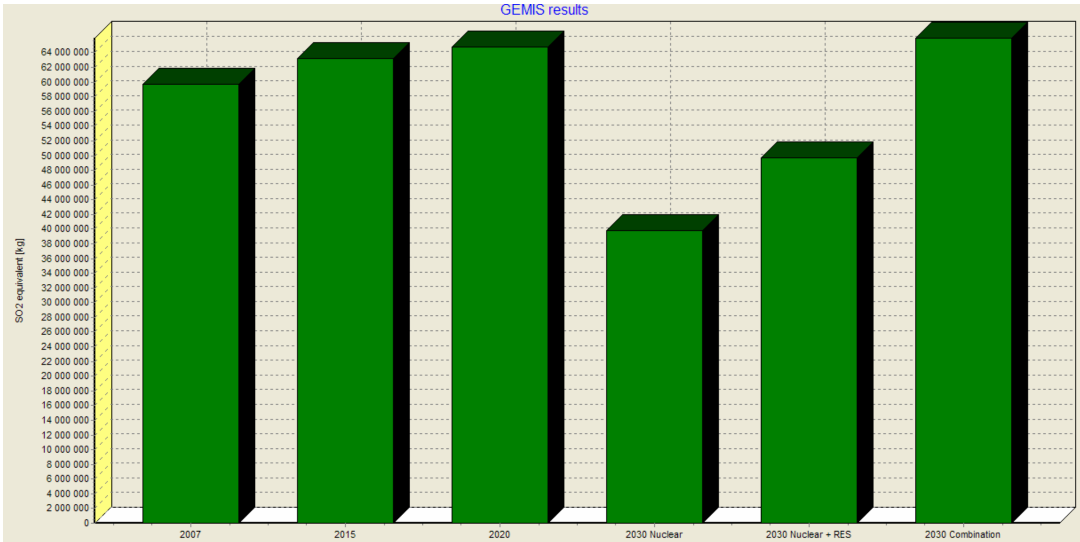

Figure 7.14 Airborne emissions from energy models

Noticeable from the airborne emissions results is the fact that even though the CO_2 equivalent emissions have gone down in 2020 compared with the amount of 2007 and 2015, but the airborne emissions have gone up significantly. This is caused by the high airborne emissions coming from wood product-based energy production. Combination models airborne emissions surpass the emissions coming from the other models.

7.6.4 Economic aspects

GEMIS displays the costs from processes by giving out following costs:

- Internal costs: Sum of capital costs, fixed costs, variable costs and fuel/input cost.
- External costs: Costs of emissions i.e. nuclear waste-fuel, SO_2, NO_x, particulates, $CO_{2,eq}$
- Investment costs: Investment costs from power plants
- Variable costs. Internal costs / produced energy

Table 7.15 below shows costs of energy production models calculated with all up and down stream process costs included. Table 7.16 shows the costs when other processes are not included.

Table 7.15 Division of costs in different models into categories, including waste treatment, mobile transport and construction

Costs **Option**	**Internal costs [€]**	**External Costs [€]**	**Internal + external costs [€]**	**Invest costs [€]**	**Variable costs [€/MWh]**
2007	6,58E+09	1,05E+09	7,63E+09	2,93E+10	84,88731
2015	7,39E+09	1,35E+09	8,74E+09	3,36E+10	77,23626
2020	7,99E+09	1,25E+09	9,25E+09	3,61E+10	79,34686
2030 Nuclear	7,68E+09	1,52E+09	9,19E+09	4,03E+10	67,44069
2030 Nuclear + RES	8,30E+09	1,34E+09	9,65E+09	4,03E+10	73,00584
2030 Combination	8,65E+09	1,43E+09	1,01E+10	3,88E+10	75,90262

Table 7.16 Division of costs in different models into categories, excluding waste treatment, mobile transport and construction

Costs **Option**	**Internal costs [€]**	**External Costs [€]**	**Internal + external costs [€]**	**Invest costs [€]**	**Variable costs [€/MWh]**
2007	6,54E+09	9,71E+08	7,51E+09	2,93E+10	8,45E+01
2015	7,36E+09	1,26E+09	8,62E+09	3,36E+10	7,68E+01
2020	7,94E+09	1,17E+09	9,11E+09	3,61E+10	7,89E+01
2030 Nuclear	7,63E+09	1,47E+09	9,10E+09	4,03E+10	6,71E+01
2030 Nuclear + RES	8,25E+09	1,28E+09	9,53E+09	4,03E+10	7,25E+01
2030 Combination	8,59E+09	1,34E+09	9,93E+09	3,88E+10	7,54E+01

Regardless of the calculation method, the total costs grow evenly until year 2020. Nuclear scenario of 2030 is slightly cheaper than the 2020 model, but the nuclear + RES and the combination models are more expensive. External costs resulting from emissions and waste management are highest with the nuclear model, but the low fuel costs lower the total costs still to its favour. The most expensive model is the Combination model with high internal cost, and external costs also exceed just below costs of nuclear model. Figure 7.15 displays the internal and external costs in a graph.

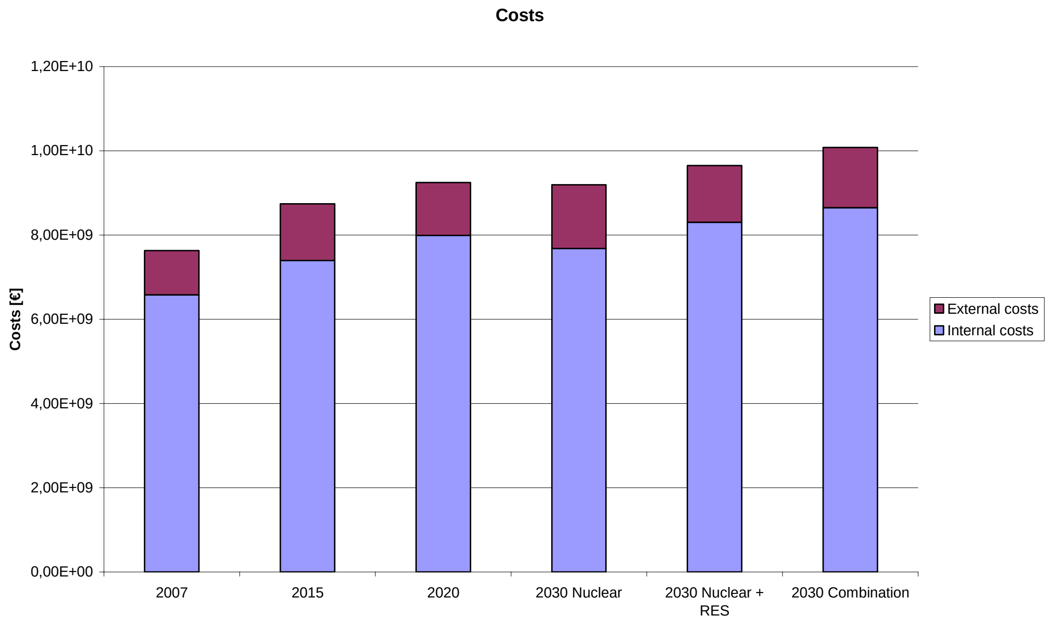

Figure 7.15 External and Internal costs of models

Inspection of investment costs alone show how the high capital costs of nuclear power raise the investment costs of Nuclear model high, but in truth with more accurate inspection, can be noticed that the investment costs are the highest with Nuclear and RES mode by 30 million € higher than Nuclear model. Figure 7.16 below shows a graph of the investment costs.

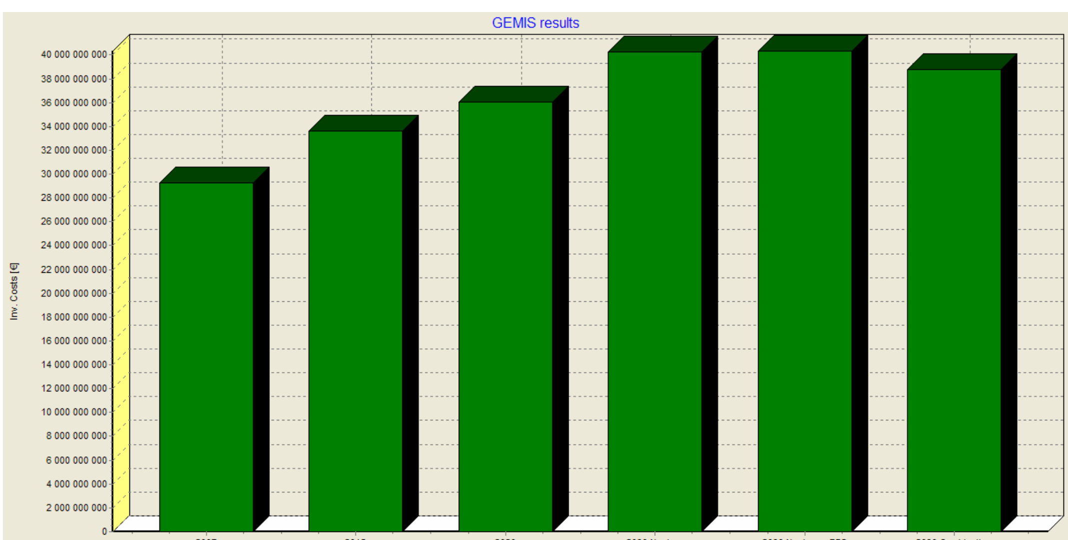

Figure 7.16 Investment costs of energy models

By dividing the internal cost with the total energy produced can be seen the costs per energy. Figure 7.17 displays the specific costs € per MWh.

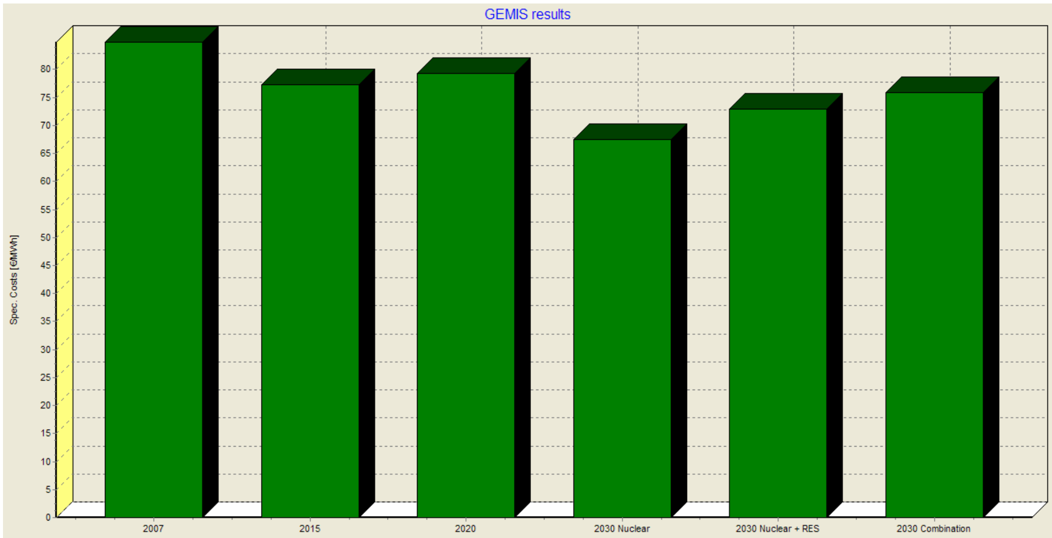

Figure 7.17 Specific costs of energy models [€/MWh]

Specific costs show a decrease each time more nuclear power has been added. 2007 model shows the highest specific costs due to the large share of energy production with high fuel price. In 2007 fossil-fuel based power caused the high specific costs and after decrease in 2015, the 2020 model shows another increase with added biomass production. All 2030 scenarios have lower specific costs compared with 2007, 2015 or 2020.

7.6.5 Capacity

Energy provided by the energy models will be practically adequate to satisfy the energy demand by year 2030 with all the scenarios. On the other hand, capacity for peak load needs is not enough. In previous studies, it has been mentioned that wind power's capacity substitution is practically zero. This means that during peak-loads it is not certain if wind power will be available. Especially in Finland's case this might be quite true, due to the fact that peak loads usually occur during high degrees of frost, when there is not much wind. In Pöyry Energy's research was used amount of 6 % of wind power during peak load, and the same is used here. Figure 7.18 describes the capacities of the models and the demand of capacity.

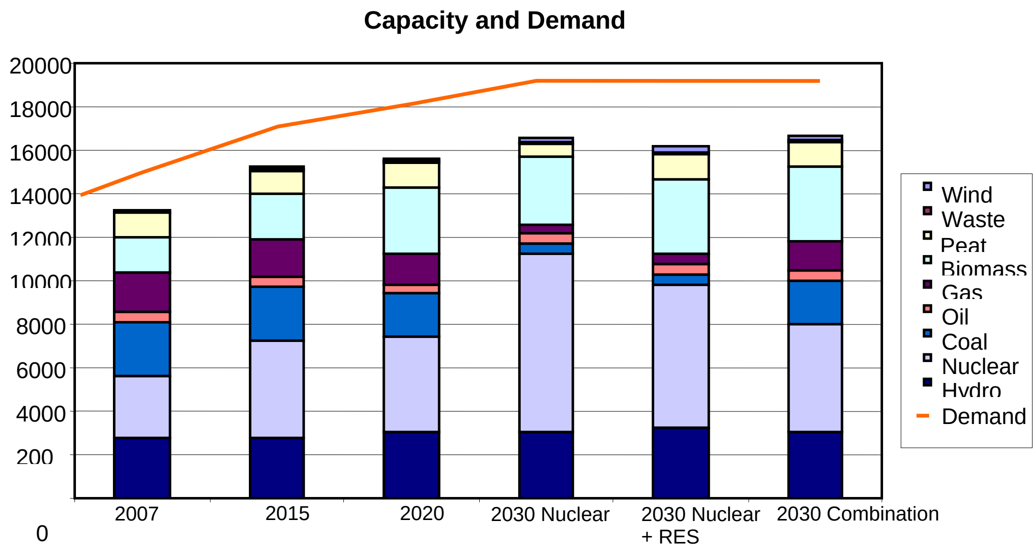

Figure 7.18 Peak capacity and demand when 6 % wind is available, [MW]

Capacity need becomes smaller in 2015 with the new nuclear reactor, but after decommissioning of several condensing plants by year 2020 and 2030 the peak load capacity need grows. As table 7.2 showed, Finland's importing capacity is 4240 MW, which is more than enough to supply that capacity need, but it does not solve the problem of being self-sufficient regarding power supply. Capacity need, in theory, could be supplied with wind power, but due to wind powers intermittency availability of the capacity is not certain. Full capacity from hydropower is not either guaranteed due to seasonality of hydro power capacity. Table 7.17 describes the peak load capacity need in different models with 6 % of wind capacity but full hydro capacity.

Table 7.17 Total peak load capacity need in models

	2007 [MW]	2015 [MW]	2020 [MW]	2030 Nuclear [MW]	2030 Nuclear + RES [MW]	2030 Combination [MW]
Capacity need	1784	1770	2365	2445	2855	2315

Peak load capacity need requires still more investments on power capacity even if the energy need would be satisfied, if imported energy is not desired or if it is not available. Investment on power reserves will come with high price especially in case of Nuclear + RES model where the capacity need is almost 3000 MW. The type of reserve power depends on the duration of peak loads. With longer duration time it is reasonable to invest on coal condensing plants rather then fast gas turbine plants.

8 Conclusions

Objective of this thesis was to clarify environmental and energy policies at present and what are the technological and economical backgrounds for the direction that energy politics have taken. First part of this thesis went through the legislative framework in place concerning environmental effects from power generation, described power generation technologies in use as well as their means of causing environmental impacts and examined the relationship between world economy and environmental impacts. Second part of this thesis formulated an example computation for environmental effects from alternative power generation possibilities in future in Finland.

At present political acts and public opinion is to lower GHG emission by building more RES power supply, even though switching from fossil fuel sources to renewable sources brings extra costs. At the present energy fuel prices changing to renewable sources will raise the electricity prices. Comparing energy price between energy produced with nuclear and wind, the factor is 2 - 3. In some cases additional drawbacks from RES appear from the nature of being intermittent, so they are not suited for base power production, and they are highly dependent on its location. RES are usually best suited for extra-power production, but in most cases they can't be calculated as extra-capacity.

The relationship between environment and world economics goes both ways and the effects can be seen on both side in the long run. Weather or not the effects of climate change will be 1,4 – 5 °C temperature increase and whether that will cause 5 - 20 % fall on GDP of the world can be argued, but in any case environment will cause damage both to the world economy and energy industry unless changes are made towards more sustainable power production structure.

The example computation was made for this thesis with GEMIS (Global Emissions Model for Integrated Systems) program to form scenarios for Finland's power generation until year 2030. GEMIS uses Life-Cycle Assessment method for calculating environmental effects from integrated systems. Scenarios were made in accordance with Finland's possibility to add certain generation types and also with Finland's commitment for improving energy efficiency, increasing share of renewable energy sources use and decreasing emissions.

The results of the calculations presented in this thesis are not exact and the models can not fully describe the different technologies characteristics in fuel consumptions and emissions being emitted. Furthermore the costs of power plants construction or operation are not exact and costs of different emissions and releases can not be perfectly valued. Nevertheless, the results shown by the GEMIS life-cycle analysis are indicative to the true scale of results and conclusions can be made in that respect.

Some assumptions made in this computation can also be argued, but from the results can be made estimates for other alternative energy model for the future. For instance the 2015 model shows an increase in emissions and 2020 shows an emission decrease at the cost of electricity price, which will most likely rise due to higher production costs. Both of these “faults” might be possible to correct by keeping the amount of imported energy the same and by lowering the amount of energy produced with fossil-fuel sources or other production types with higher marginal costs.

The scenarios for 2030 have also disputable issues. It has been assumed that the future technologies used in the new power plants have higher efficiencies and lower emissions than the existing power plants. CCS has not been added. CCS would lower the emissions from the Combination-model from the part of new plants and it could be possible to add CCS to the old plants in all of the models lowering the emissions from other models also. Emission levels from Combination model would most likely be similar to emissions from Nuclear + RES-model, but the costs would grow even higher, caused by lowering of efficiencies and rise capital and operating costs. CCS was not included for the calculation due to lack of data.

Another possibility for changes in energy modelling is the possibility that the energy demand would not increase. With stable demand of 90 TWh from 2007, the need for new capacity would only be directed at substituting power plants that are coming obsolete and for substitution of imported energy. Emissions coming from energy production can be lowered by changing into renewable energy sources or low-carbon energy sources. Right course of action is not clear. RES guarantees continuous energy supply but with high cost, intermittent power supply and possible effects on prices of other commodities e.g. effect cultivation of biomass and bio-fuel on food prices. Nuclear power brings big supply of cheap energy, but it has its waste handling requirements among other issues.

Seemingly best choice would be the Nuclear + RES model where there would be continuous support for RES yet still energy production with decent price would be ensured by large quantity of new nuclear power. Further need for large quantity of cheap energy in Finland comes when last two older BWR reactors are decommissioned, which will happen in following decade after 2030. As the coal resources are still abundant in close future, further development and inauguration of CCS technologies would be beneficial. Nuclear + RES-model also would require addition of hydropower, which would mean further examination of environmental laws in place.

All of the energy models would still require additional reserve capacity. Peak load capacity needs grow from 2007 steadily and none of the models can satisfy the capacity need. Capacity would be in all of the models enough if full wind and hydro power could be accounted for peak load capacity needs. Capacity need requires further investment on reserve power plants or in Nuclear-models case retaining coal and gas power for reserve purposes.

For countering the challenges of emission reduction would be best to concentrate on all low-carbon emitting power production technologies, such as nuclear power, as well as to promote and make more cost-effective the use of emission reducing technologies such as CCS. Concentration on promoting only RES technologies is not beneficial for power systems operation and it raises the energy prices unnecessarily while it is still possible to produce cheap base power. Change will have to be made gradually so that all possible low-carbon power production is used while it is still available. Future will bring new challenges with depletion of fossil fuels and Uranium-235. Solution may be found in IV generation nuclear reactors and possibly fusion technology, while many RES technologies (e.g. solar, wave and geothermal) have to also become more mature for lowering the energy price.

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ANNEX I

EU legal acts

General overview

- Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora
- Regulation No 1980/2000 on a revised Community eco-label award scheme
- Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market
- Regulation No 761/2001 allowing voluntary participation by organisations in a
- Community eco-management and audit scheme (EMAS)
- Directive 2002/49/EC relating to the assessment and management of environmental noise

Environmental permitting and integrated environmental protection

- Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment (as amended by Directive 97/11/EC)
- Directive 96/61/EC on integrated pollution prevention and control
- Directive 96/82/EC on the control of major-accident hazards involving dangerous substances
- Directive 2000/76/EC on the incineration of waste
- Commission Decision 2000/479EC on the implementation of a European Pollutant
- Emission Register (EPER) according to Article 15 of Council Directive 96/61/EC concerning integrated pollution prevention and control (IPPC)
- Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment

Air protection

- Directive 96/62/EC on ambient air quality assessment and management
- Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations
- Directive 1999/30/EC relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air
- Directive 1999/32/EC relating to a reduction in the sulphur content of certain liquid fuels
- Directive 2000/69/EC relating to limit values for benzene and carbon monoxide in ambient air
- Directive 2001/80/EC on the limitation of emission of certain pollutants into the air from large combustion plants
- Directive 2001/81/EC on national emission ceilings for certain atmospheric pollutants
- Directive 2002/3/EC relating to ozone in ambient air

Water protection

- 2000/60/EC establishing a framework for Community Action in the field of water policy
- Decision 2455/2001/EC establishing the list of priority substances in the field of water policy

Waste management legislation

- Directive 75/439/EEC on the disposal of waste oil
- Directive 75/442/EEC on waste (later amended by Directive 91/156/EEC)
- Directive 91/689/EEC on hazardous waste
- Council Regulation 259/93/EC on supervision and control of shipments of waste within, into and out of the European Community
- Directive 96/59/EC on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCBs/PCTs)
- Directive 99/31/EC on the landfill of waste
- Commission Decision 2000/532/EC establishing a list of wastes (as amended by Commission decision 2001/118/EC)
- Council Decision 2003/33/EC establishing criteria and procedures for the acceptance of waste at landfills

Other formal EU documents

- Green Paper COM(2001)68 on integrated product policy
- Communication COM(2001)580 on the implementation of the first phase of the European Climate Change Programme
- Decision No 1600/2002/EC laying down the Sixth Community Environment Action Programme.
- COM(2002)304 Amended proposal for a Directive concerning rules for the internal markets in electricity and natural gas
- Communication COM(2002)412 on Environmental Agreements at Community Level
- Within the Framework of the Action Plan on the Simplification and Improvement of the Regulatory Environment
- COM(2002)415 Proposal for a Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market

ANNEX II

	EMAS	ISO/EN ISO 14001
Status	Under legal bases (EU Member States and EEA countries). Regulation of the European Parliament and the Council under public law	Under no legal bases. (International: world wide) ISO standard under private law
Organisation	Entity to be registered shall not exceed the boundaries of the Member State, and it is intended to go towards entities and sites	Does not go towards entities or sites
Environmental policy	Included commitment to continual improvement of environmental performance of the organisation	Does not include a commitment to the continual improvement of environmental performance but of the performance of the system
Initial environmental review	Obligatory preliminary review, when is the first time that the organisation sets its environmental status	Initial review is recommended, but not required
Environmental aspects	Identification and evaluation of the environmental aspects (direct and indirect). Establishment of criteria for assessing the significance of the environmental aspects	Required only a procedure able to identify environmental aspects
Legal compliance	Obligatory to demonstrate it. Required full legal compliance. _ere is a compliance-audit	Only commitment to comply with applicable legal requirements. _ere is no compliance-audit
External communication	Open dialogue with the public. Public Environmental Statement (validated for verifiers)	Not open dialogue with the public. Only is required to respond to relevant communication from external interested parts. Control by public is not possible
Continual improvement	Required annual improvement	Required periodically improvement without a defined frequency
Management review	Is wider and requires an evaluation of the environmental performance of the organization, based in a performance-audit	Required an environmental performance in the management, but not through a performance audit
Contractors and suppliers	Required influence over contractors and suppliers	Relevant procedures are communicated to contractors and suppliers
Employees involvement	Active involvement of employees and their representatives	No
Internal environmental auditing	Includes: system-audit, a performance-audit (= evaluation of environmental performance) and an environmental compliance-audit (= determination of legal compliance)	Included only system audit against the requirements of the standard
Auditor	Required the independence of the auditor	Advised the independence of the auditor
Audits	Check for improvement of environmental performance. Frequency required: 3 year cycle during which all areas are verified at least once	Check environmental system performance. No frequency required
External verification	Accredited environmental verifiers	No
Verification/Certification Scope	Verifiers accredited according to NACE codes	Certifiers accredited according to EAC code
Authorities are informed	Obligation by Validation of Environmental Statement	No obligation
Logo	Yes	No