MSc Program
Renewable Energy in Central & Eastern Europe

Investment Needs for Electricity Generation from Renewable Energy Sources in Austria

A Master's Thesis submitted for the degree of

"Master of Science"

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Affidavit

I, **Terry Werner Hlawna,** hereby declare

1. that I am the sole author of the present Master Thesis, "Investment Needs for Electricity Generation from Renewable Energy Sources in Austria", 130 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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I. Abstract

Energy consumption is the main cause for greenhouse gas emissions, which need an active mitigation in the coming decades. Industrial countries, like Austria, have assumed responsibility by sharing international endeavors, like the Kyoto protocol and the EU 2020 targets. Austria already has one of the highest shares of renewable sources in electricity generation, of which the main part is produced by hydropower. The basic idea of this master thesis is to determine the investments needed to increase the share of renewable power, up to a full replacement of the fossil plant park until 2030.

The analysis starts with the structure of primary energy sources as the traditional transformation input for the electricity system. For reshaping the Austrian electricity system, the future development of electricity demand is estimated, which depends not only on the growth of real GDP but also on possible shifts in final energy consumption towards a higher share of electricity. For covering the growing electricity demand, the potentials from renewable sources are examined and defined. For the case of Austria, the focus of the analysis lies on hydro, biomass, wind, and solar photovoltaic sources.

Many different factors are influencing the costs of electricity generation. Thus, for determining the investment needs, it is necessary to answer the question of economic feasibility of an on-going transition to renewable power technologies. Only if the cost gaps are closed by adequate support mechanisms, e.g. feed-in tariffs, the investments will take place in real life. The structure and efficiency of such policy instruments is a pre-condition for the transition to renewable electricity, but not part of this paper.

In the scenario model developed and used in this paper, the power generation gaps are determined upon different trend paths of electricity demand growth, combining its outcome with the successive reduction of fossil power over the next twenty years. The investments needed are calculated by using specific investment costs of renewable power technologies, which until 2030 decline according to the technological progress rates.

To summarize the abstract, the author of this master's thesis intends to answer the following main questions:

- What is the range of the future development of electricity demand?
- What are the key factors of influence for the transition to renewable power generation?

- What are the investments needed until 2030 for a renewable electricity system in Austria?

The author's motivation to address these questions origins from his confidence that Austria is one of the few countries in the world that can proof the feasibility - economically and technically - of an electricity system based on renewables, and hereby demonstrates to the world the possible solution of the looming climate and energy problems. The author, himself being employed by a large international banking group, hopes that his results and conclusions may convince many financiers and investors that the transition to a renewable electricity system opens up large business potentials with relatively low risks.

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1 Executive summary

Like other industrialized countries, Austria enjoys a high level of energy consumption. Energy intensity, per unit of GDP as well as per capita of population, is aimed for stabilization by the Austrian government. The Austrian energy strategy intends to keep final energy consumption on a constant level until 2020 by implementing measures and policies for improved energy efficiency.

The author agrees with the key objective to improve energy intensity, but merely achieving a demand stabilization means that a change in the final energy mix also is necessary to mitigate the greenhouse gas emissions. Austria by now is lagging behind the fulfillment of its climate change obligations. The domestic efforts to reduce greenhouse gases are so far not sufficient, especially in the field of new renewable energies like wind and solar, the time for more action has come.

The basic idea of this master's thesis is to demonstrate that the share of renewable energy can be increased by using domestic potentials for clean power generation. An active policy for more electricity in the final energy use, combined with a maximum share of renewable power sources, is the best way to reduce substantially the carbon footprint of Austria. The scenario model shows that a continuation of the historic average growth rate of electricity consumption over the next two decades is possible, which means that many energy applications have to be shifted to the electricity sector.

The cost of electricity from renewable sources is declining, because of the learning effect of new technologies during market diffusion. Also technological risks decrease with wide spread implementation and growing standardization. Conventional power plants on the other hand could become more expensive because of surging fossil fuel prices and internalization of carbon costs. Financiers and investors could soon reconsider risk margins and discount rates in favor of capital-intensive renewable power installation because of higher predictability of the project parameters.

In the author's calculation and scenario model, the relevant factors of influence are combined with possible electricity demand paths. The core result is that in addition to the growing demand for electricity, it is possible to replace successively the existing, ageing fossil plant park. Obviously, the realization of such a strategy depends on the legal and subsidy framework for the time being, when grid parity of renewable power generation still is not fully achieved. The cost sensitivity analysis demonstrates that in the optimal constellation of the different input parameters, high attractiveness and profitability of renewable power soon is reached.

The investment volumes needed for the transition to a renewable electricity system are higher than for prolonging the status-quo. The main reason is that variable fuel costs for operating are substituted by initial capital costs. Using a growing share of renewable sources, the development of electricity prices is more predictable than depending on highly volatile market prices for fossil commodities. Thus, renewable power generation offers to the financial industry and private investors a large potential of low-risk business - in all customer segments and along the whole value chain of renewable power technologies.

For electricity generation in Austria, the main results of the calculation and scenario model are:

- LCOE development: The cost-competitiveness of renewable electricity depends on the speed of technological learning in combination with the price development on primary energy markets, including carbon emission certificates. The LCOE of hydropower remains on the low end of power generation costs (down from 37 to 35 €/MWh by 2030). Wind power LCOE decline from 59 €/MWh to a level close to hydropower by 2020 (50 €/MWh), only slightly falling afterwards due to its already far advanced status by then. LCOE of solar PV is quickly decreasing from 247 €/MWh in 2010, approaching a level of 156 €/MWh by 2020, and afterwards further declining to 112 €/MWh until 2030, due to continued fast growth of global cumulative production. High cost uncertainties are related to biomass plants, because its fuel prices tend to fluctuate with fossil fuel prices. Under the assumption of increasing fossil prices, the LCOE of electricity production by biomass, excluding revenues from co-generated heat, goes up from 138 €/MWh in 2008 to 180 €/MWh by the year 2030.

- Power generation gaps: The yearly power generation gaps result from continued demand growth, depending on the electricity consumption scenarios. Gross final electricity demand grows from 69.2 TWh in 2008, to a range from 78 to 88 TWh in 2020, and afterwards to 86 to 107 TWh in 2030. Without replacement of fossil power plants the annual electricity gaps, which have to be filled by new generation capacities, grow to 0.8 - 1.7 TWh until 2020, and to 0.9 -2.1 TWh until 2030. For replacing the fossil plants until 2030, an additional power generation gap of approximately 0.9 TWh must be covered on average per year.

- Plant capacities needed: The additional plant capacities needed are calculated by using the technology-specific average load factors. Biomass power generation has the highest capacity utilization during one calendar year, and solar PV the lowest.

The overall capacity needed per unit electricity output changes over the years, because the share of solar PV is steadily growing, and after using up other renewable sources, mainly solar potentials are left over. Capacity figures per type of technology are necessary for calculating the investments needed, but due to the different load factors, they are not a meaningful indicator.

- Investment costs (in 2009 real prices): The investments needed, covering the expected growth of electricity demand, are calculated for five-year periods and range, depending on the different scenarios, from 2.5 to 6.3 billon € in the period 2011-15, up to a range from 3.2 to 9.7 billion € in the period 2026-30. For additionally replacing the fossil plant park, the investments needed are significantly higher, because the share of solar PV, which has the highest specific investment costs, grows more quickly over the years to come. In the last five-year period (2026-30), the investments needed range from 5.8 to as much as 25.9 billion €. This high amount on the top end is a consequence of by then largely developed hydro, wind, and biomass potentials, which happens in the scenario variation of high electricity demand growth combined with full replacement of fossil plants. In such a constellation, only solar PV would remain for additional renewable installations in Austria.

The scenario model is based on literature from different sources showing a wide range of data for the relevant parameters of influence. Thus, the results derived for Austria must be considered as uncertain to some degree. The scenario model could be enhanced by using empirical data, e.g. for specific investment costs, which was not available for this paper. In addition, the estimation of potentials depends on many assumptions, which in reality likely diverge from long-term materialization of the input parameters.

2 Introduction

Austria is one of the wealthiest countries in the world, and the energy system is functioning in a nearly perfect manner. Due to the abundance of rivers and forests, the share of renewable energy sources is higher than in most other countries in the EU and in the rest of the world. In the field of electricity generation, Austria is one of the leading countries in using renewable sources. Nevertheless, there is also much room for further enhancement because the overall share of renewable energies in gross energy consumption is still less than 30 per cent.

The master thesis will start with an overview of the worldwide efforts and targets aiming to reduce greenhouse gas emissions, which are now broadly acknowledged of being the main cause of dangerous warming processes. The most developed countries of the world, including Austria, together have contributed by far the largest share to the existing stock of greenhouse gases in the atmosphere. The high GDP level in these countries depends on a high level of energy input, and rather small improvements in the energy intensity of the GDP are not coping with the surging energy consumption.

In the second chapter, the electricity generating system is described by analyzing the flow and transformation of energy from primary sources to final electricity use. The analysis starts with the global supply and demand structure, briefly describes the key elements of the electricity system, and focuses on the future development of energy needed and its share of electricity demand. For all developments analyzed, specifically the situation and development in Austria is of interest as the fundament and input for the scenario model in the chapter afterwards. The final section in this chapter deals with the renewable sources for electricity generation and which volume of it is available in Austria.

After outlining and reshaping the electricity system, the key factors influencing the future investment needs for renewable electricity generation are analyzed and determined. The underlying notion is that 100% electricity generation from renewable sources is possible, but the willingness to do so depends on a certain perimeter of influencing factors. These parameters are entered into a calculation model for deriving the levelized costs of electricity. The cost results of the various renewable power technologies will be compared to their fossil peers in a sensitivity analysis over the time horizon from now until 2030.

The set-up scenario model then combines three possible trend paths depicted for the future electricity demand, which depend on different economical and political environments, with the successive replacement of fossil power plants in Austria. Over a period of 20 years, the additional electricity demand is summed up with the linearly reduced output of fossil power plants. Depending on the overall development of the power generation gaps, the volume and structure of renewable energy sources is defined for each year, upon which the investment costs per year are calculated.

The data used origins from various institutions and publications, as indicated in the tables, figures, and footnotes. Many figures had to be converted or recalculated, e.g. for the purpose of comparison, or for drafting chart, which is indicated on the figures and tables ("own calculations"). Generally, with only few exceptions, the energy unit used is a multiple of watt-hours (kWh, MWh, GWh, TWh), and the cost figures are shown in real € values of 2009.

3 Objectives mitigating greenhouse gas emissions

3.1 Energy demand causing climate risks

3.1.1 Climate change

The infrared radiation given off by the Earth’s surface carries energy away through the atmosphere. A part of this radiation gets absorbed by greenhouse gas molecules, such as carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O). The atmosphere itself radiates the infrared heat in all directions, so a part of the infrared heat is reflected downwards and leads to the warming effect in the atmosphere. It is obvious that the more greenhouse gas molecules are concentrated in the atmosphere the higher the warming will be.

Today it is known that the ranges of infrared wavelengths absorbed by carbon dioxide and methane are different to that of water vapor. ‘As a result, the effect of carbon dioxide and methane is not overwhelmed by water vapor, and both are important absorbers of the Earth’s infrared radiation all by themselves. Methane, which molecule for molecule is a much stronger absorber of infrared radiation than is water vapor or carbon dioxide, does not last for extended times in the atmosphere because it is much more chemically active. Carbon dioxide lasts a lot longer in the atmosphere because it is much more chemically inert than methane.’[1]

From the years 1000 to 1800, the atmospheric CO_2 remained at a level of about 280 ppmv. Over hundreds of thousands of years, the CO_2 concentrations varied from just under 200 to about 300 ppmv. Over this long-time period, the temperature varied by about 10° Celsius. The temperatures closely corresponded to the carbon dioxide levels in the atmosphere. In 2008, the CO_2 level was about 386 ppmv and it is increasing at a rate of over 1.4 ppmv per year for the time being. ‘Clear and conclusive results from the analysis of trapped air and ice extracted from cores taken from the deep inside glaciers show that the level of CO_2 in the air is now about one-third higher than it has been for more than 800.000 years (…).’ [2]

In 2005, CO_2 and CH_4 exceeded by far the natural range of greenhouse gases over the last 650,000 years. The global increase of carbon dioxide is due primarily to fossil fuel use, with land-use change providing another high contribution. The observed increase in methane is predominantly due to agriculture and fossil fuel use. There is very high

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[1] Cocks (2009), p. 29

[2] Cocks (2009), p. 32 seq.

confidence that the global average net effect of human activities since 1750 has been one of warming, states the IFCC in its most recent report on climate change.[3]

'Global average surface temperatures during the last three decades have been progressively warmer than all earlier decades, making 2000-09 (the 2000s) the warmest decade in the instrumental record. The 2000s were also the warmest decade on record in the lower troposphere, being about 0.6°C warmer than the 1960s and 0.2°C warmer than the 1990s. The decadal warming has been particularly apparent in the mid- and high-latitude regions of the Northern Hemisphere. Globally averaged surface temperature anomalies are shown to be robust given the close agreement between independently derived datasets and strong corroborative evidence across a wide range of other climate variables.'[4]

The decadal temperature anomalies compared to the 1961-1990 global average temperature are shown in following figure:

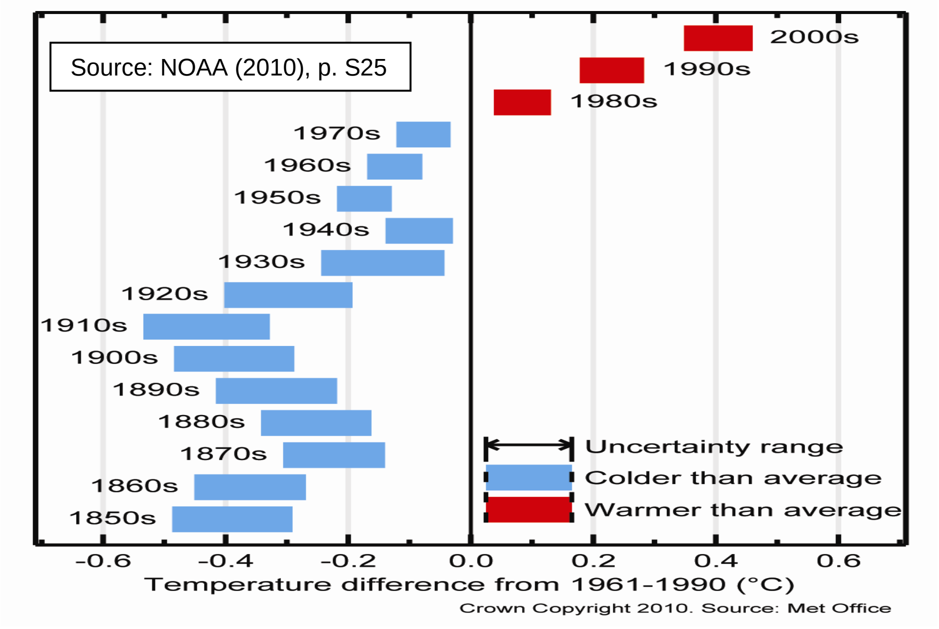

Figure 1: 95% confidence range of decadal average temperatures

At present, the CO_2 level is further increasing at a speed never seen before in the historical record, and this increase is accelerating. ‘Even if the rate of growth could be moderated enough to stabilize the atmospheric level at about 550 ppmv, the resulting temperature rise could be in the range of about 2-5°C. If the warming oceans begin to yield back to the air even a small fraction of the dissolved CO_2 they contain, or if seabed

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[3] IPCC (2007), p. 37

[4] NAOO (2010), p. S19

solid methane hydrates begin to decompose, the resulting increase in global temperature might become uncontrollable.'[5]

Global emissions from 2000 to 2010 will account for roughly 500 billion tones of CO_2 equivalents. Scientists have executed a large number of scenarios in the last couple of years concluding that greenhouse gas emissions could accumulate to roughly 2000 billion tonnes of CO_2 equivalents between the year 2000 to 2050, in order to have a 50% chance to meet the target of maximum 2°C temperature increase. A reduction of these cumulative emissions to a maximum of 1500 billion tonnes of CO_2 equivalents would increase the probability to stay below 2°C to 75%. Every year at current emissions of roughly 50 billion tonnes of CO_2 equivalents consumes a significant share of the available amount until 2050.[6]

Four generic options for global emission pathways consistent with the 2°C limit are available which all require urgent deviation from the current reference development:

- Immediate action pathway: Global emissions peaking as soon as 2011 and then decline at 6% per year (2°C limit is met with a 75% chance)
- Accelerated action pathway: Later peaking in global emissions (2013), decline of 10% per year later in the century (also meets the 2°C limit with a 75% chance)
- Steady decline pathway: Slower decline of emissions by 3% per year (2°C limit with probability decreased to 50%)
- Guardrail pathway: Peaking delayed until 2017, steep reductions as large as 8% per year necessary (to meet 2°C limit with a 50% chance)

'The annual reductions required to meet the pathways are ambitious. Achieving steep reduction rates would possibly require early retirement of capital invested in present technologies. It would also require fast market introduction of new technologies. Delaying the year when global emissions peak would lead to even more ambitious reduction rates. It would also narrow the options to adjust the pathway once new scientific information becomes available.'[7]

About 65% of all greenhouse-gas emissions are related to energy supply and energy use. The worldwide rising demand for mainly high-carbon energy runs directly counter to the

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[5] Cocks (2009), p. 33 seq.

[6] ECOFYS (2009), p. 8

[7] ECOFYS (2009), p. 9

emissions reductions required to prevent dangerous climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that reductions of 50% to 85% in global CO_2 emissions compared to 2000 levels will need to be achieved by 2050 to limit the long-term global mean temperature rise to 2.0°C to 2.4°C. However, recent studies have already suggested that an only 50% reduction in global CO_2 emissions by 2050 may not be enough to avoid dangerous temperature increases.[8]

3.1.2 Kaya Identity

The future CO_2 concentration levels in the atmosphere can be estimated by using the so-called Kaya Identity. In general, the rate at which carbon is emitted (as carbon dioxide) is given by this formula:[9]

$$C = N * (GDP/N) * (E/GDP) * (C/E)$$

C	Carbon emissions
N	Population number
GDP	Gross domestic product, in real terms
E	Primary energy consumption

The carbon emissions are expressed as the product of population (N), per capita gross domestic product (GDP/N), primary energy intensity (E/GDP), and carbon intensity (C/E). Primary energy consumption is expressed as the total burn rate from all fuel sources and the gross domestic product in real terms. Carbon intensity is the weighted average of the carbon-to-energy emission factors of all energy sources.

To forecast the growth of the world's population is only possible in a short to mid-term horizon. In general, it is assumed that the growth rate of population slows down and levels off at a higher amount in the future. The second term in the equation is the GDP per capita that originally was expressed in 1990 U.S. dollars. The energy intensity is the amount of primary energy required to produce a dollar of GDP reflecting the energy efficiency of the economy determined also by the industrial structure making up the GDP, e.g. light versus heavy industries and the overall share of the service sector. The last term is the carbon efficiency expressing the amount of carbon depending on the used energy sources.

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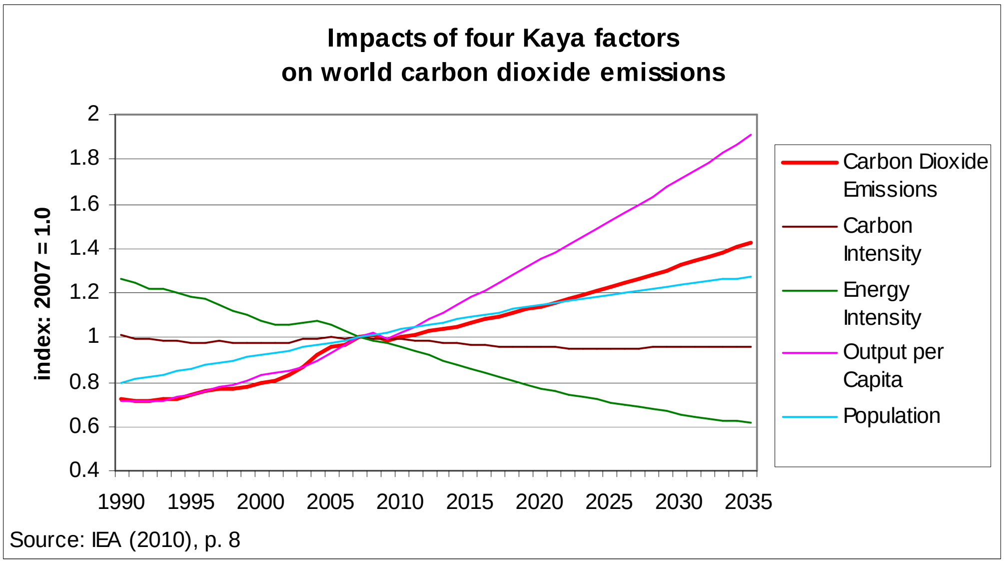
[8] IEA/ETP (2010), p. 61 seq.

[9] Hoffert (1998), p. 882

All four factors used in the Kaya Identity formula have a significant degree of uncertainty leading to a broad range of long-term projections of future carbon emissions from energy consumption. Policymakers today are most actively concerned with the energy intensity of the economy and carbon intensity of energy, which are more readily affected by the policy levers available to them for reducing greenhouse gas emissions. In the Reference case of the International Energy Outlook 2010 by the EIA, assuming no new climate policies, worldwide increases in output per capita and relatively moderate population growth overwhelm the projected improvements in energy intensity and carbon intensity.[10]


Impacts of four Kaya factors
on world carbon dioxide emissions

Source: IEA (2010), p. 8

Figure 2: Impact of four Kaya factors on world carbon dioxide emissions

In the chart shown above, the influence of the four Kaya components on the development of carbon emissions is drafted until the year 2035. For the Reference case of the International Energy Outlook 2010 a steep increase of carbon emissions is predicted mainly caused by the globally growing GDP output per capita which by far cannot be compensated by improvements in the energy intensity dramatically showing the huge need for strong and fast reductions of the carbon intensity in the world's energy system.[11]

3.1.3 Economic growth

The level of energy consumption is strongly related to the development state of an economy. Energy consumption per person is obviously much lower in less developed countries than in the industrialized countries. The high GDP growth rates in many of the threshold countries cause strongly increasing demand for energy. But also in the highly industrialized parts one of the core political goals is a continued real growth of the GDP.

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[10] EIA (2010), p. 7 seq.

[11] EIA (2010), p. 8

Up till now, no solution was found to de-couple the GDP growth from that of energy. The main factor of influence for energy demand in the manufacturing and services sectors is the overall economic development. For private households, the development of the population and the stock of apartments is the most representative indicator for energy demand changes.[12]

For Austria, the forecasted growth of real GDP lies between 1.3 and 2.1 percent for the years 2010, 2011 and 2012.[13] In a long-term projection, drafted before the start of the recent economic crisis, the real GDP growth was forecasted in the range from 2.0 to 2.2 per cent per year until 2020.[14] The Austrian government has established an energy efficiency goal in its energy strategy by defining an energy consumption target for the year 2020. This target is fixed at 1.100 PJ and it lies a little below the 2005 base value. This target compares to a relative energy saving of about 200 PJ in means of improved energy intensity.[15] But it also shows that due to the higher population and a higher GDP per capita, no absolute reduction of energy consumption will be achieved until 2020.

Economic growth in a country is also influenced by the growth of its population. That's why the GDP is input to the Kaya Identity as a per capita ratio. A real GDP growth per capita, e.g. in threshold countries, combined with an increased population, the inevitable consequence is strong rising energy demand assuming that energy intensity has remained on the same level. For industrialized, e.g. Austria, the issue of population growth is of less importance for energy projections in comparison with developing countries, where the population grows faster and builds an important factor of influence for the future energy demand.

Because of the growths of population and economic output, world energy demand continues to rise by about 60% until 2030, of which two thirds take place in developing countries. The share of developing countries will rise from about one third in 2000 to almost half of global energy demand in 2030. However, energy demand per capita will remain on much lower levels in developing countries consuming just 1.2 toe per capita compared to 6.4 toe in the industrialized countries.[16]

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[12] Kratena (2005), p. 12

[13] OeNB (2010), p. 17

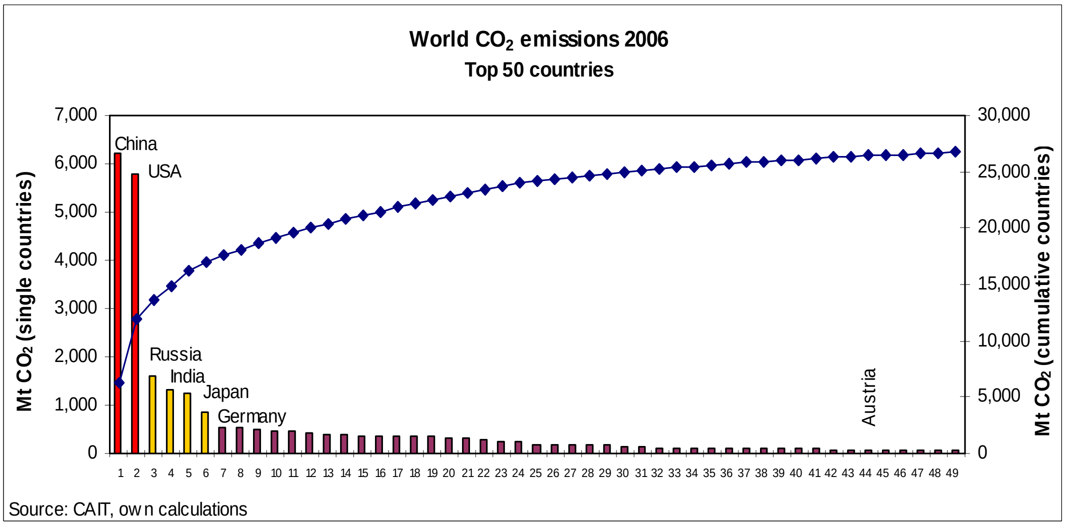
[14] Kratena (2005), p. 17

[15] BMWFJ (2009), p. 9

[16] EWI (2005), p. 14

3.1.4 Greenhouse gas emissions

The member states of the European Union are obliged to submit individual greenhouse gas inventories to the UNFCCC and to the EEA. The EEA compiles an aggregated inventory for the EU-15 countries, which were member states of the EU when the Kyoto protocol was signed; and it also aggregates the figures for all EU-27 countries as well as for all 32 EEA member states. The emission inventories include the following greenhouse gases: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); sulphur hexafluoride (SF_6); hydro fluorocarbons (HFC), and perfluorocarbons (PFC). Each greenhouse gas has a different capacity to cause global warming. The global warming potential (GWP) of each greenhouse gas is defined in relation to a given weight of carbon dioxide and for a set time period. The GWP factors are used to convert emissions of other greenhouse gases into CO_2 equivalents – making it possible to compare the potential effects of different gases.[17]



Source: CAIT, own calculations

Figure 3: World CO2 emission of top 50 countries, 2006

The chart above shows the world-wide distribution of absolute CO_2 emissions, which in total amounted to 28.4 Gt in 2006. Total CO_2 emissions of EU-27 member states were 4.1 Gt, a share of 14.5% in the world. Five countries plus EU-27 are responsible for as much as 71% of global CO_2 emissions. This huge share demands for a strong leadership role of these countries establishing a stringent governance model for the necessary mitigation of GHG emissions.

The main source of greenhouse gas emissions in the EU-27 is fuel combustion and fugitive emissions. Throughout the period 1990 to 2007, fuel combustion and fugitive

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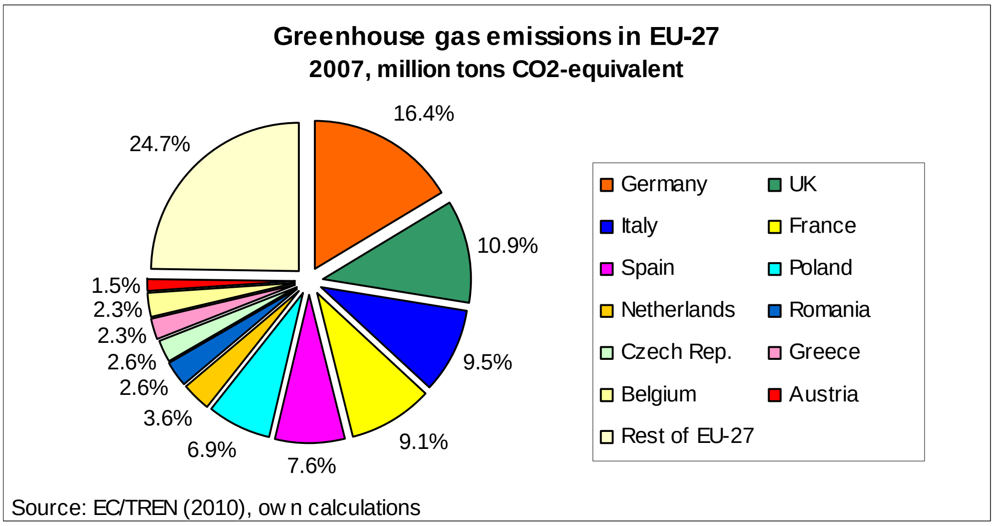
[17] Eurostat (2009), p. 16 seq.

emissions accounted for between 77 % and 80 % of all EU-27 greenhouse gas emissions. ‘Emissions resulting from fuel combustion (…) come from two principal sources: oil and gas-fired power stations generating electricity (which are estimated to have accounted for almost one third of all greenhouse gas emissions), and road transportation, which includes the use of cars and collective passenger road transport, as well as freight transport (which accounted for almost one fifth of all emissions).’[18]

In the European Union, total greenhouse gas emissions were 5.045 Gt CO_2 equivalents in the year 2007.[19] The split-up by member states is shown in the following figure:



Source: EC/TREN (2010), own calculations

Figure 4: Greenhouse gas emissions in EU-27, 2007

Emission intensity is generally measured as the level of greenhouse gas emissions per unit of GDP (economic output). The GDP data for this indicator are presented in terms of purchasing power standards (PPS), thereby removing distortions that result from differences in price levels between countries. There is particular interest in this relationship from a sustainable development perspective, in order to analyze whether greenhouse gas emissions can be decoupled from economic growth, in other words, to ascertain in what way environmental pressures are linked to economic growth.

The emission intensity, measured as the ratio of greenhouse gas emissions per unit of GDP, has fallen across most developed economies in recent decades reflecting reductions in energy intensity and changes in the energy mix. ‘Post-industrialization has seen developed economies move away from ‘heavy’ industries to focus on technology and service sectors, and as a result their wealth creation is increasingly decoupled from energy-intensive inputs. For example, some of the countries with the highest standards of

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[18] Eurostat (2010), p. 22

[19] EC/TREN (2010)

living in Europe (as measured by GDP per capita) are found at or near the bottom of the ranking of greenhouse gas emissions per unit of GDP.'[20]

In Austria total GHG emissions, excluding land-use change and forestry, amounted to 86.6 Mt CO_2 equivalents in 2008 and increased by 10.8% compared to the base year 1990. Carbon dioxide contributed 85% to the total national GHG emissions, followed by CH_4 and N_2O each of them accounting for about a 6.6% share of total CO_2 equivalents in 2008. The energy sector caused 74.7% of the total GHG emissions followed by industrial processes (13.7%), agriculture (8.8%), waste (2.3%) and solvents (0.4%). GHG emissions from the energy sector increased by 16.8% from 55.4 million tons CO_2 equivalents in 1990 to 64.7 million tons CO_2 equivalents in 2008, which was mainly caused by increasing emissions from transport.[21]

3.1.5 Mitigation efforts

In order to stabilize the concentration of greenhouse gases in the atmosphere, yearly emission levels need to peak soon and to decline thereafter. The lower the stabilization level headed for, the sooner annual GHG emissions have to reach its historical maximum. The mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels. Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilization. Stabilizing greenhouse gas emissions at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.

In the following table, the key data of the IPCC scenarios about the emission and temperature levels are summarized:[22]

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[20] Eurostat (2010), p. 30

[21] UBA (2010), p. 16 seqq.

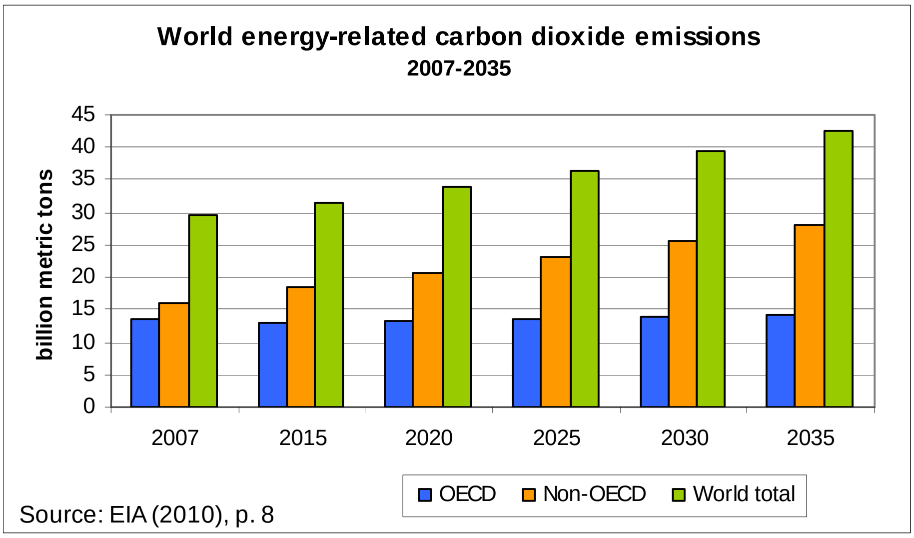
[22] IPCC (2007), p. 66 seq.

Table 1: Characteristics of emission stabilization scenarios by IPCC

CO_2 level at stabilization	**CO_2-equivalent at stabilization**	**Peaking year CO_2 emissions**	**CO_2 emissions 2000 to 2050**	**Average temperature rise**	**Average sea level rise**
ppm	ppm	year	%	°C	metres
350 - 400	445 - 490	2000 - 15	- 85 to - 50	2.0 - 2.4	0.4 - 1.4
400 - 440	490 - 535	2000 - 20	- 60 to - 30	2.4 - 2.8	0.5 - 1.7
440 - 485	535 - 590	2010 - 30	- 30 to + 5	2.8 - 3.2	0.6 - 1.9
485 - 570	590 - 710	2020 - 60	+ 10 to + 60	3.2 - 4.0	0.6 - 2.4
570 - 660	710 - 855	2050 - 80	+ 25 to + 85	4.0 - 4.9	0.8 - 2.9
660 - 790	855 - 1130	2060 - 90	+ 90 to + 140	4.9 - 6.1	1.0 - 3.7

Source: IPCC (2007), p. 67

The table shows that for limiting the global average temperature rise to a range from two to 2.4 centigrade the time has almost run out, because the peaking of emissions needs to be at the latest in the year 2015. Knowing that higher temperature rises would lead to catastrophic impacts around the globe – e.g. rising sea levels, as shown in the table – any hesitation on implementing sufficient and powerful policies to reduce greenhouse gas emissions significantly is unacceptable. Moreover, the continuously growing consumption of fossil energy sources must be reigned in immediately.



Source: EIA (2010), p. 8

Figure 5: World energy related carbon dioxide emissions, 2007-35

The chart above shows that according to the Reference case of the International Energy Outlook 2010 by the EIA the world global CO_2 emissions could surge by almost 50 % even within the period until 2035.[23] In a rough comparison with the IPCC scenarios, such a “business-as-usual” trend would put the Earth onto the most dangerous scenario paths leading to temperature and sea level rises much higher than the widely accepted climate change goal of maximum 2°C.

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[23] EIA (2010), p. 8

From this brief overview on the relationship between economy, energy and emissions it obviously must be concluded that there certainly is no easy solution to climate change. As the Kaya Identity states clearly, global GHG emissions only can be reduced by lower energy intensity of the world economy combined with a minimized carbon intensity of the energy mix. On-going growth of global population and economic output per capita requires substantial improvements in energy and carbon intensities.

3.2 Climate change policies

3.2.1 Kyoto protocol

The Kyoto Protocol was established based on the UNFCCC, which was signed in 1992 and ratified by 194 countries by 2009. The Kyoto Protocol addresses six main greenhouse gases that are combined into a basket and accounted in terms of CO_2 equivalents. The reductions targets are generally measured against the base year of 1990. Under the terms of the Kyoto-Protocol, the developed countries pledged to reduce greenhouse gas (GHG) emissions by 5% below 1990 levels by the period 2008-2012. The European Union agreed on a reduction of 8% below 1990 levels during the five-year period from 2008 to 2012.[24]

The fulfillment of the national Kyoto target assignments by the EU member states is very heterogeneous. In an overall picture, the EU-15 member states have reduced the Kyoto base year emissions by 6.9 % until 2008, including the new member states a higher reduction of 14.5 % was realized. Especially the restructuring of heavy industries in Eastern Europe helped in the greenhouse gas abatement. The same is partly the case for Germany which is counted into EU-15 including East Germany. [25]

Only a few countries, like e.g. Italy, Spain, and Austria, are not positively contributing to the overall goal achievement. The following figures give an overview about the Kyoto target deviations by 2008:

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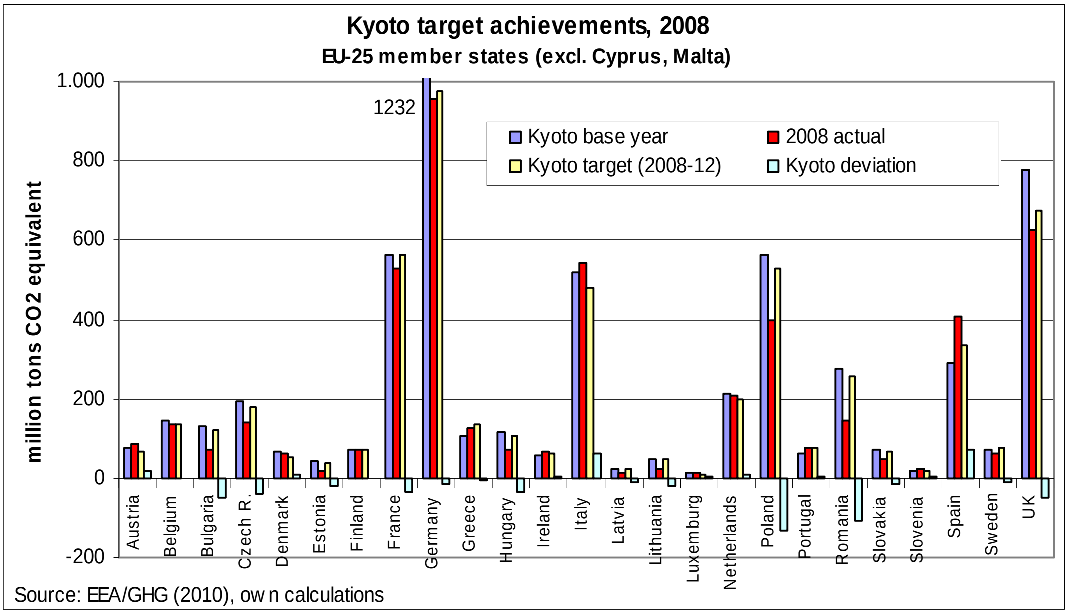
[24] Eurostat (2010), p. 11 seq.

[25] Eurotstat (2010), p. 27 seq.



Source: EEA/GHG (2010), own calculations

Figure 6: Kyoto target achievements, EU-25, 2008

For the time after 2012, a binding agreement for continued mitigating of greenhouse gas emissions has not been finalized and signed up to now. The main points for the further negotiations were included in the so-called Copenhagen Accord in December 2009:[26]

- recognition of a maximum 2°C global temperature increase
- provision of additional finance for developing countries to help combat the impacts of climate change
- reporting and monitoring of country-specific pledges of mitigation actions
- recognition that financial resources are required from developed countries to remove GHG by forests
- agreement on the possible use of carbon markets

3.2.2 EU targets

The European Union has committed itself to a set of climate change objectives reaching ahead of the Kyoto target time horizon. The main targets by 2020 are:[27]

- Cutting greenhouse gas emissions by 20%
- Increasing energy efficiency by 20%
- Using renewable energy sources by 20%

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[26] Eurostat (2010), p. 12 seq.

[27] UBA (2010a), p. 11 seq.

Reducing the current level of GHG emissions by 20 % from 2005 to 2020 is an ambitious target, though absolutely necessary. Since 1990, GHG emissions in the EU have declined only little, mostly resulting from restructuring of the heavy industrial sectors in the new member states in central and eastern member states.

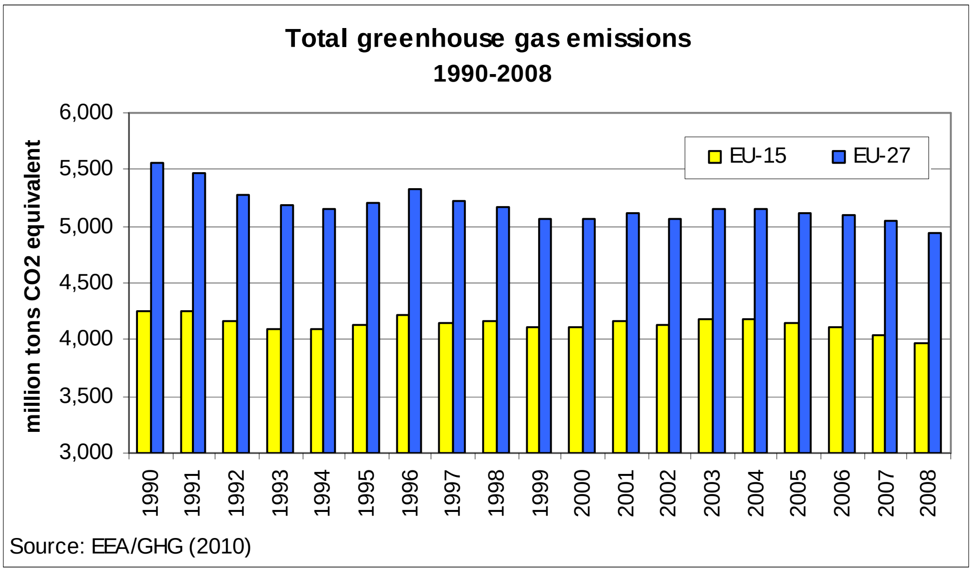

Figure 7: Total greenhouse gas emission in European Union, 1990-2008

A big impact for GHG mitigation is expected from improved energy efficiency. Three EU directives are determining the framework of energy efficiency improvement:

- Energy Performance of Buildings Directive (2002/91/EC), aiming for transparency of buildings' energy consumption
- Cogeneration Directive (2004/8/EC), aiming for combined heat and power production
- Energy Services Directive (2006/32/EC), aiming to foster energy service markets while requiring energy efficiency action plan form the EU member states

According to the Energy Savings Directive, the EU member states have to set an indicative 9% reduction target in end-use energy consumption by 2016, based on the average yearly consumption from 2001 to 2005. The mechanisms, the incentives, and the institutional, legal and financial frameworks to achieve this targets, must be documented in national energy efficiency action plans, as well as the conditions for the development and promotion of energy services markets.[28]

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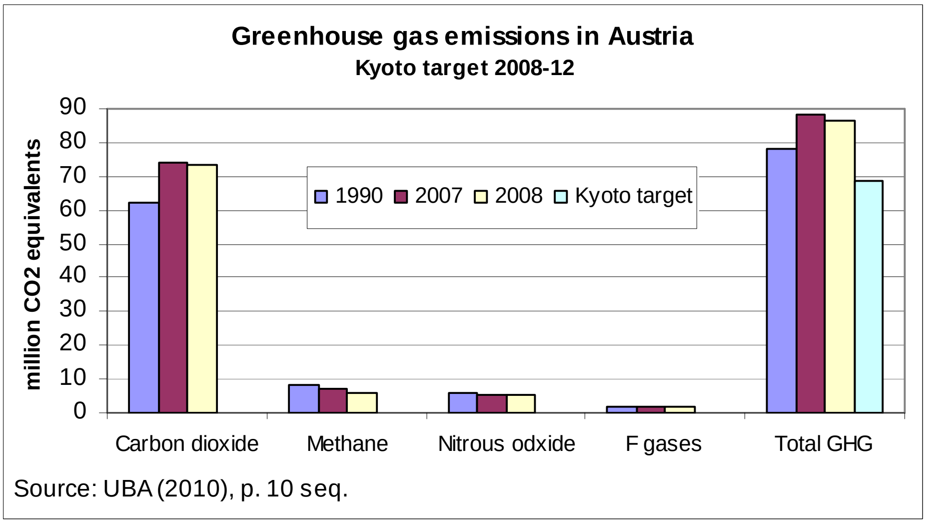
[28] EEW (2009), p.4

3.2.3 Austria's contribution

Under the burden sharing agreement of the European Union, each EU-15 member states agreed upon targets ranging from minus 28% to plus 27% depending on the countries' special circumstances. In the case of Austria, the target to reduce greenhouse gas emissions was set at minus 13% for the annual value of 2008-2012.[29]

The yearly maximum level of GHG emissions is 68.8 Mt CO_2 equivalents for the years 2008 to 2012; but in 2008, this goal by far was not reached. Considering emission trading as well as Joint Implementation and Clean Development Mechanism (JI/CDM) projects and the forestation balance, the remaining deviation from the target is 8.1 million tons of CO2 equivalents.[30]

Austria's GHG balance compared to the Kyoto target is shown in the following figure:[31]



Source: UBA (2010), p. 10 seq.

Figure 8: GHG emissions in Austria and Kyoto target 2008-12

In 2008, Austria's total greenhouse gas emissions (without LULUCF) amounted to 86.6 million tonnes of carbon dioxide equivalents, which is 10.9 % above the base year 1990.[32] About three thirds of the GHG emissions in Austria are caused by the energy sector that shows a plus of 17 % since 1990, mainly due to the strong growth of road transport. From 1990 to 2008, in the energy sector, the main drivers for GHG emissions were electricity generation (+26%) and heat production (+146%).[33]

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[29] UBA (2010), p. 10

[30] UBA (2010a), p. 11

[31] BMLFUW (2010), nop.

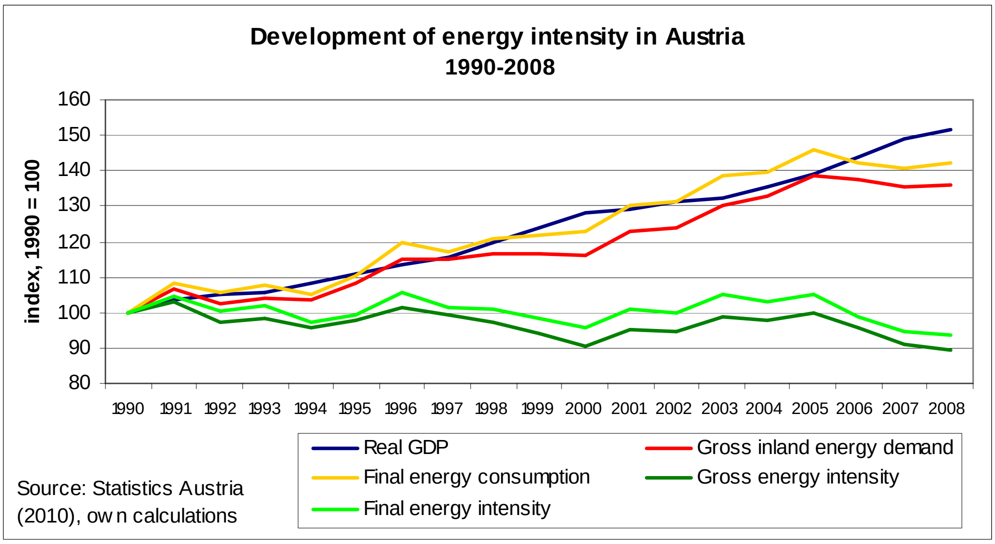
[32] UBA (2010), p. 10

[33] UBA (2010), p. 13

One of the core concepts to achieve the mitigation of GHG emissions is to improve energy efficiency. The target set by the EU is to save 20 % of the energy by the year 2020. According to the baseline scenario of energy demand in Austria, which evaluates all policies set up until 2005, an improvement of energy efficiency at the defined target level would not be achieved. The baseline scenario would lead to only 14 % improvement of the energy intensity. Under the assumptions of an improved scenario, including more ambitious energy savings policies, the 20 % target could be reached.[34]

The energy intensity in Austria was rising in the years from 1991 until 2005, when it reached its highest level since 1991: 5700 TJ per billion € GDP. This unfavorable development was caused by the higher rise of final energy consumption (plus 33 %) compared with only 26 % increase of the real GDP. This negative development of energy efficiency in Austria was caused by the strong growth of the services sector, where the energy intensity increased 63 % from 1995 to 2005.[35]

Since the year 1990, Austria's real GDP grew about 50 %, but energy intensity improved only less than 10%. This shows that until today the close linkage between GDP growth and energy consumption still largely exists, resulting in a continued surge of final energy consumption. The chart inserted below shows the development of energy intensity in Austria in the last two decades:


Development of energy intensity in Austria
1990-2008

Source: Statistics Austria (2010), own calculations

Figure 9: Development of energy intensity in Austria, 1990-2007

The actual Austrian government program aims for an improvement of energy intensity by at least 5 per cent until 2010, and by at least 20 % until 2010. One of the measures to be

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[34] AEA (2008), p. 5

[35] AEA (2008), p. 7

implemented is thermal renovation of buildings constructed between 1950 and 1980.[36] In accordance with the EU directive 2006/32/EC, the energy efficiency action plan was defined for Austria. Based on the mean energy consumption 2001-2005 (893.4 PJ), the national energy savings target is 9 % by 2016 (80.4 PJ). The intermediate target for 2010 is a consumption reduction of 2 % (17.9 PJ).[37]

Up until now, Austria is not fulfilling its climate target obligations. The continued increase in energy consumption combined with a slow progress in energy efficiency has put behind the country in the international rankings. Looking at the real developments in the past two decades, there is not much room for optimism about future contributions of energy efficiency objectives, though often repeated and promised by politicians to solve the climate and energy problem. Up until now, no evidence exists for huge energy savings will really occurring in Austria, which urgently would be needed to compensate for the continued growth of energy demand.

The recent economic downturn alleviated the non-compliance with climate change objectives, but in the future Austria needs an enhanced climate and energy strategy. Increasing the share of renewable energies must become one of the core policies, especially power generation from renewables sources. For example, the Austrian associations of renewable energy technologies are repeatedly calling for optimized framework conditions of renewable power generation:[38]

- quick definition of useful tariffs
- creation of suitable fostering policies
- new ecopower act (similar to Germany)
- optimal implementation of the EU RES directive
- improved framework conditions for grid integration
- optimization of approval procedures
- optimization and enforcement of agricultural energy production
- set-up and support of competent and independent advisory
- increased energy efficiency measures

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[36] BMWA (2007), p. 13

[37] BMWA (2007), p. 12

[38] PV Austria (2009), p. 14

4 Reshaping the electricity generation system

4.1 Primary energy sources

4.1.1 Fossil energy

In its physical definition energy is understood as the capacity to perform work. A quantity of energy can be assigned to any particle, object, or system of objects as a consequence of its physical state. In opposite to common use of language, energy can neither be produced nor consumed because it is subject to the law of energy conservation. Energy only can be transformed from one state into another. Types of energy are for example mechanical energy, heat energy, electrical energy and chemical energy. Concerning the primary energy supply, renewable and non-renewable sources are distinguished.

The present dependence on fossil energy sources is relatively new in human history. Both coal and oil were already known in antiquity, but were used only in small quantities at locations where they were easily accessible on the earth's surface. Wood remained the principal primary energy source until the late 18th century when the steady population growth had led to strong decrease of Europe's forests. The wood shortages led to broader use of coal, which before had been considered inferior to wood because of its worse air pollution. The higher energy-to-weight ratio made coal preferable for newly emerging manufacturing processes that set the stage for the industrial revolution. The industrial revolution led to widespread use of coal and to electricity generation beginning in the late 1800s, and coal has continued its role as an important primary energy source until today.[39]

Oil and natural gas are the other two predominant fossil energy sources. Overall, oil is the largest single primary energy source providing considerably more energy per unit than coal or gas. Oil has become the synonym for a non-sustainable energy system, which causes tremendous climate risks. 'It's ironic that the first successful oil well – in Pennsylvania – was drilled in 1859, the same year the great Irish scientist John Tyndall determined that CO_2 molecules intercept infrared radiation, a discovery that led to the science of global warming.'[40]

Natural gas seems to be a "better" fossil fuel compared with oil and coal, because a significantly lower amount of carbon dioxide is emitted when burnt. The main constituent of natural gas is methane, which contains just one carbon and four hydrogen atoms in one

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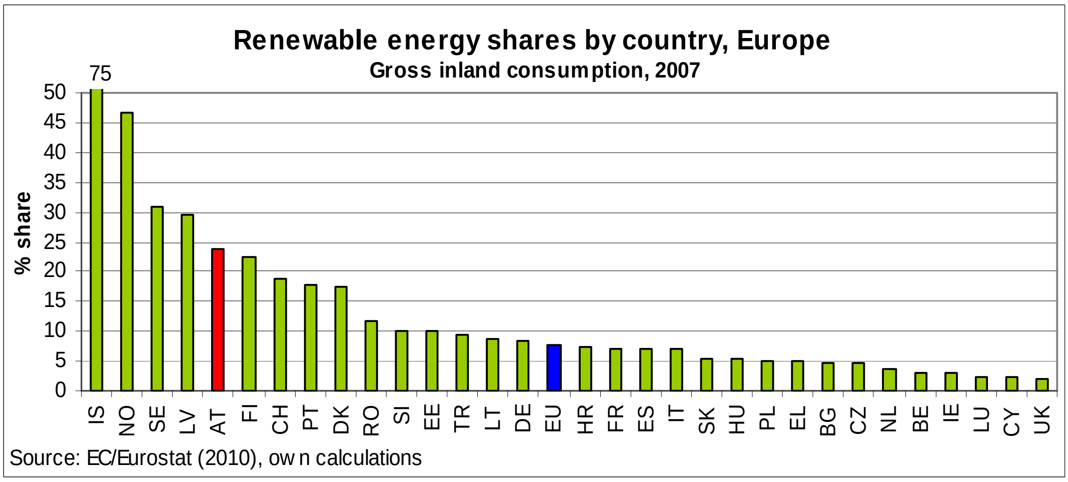
[39] Gore (2009), p. 52

[40] Gore (2009), p. 54

molecule. Unfortunately, in practice two to four per cent of the gas used leaks into the air before it is burnt, e.g. along the thousands of kilometres of pipelines, but also at production sites and in private homes. 'The problem with these escapes of methane is that this substance is twenty-four times more potent a greenhouse gas than carbon dioxide. Fortunately, it has a relatively short residence time in the air, and about 8 per cent of it oxidizes naturally each year. (…) If approximately 2 per cent of natural gas used each year leaks before burning, it causes over a period of twenty years a peak global warming equal to that of burning coal instead of natural gas (…). The claim that burning gas halves the emission of greenhouse gases for the same energy production as coal is therefore only true if there are no leaks anywhere, from the production source to the combustions chamber.'[41]

4.1.2 Renewables

The shares of renewable energy in gross inland consumption are ranging widely in Europe. The highest share of 75% has Island because of using its geothermal resources. In regions with large hydropower utilization, e.g. in the Alps and in Scandinavia, the renewable energy shares are above the European average, too. The figure below shows the ranking of European countries by renewable energy shares:



Source: EC/Eurostat (2010), own calculations

Figure 10: Renewable energy shares in Europe, gross inland consumption, 2007

The share of renewable energy sources in gross inland energy consumption has slowly increased over the last tow decades. Due to the fact that only in a few member states, e.g. Denmark, Germany, higher growth rates have been achieved, but others like France or Austria have been stagnating in its share, the overall EU renewables share was only around 8% in 2007. To reach the ambitious goal of 20% renewable energy in the EU,

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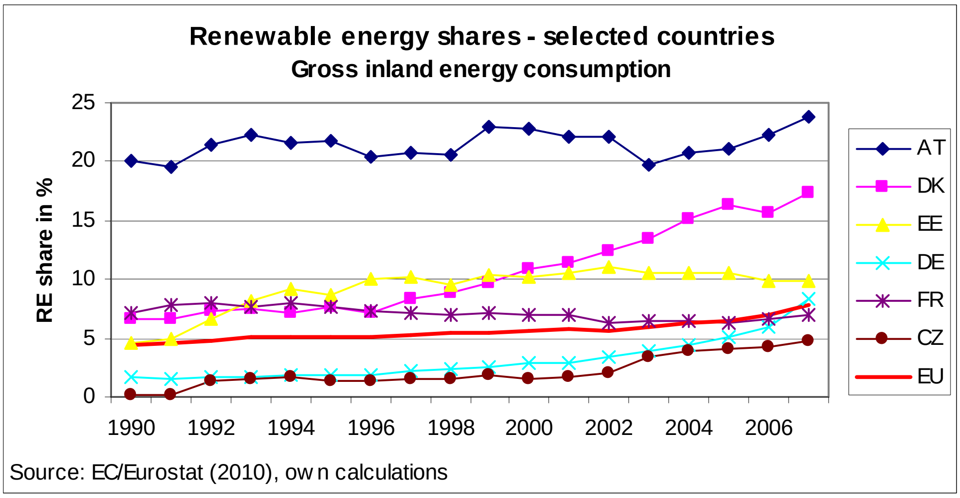
[41] Lovelock (2006), p. 74 seq.

stronger efforts than in the past are needed. Some countries have successfully demonstrated the high potential of renewable energy, as is shown in the following chart:



Source: EC/Eurostat (2010), own calculations

Figure 11: Shares of renewables in gross inland energy consumption, EU-25, selected countries, 1990-2007

Austria is one of the leading countries in means of renewable energy utilization, dominated by the use of hydropower and bio energy. In recent years, growing wind power generation helped to push up the renewable share to about 24%. Over the last 15 years, the most dynamic growth took place in Denmark, where the renewable share more than doubled, mainly because of strong expansion of wind power parks.

4.1.3 Energy dependency

Europe stands out as energy intensive region that is heavily reliant on fossil energy imports. Today about 54% of primary energy demand, possibly growing to 65% by 2030 is imported from other regions in the world. 57% of the natural gas and 82% of oil is imported; and these shares are expected to grow to 84% (gas) and 93% (oil) until 2030. The IEA predicts that global demand for oil will go up further, but also is uncertain about the ability and willingness of major producing countries to meet the rising demand, and raises doubts about the level of remaining reserves. 'The use of fossil fuel fired power plants exposes electricity consumers and society as a whole to the risk of volatile and unpredictable fuel prices. To make matters worse, government energy planners, the European Commission and the IEA have consistently been using energy models and cost-of-energy (COE) calculation methods that do not properly account for fuel and carbon price risks.'[42]

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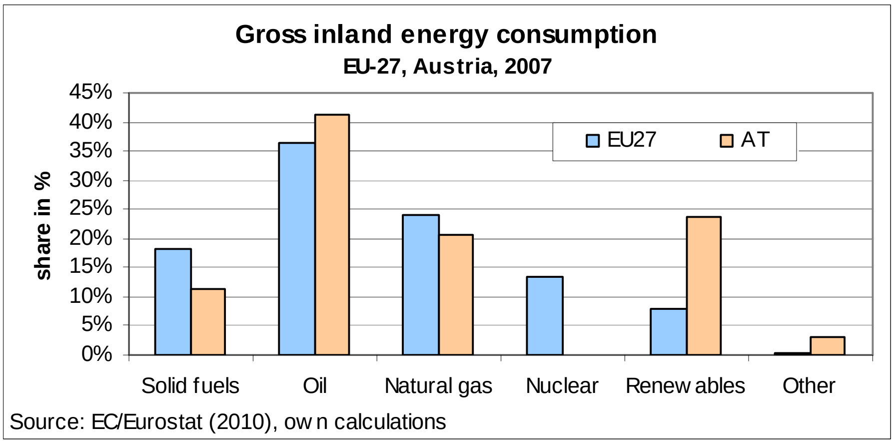
[42] Krohn (2009), p. 20

The following figure shows the shares of energy sources, which make up gross inland energy consumption in EU-27 and Austria:



Source: EC/Eurostat (2010), own calculations

Figure 12: Gross inland consumption, shares by energy source, EU-27 and Austria, 2007

Gross inland energy consumption rose by an average rate of 0.5 % per annum from 1990 to 2007. At present, the EU-27's economy depends upon imports by over 53%, fed by the opposing trends of lower indigenous primary energy production and increased energy demand. 'Given the scarcity and decline in European indigenous fossil fuel reserves, it would appear that any efforts to increase domestic production will need to be based on the promotion of low- or zero- carbon technologies in the EU's energy mix. These are primarily renewable energy sources (wind, solar, hydropower and biomass), while hydrogen may also play an important role in the energy mix in the more long-term future; an alternative would be to have nuclear energy as part of the energy mix. Any such changes in the EU's energy mix are likely to have a beneficial effect on greenhouse gas emissions.'[43]

Comprising the European OECD member states, total primary energy supply in Europe has increased only slightly since 2000. Oil accounts for more than one-third of primary energy needs. Coal, oil, hydro and nuclear leveled off or slightly declined between 2000 and 2007, whereas natural gas and renewables where showing growth rates. Renewables have grown, albeit from a low base, accounting for 9% of total primary energy supply in 2007. 'OECD Europe imports 45% of its coal supplies, mainly from Russia, South Africa, Colombia, and Australia. The increasing use of gas for power generation and increased gas use in industry and the residential sector have led to growth of almost three-quarters in natural gas consumption in OECD Europe between 1990 and 2007. (…) The United Kingdom, Germany, and Italy are the largest gas consumers, representing 51% of OECD Europe's consumption in 2007. Indigenous gas supplies met roughly half of all demand in

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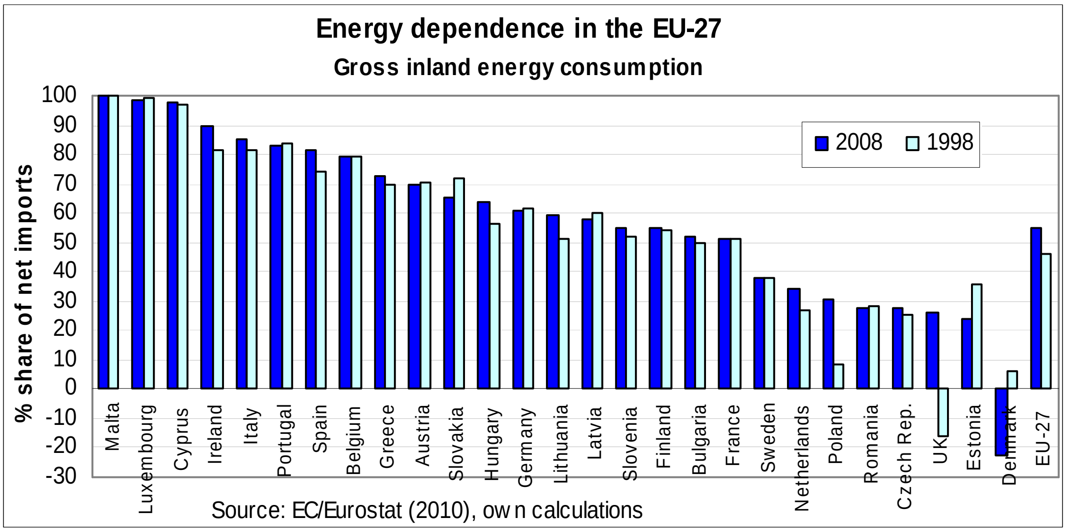
[43] Eurostat (2010), p. 48

2007. Imports from Russia and Algeria accounted for more than 70% of OECD Europe's gas imports. OECD Europe accounted for 17% of global oil demand in 2007. Nearly two-thirds of its petroleum demand was satisfied by imports, mainly from Russia, the Middle East, and Africa.'[44]

The dependence on energy imports is widely ranging, from below zero in Denmark to 100% on the island of Malta. Austria is energy dependent from imports nearly by 70%, what is well above the EU-27 average of around 55 % in 2008.[45] The figure below shows the changes of energy dependence in the EU-27 member states from 1998 to 2008:



Source: EC/Eurostat (2010), own calculations

Figure 13: Energy dependency of EU-27 and member states, 1998, and 2008

In Austria, energy import dependence has worsened over the last two decades, as is shown in the following chart:

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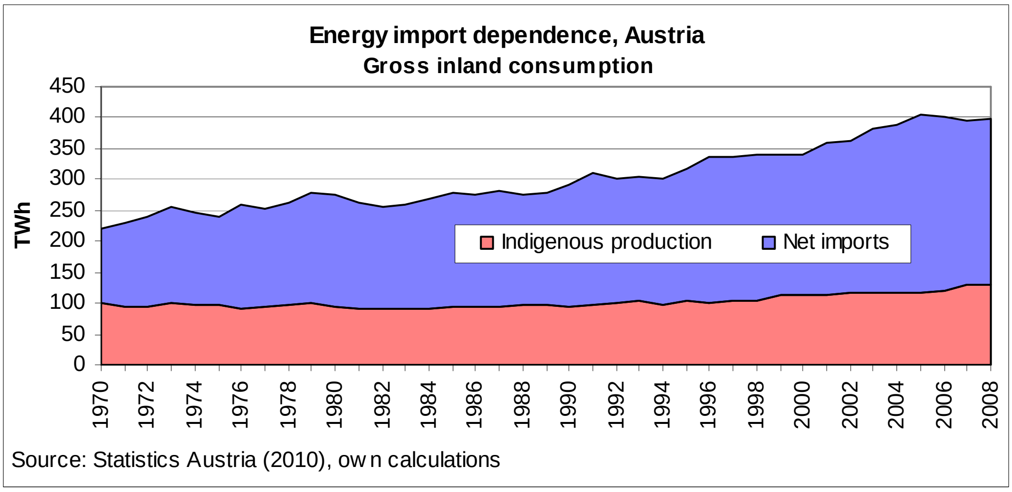
[44] IEA/ETP (2010), p. 299

[45] Eurostat (2010), p. 48

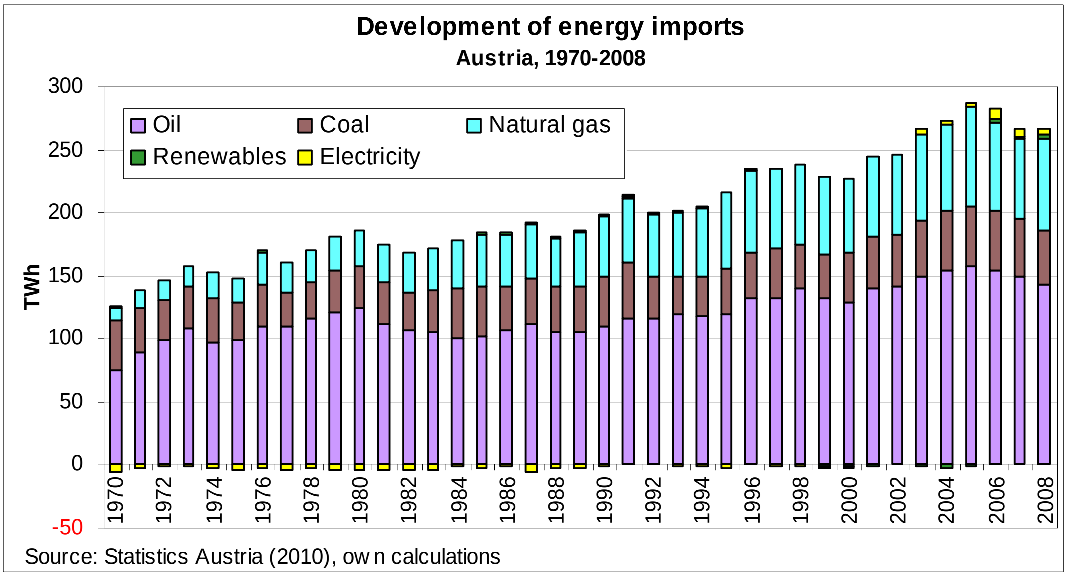


Source: Statistics Austria (2010), own calculations

Figure 14: Energy dependence of Austria, 1970-2008

From 1970 to 2008, gross inland consumption almost doubled in Austria. The strong increase in energy consumption led to a higher share of energy imports (net of stock changes), up from 54 % in 1970 reaching 67% in 2008, after it already spiked to 71% in 2005. Coal imports fluctuated over the years, but in absolute terms remained fairly on the same level. Coal's share in primary energy supply is now down to 11%, whereas oil and natural gas imports increased steadily over the decades; today they are at shares of 39% and 22%.

The structure of net energy imports, excluding changes in stock, by main sources is shown in the following figure:



Source: Statistics Austria (2010), own calculations

Figure 15: Development of energy imports in Austria, 1970-2008

In the last couple of years, Austria's energy dependency has entered a new stage. Austria now is not only dependent on foreign fossil, but also turned into a net electricity importer, different to its role for many years as electricity self-supplier, as can be seen in the following chart:

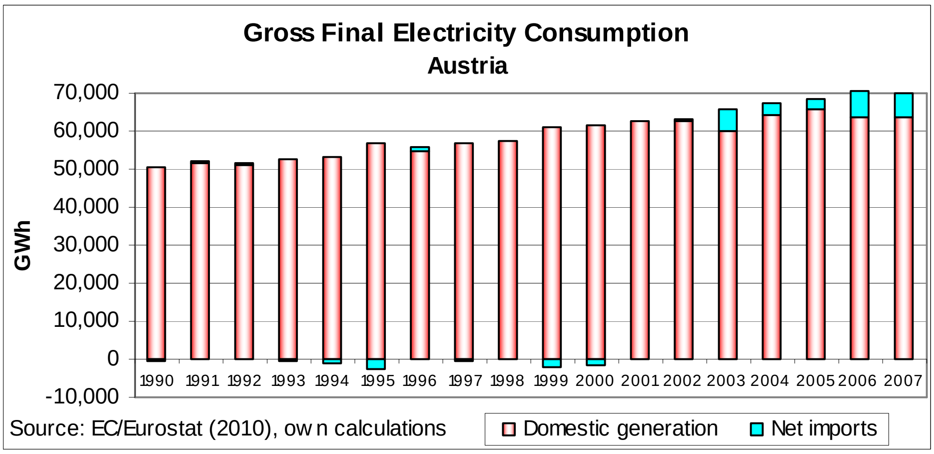


Figure 16: Gross final electricity consumption, domestic & net imports, Austria, 1990-2007

4.2 Electricity system

4.2.1 Energy transformation

Any form of primary energy available has the potential to be transformed into other types of energy, e.g. oil into gasoline, coal into heat, running or falling water into electricity. The efficiency of energy transformation depends on the technology used and the kind of input and output energy carriers. Non-thermal energy transformation is more efficient than thermal transformation processes, because by burning fuels, e.g. natural gas, a significant part of the energy is released to the environment and thus lost for final consumption.

Other than electricity, there are secondary energy commodities such as gasoline and diesel oil. Fossil energy carriers, which are derived from primary fossil sources, include a range of products that keep the potential of creating greenhouse gas emissions, in particular, following their combustion. During the transformation process, there is also the potential for emissions and air pollution, as many such processes require considerable heat in order to change the chemical and/or physical properties of material inputs for example.[46]

Electricity is an energy carrier that can be derived by transforming many kinds of primary energy sources such as coal, natural gas, wind, and sunlight. The main disadvantage of electricity is that about 40% of all electricity worldwide is produced by burning coal and about 20% by burning natural gas causing a big part of the carbon emission problem. The remainder of electricity comes mainly from hydro and nuclear power, and only small

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[46] Eurostat (2009), p. 51

amount origins from solar, wind, and geothermal, relatively new renewable energy sources that are expected to grow rapidly in the next quarter-century.[47]

‘Electricity generation is the single most important source of greenhouse gas emissions in the EU. The level of emissions from thermal power plants in the EU-27 fell slightly during the period from 1990 to 2007 largely as a result of changes in the fuel mix. The switching from coal to gas in the power generation sector was encouraged through the implementation of environmental legislation and the liberalisation of electricity markets, stimulating the use of combined-cycle gas plants; furthermore, natural gas prices were relatively low during most of the 1990’s in relation to the price of coal. These factors may help explain how the share of natural gas in EU-27 electricity generation rose by a factor of three between 1990 and 2007, helping to offset greenhouse gas emissions despite an increase in total electricity generation.’[48]

Electricity is the most important energy carrier for increased use of renewable energy sources in the future. A pre-condition for a transition to renewable power is that final energy use also is shifted away from fossil products, like e.g. gasoline and diesel, to increased electricity utilization, like e.g. in the transport sector. Electricity is a very convenient way of using energy in all fields of life and economy, so for the future the objective lies in a low-carbon, clean and sustainable electricity system from renewable energy sources.

4.2.2 Electricity sector

‘The electricity sector has seen significant changes in regulation over the last 20 years in many regions. Changes in the generation, transmission, distribution, and retail businesses have brought both positive and negative consequences. From a customer point of view, the introduction of competition into parts of the electricity value chain have brought new service offerings and driven down prices. From a generation point of view this process has allowed new entrants into the market, bringing new capital for investment both in conventional generation technologies and also in distributed technologies such as CHP and renewables.’[49]

'One can observe today the characteristics of the past, in particular in the EU's power sector, a centralised, nationally organised electricity supply system with ageing

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[47] Gore (2009), p. 55

[48] Eurostat (2009), p.54

[49] IEA/ETP (2010), p. 159

technologies and underdeveloped power markets. Still, more than 20 years after the Single European Act was signed (in 1986), the EU is lacking a well-functioning internal market for electricity. However, in order to meet its 2020 climate and energy targets, the EU has to accelerate its ambition to create a single European power market, based on renewable electricity (RES-E), an EU Super Grid as well as a Smart Grid in order to facilitate an intelligently and efficiently interconnected electricity system of both centralised and decentralised renewable energy installations.'[50]

In the period up to 2020, Europe has to replace many ageing power plants while also meeting future demand growth. Approximately 330 GW of new power capacity needs to be built by 2020, representing 42% of the current EU capacity. 'The EU must use such an opportunity created by this up-coming large turnover in capacity to construct a new, modern renewable energy power supply and grid system capable of meeting the energy and climate challenges of the 21st century, while enhancing Europe’s competitiveness and creating hundreds of thousands of jobs. The new power system must be supported by a well functioning internal market in electricity in which investors, rather than consumers, are exposed to carbon and fuel price risk.'[51]

Thinking about reshaping the electricity system needs a blueprint for the future electricity infrastructure. Existing power plants, typically of medium or large size, will step-by-step be replaced and/or supplemented by new units of much more variable sizes and wider-spread locations. A change in the ownership structure of power plants is occurring because small and medium sized installations often are run by private investors, either using the power themselves and/or feeding it into the electricity net.

4.2.3 Power plants

Electricity is generated in power stations of different sizes depending on the kind of energy transformation process used. Fossil and nuclear power plants are generating electricity in large-scale installations whereas renewable energy power plants today mainly are realized in low and medium sizes. Hydropower plants are covering the full range of sizes, as applicable to the water potential available at a certain location. Solar PV became popular mainly on a smaller scale; also, biomass firing mostly is applied in small or medium plants. More recently, windmills and solar modules are integrated to larger plant parks; thus, their scale can reach the sizes of conventional thermal power plants.

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[50] EREC (2010), p. 23

[51] EREC (2010), p. 23

In 2000, in the EU-15 countries a total power plant capacity of 584 GW was installed that produced 2.572 TWh of electricity. In the coming 30 years around 650 GW new power generation capacity will be needed, including 330 GW replacements of existing plants.[52]

Because of the different sizes, counting of power plants is only of bounded interest for comparison. Concerning conventional power generation, in Austria 92 power plants are natural gas, coal and oil power plants, and 154 hydro reservoirs and run-of-river plants. In the year 2008, these 246 medium to large plants had a share of about 88% in generation capacity, producing about 86% of electricity. Electricity is also generated from a growing number of smaller sized units, which use biomass, waste, small hydro, wind, solar, and geothermal energy sources. Around 2.000 MW peak generation capacities are installed in about 5.500 units, which deliver an annual electricity output of about 7.000 GWh. The structure and key data of the Austrian stock of power plants is shown in the following table:

Table 2: Stock of electric power plants, Austria, 31 December 2008

Power plant technology	**Number of plants**	**Power Capacity**		**Electricity production**		**Capacity utilization**	
		MWp	share	GWh/a	share	h/a	factor
Natural Gas	65	4,319	20.8%	10,164	15.2%	2,353	27%
Coal & oil	27	1,907	9.2%	7,945	11.8%	4,167	48%
Biomass & Waste	96	363	1.8%	2,091	3.1%	5,758	66%
Mixed thermal	415	760	3.7%	4,179	6.2%	5,501	63%
Reservoirs > 10 MW	64	6,871	33.1%	12,039	17.9%	1,752	20%
Run-of-river > 10 MW	90	4,453	21.5%	23,823	35.5%	5,349	61%
Small Hydro < 10 MW	2,390	1,056	5.1%	4,816	7.2%	4,561	52%
Wind, PV & Geothermal	161	993	4.8%	2,031	3.0%	2,046	23%
Other small renewables	3,097	22	0.1%	n/a	n/a	n/a	n/a
Total power plants	**6,405**	**20,743**	**100.0%**	**67,088**	**n/a**	**3,234**	**n/a**

Source: E-Control (2010), own calculations

‘Despite the economic crisis, significant amounts of new renewable energy were deployed in 2008 and 2009, especially wind and solar technologies. (…) Renewable power installations represented 61% of all new power generation capacity in the European Union in 2009, the second successive year that renewable investment exceeded 50% of the total. More wind capacity was installed in 2009 than any other electricity generating technology, comprising 39% of all new EU installations. Although smaller in absolute terms, solar PV technology also expanded very rapidly in Europe during 2008 and 2009. Germany, Spain and Italy are the main PV markets. Europe is also showing renewed

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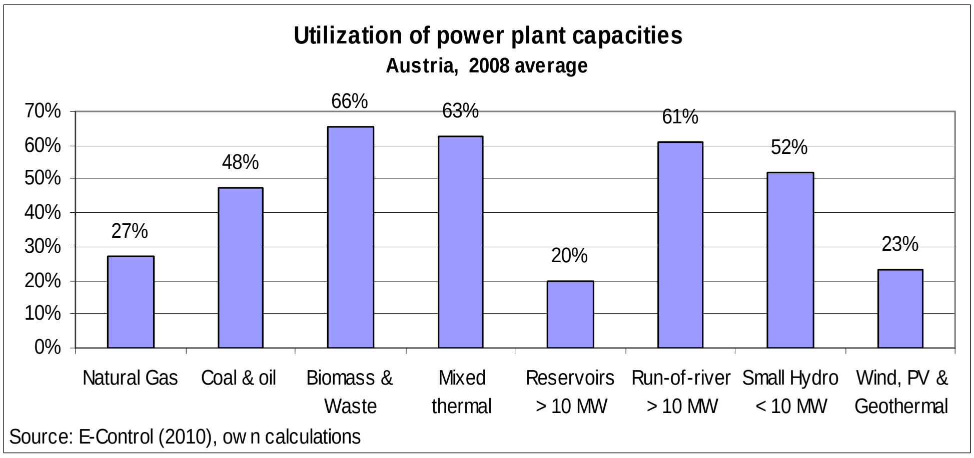
[52] Nowotny (2004), p. 247

interest in CSP, mostly in Spain. Several projects started operation in 2008 and 2009 and many others are under construction.'[53]

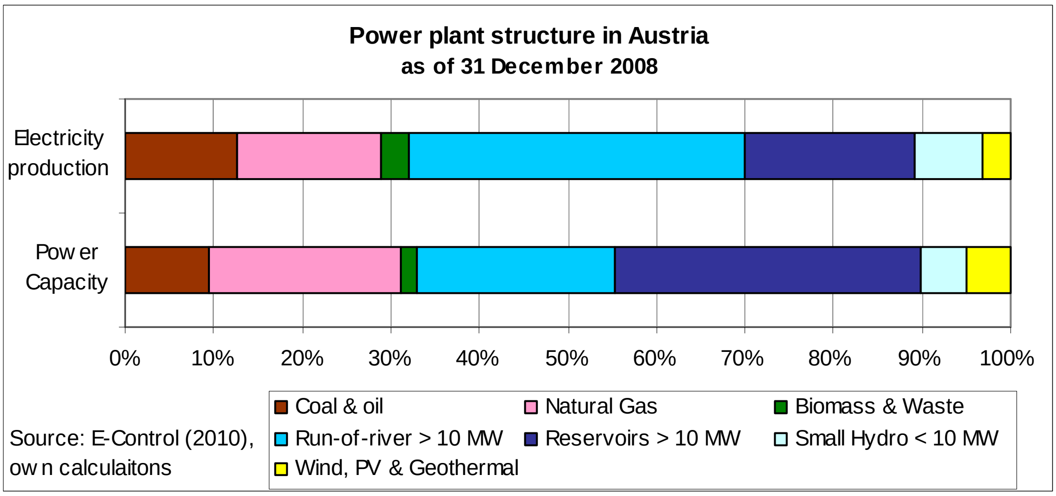
The following chart shows that the average utilization of power plant capacity is very different, ranging from 20 to 66 per cent:



Source: E-Control (2010), own calculations

Figure 17: Utilization of power plant capacities in Austria, 2008 average

In 2008, average load utilization was the highest in biomass and run-of-river plants, thereby contributing the relatively higher shares to electricity production. Large hydropower reservoirs natural gas plants have lower capacity factors, because they are used for power production in peak times. The figure below shows the different structures of electricity production output in comparison with the power plant capacities installed:



Source: E-Control (2010), own calculaitons

Figure 18: Power plant structure in Austria, 31 December 2008

The bulk of Austrian power plants were built between the years 1956 and 1985. Due to the specific geographic situation the capacity investments were largely focussed on run-of-river and reservoirs for hydropower generation. For compensating natural water level

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[53] IEA/ETP (2010), p. 133

fluctuations, conventional thermal power plants also were successively added to the plant park.[54] Assuming technical life times of 35-40 years, many of the thermal power plants built between the 1960's and 1980's now or in the near future need to be replaced. This is a great opportunity for further increasing the share of renewables in the Austrian electricity sector.

4.2.4 Power grid

Fossil and nuclear power plants are often built close to where the electricity is needed. Power generation plants using renewable energy sources must be located at well-suited places that often are distant from final energy consumers, especially hydropower stations, and wind parks. So, an important framing condition for extended power production from renewable sources is the assured and enhanced capacity of electric power grids and the well-functioning of transmission grid operation.

‘Transmission and distribution systems are often viewed as natural monopolies. Although they have not generally been opened to competition, they are now in many countries more heavily regulated to ensure that customers are treated fairly. (…) To ensure that a low carbon electricity system can be developed at least overall cost, policy makers and regulators will need to strike an appropriate balance between the various parts of the value chain. Investments in generation will influence grid costs, and grid investments may change the balance of advantage between different generation investment alternatives. Regulators and policy makers need to understand the long-term needs of the electricity system in the round, so that they can ensure that short- and medium-term investment needs in generation and in grids optimize outcomes.’[55]

As of 2008, the Austrian power grid was run by 3 transmission grid operators and around 130 distribution companies. Austrian Power Grid AG (APG), a subsidiary of the Verbund AG, is the largest grid provider and manages about 84% of the high voltage transmission lines. The grid providers are responsible for system services like power stabilization and bottle neck management. In addition to its role of a grid provider, they are operators of regulation zones for balancing the frequency and the exchange with other regulation zones in Europe. The Austrian grid operators are regulated and supervised by E-Control.[56]

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[54] Haas (2002), p. 117 seq.

[55] IEA/ETP (2010), p. 159

[56] E-Control (2008), p. 6 seq.

The lengths of the Austrian power lines at different voltage levels are shown in the following table:

Table 3: System lengths in the Austrian transmission grid, as of 31 Dec. 2006

Grid voltage level	**Kilometres**
380 kV	2,535
220 kV	3,764
110 kV	11,035
Transmission system	**17,334**
medium voltage	56,879
low voltage	149,072
Distribution system	**205,951**
Total power grid	**223,285**

Source: E-Control (2009), p. 17

Transmitting the power from generators to consumers needs a transportation infrastructure and a flexible management system to balance different supply and demand situations. 'A flexible power system can both rapidly supplement periods of low variable generation to meet demand as required, and manage large surpluses when demand is low. A flexible system is one which is able to transport, store, trade and consume electricity to maintain reliable supply in the face of rapid changes and potentially very large imbalances in supply and demand.' Power systems can be adapted in a number of ways to provide more flexibility to balance variable generation including: [57]

- Increasing the size of balancing areas
- Demand-side management
- Improving output forecasting
- Controlling of transmission capacity

Electricity transmission in Europe is organized in five synchronization areas, of which the largest one is ENTSO-E (former UCTE). In the ENTSO-E area, 29 power grid providers are integrated. Each provider, like e.g. APG in Austria, manages its own regulation zone by balancing capacity and frequency. For flexible management of demand and supply fluctuations different levels of capacity reserves are organized, which the grid provider can activate when needed. The primary reserve is automatically started within few seconds by measuring frequency deviations at the plant sites. The available primary capacity reserves in the ENTSO-E area are in total 3000 MW (of which Austria 65 MW), and the reserves

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[57] IEA/ETP (2010), p. 149

must be activated by all grid zone providers in emergencies. The secondary control reserves are used for regulating the exchange balances between the different zones within 15 minutes. In the third level, the grid provider can manually activate minute reserves to stabilize the secondary reserve on the needed availability level.[58]

To realize the potentials of renewable electricity generation, the power grids have to overcome the future challenges of intermittency. Four methods are possible to compensate for the variability in power generation:[59]

- Interregional compensation: Linkage of different regional grids for balancing power fluctuations
- Conventional back-up power, especially by combined-cycle gas turbines and pure-gas plants
- Demand-side management: Minimizing overall demand during peak periods
- Large-scale electricity storage: Harnessing excess power in times of abundance, and releasing it in peak periods

4.2.5 Electricity storage

Large-scale electricity storage offers structural advantages over both interregional grid linkage and using backup capacities. Storage provides a self-sufficient solution for a specific region. Unlike compensation by backup capacities, storage can deal with troughs and peaks of fluctuating power production. Additionally, storing electricity translates in less strain on the grid, because it can reduce fluctuations close to the power plant sites. Efficiency is the key weakness of electricity storage technologies, often causing unfavorable business cases. Other main cost factors are the number of cycles, capital expenditures, and operating expenses. The actual storage utilization is a complex function of many parameters, such weather conditions, load versus demand, and grid constraints. The five main types of electricity storage and key technologies within are:[60]

- Mechanical: Pumped hydro, compressed air (CAES), flywheel
- Thermal: Hot water, molten salt, phase-change material
- Electrical: Super capacitors, superconducting magnets
- Electrochemical: Flow and static batteries

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[58] Tretter (2010), p. 28 seqq.

[59] Pieper (2010), p. 3 seqq.

[60] Pieper (2010), p. 7

- Chemical: Hydrogen

Most promising for large-scale deployment look today compressed air energy storage, hydrogen storage, batteries, and pumped hydroelectric storage. 'Currently, however, there are relatively few examples of these technologies in large-scale use. The most common are pumped hydroelectric facilities, of which there are approximately 300.'[61] In Austria, pumped hydropower storage is actively used and planned for further extension. Total capacities of 3.1 GW (turbines) and 2.5 GW (pumps) are installed as of 2009. The capacities in the eastern regulation zone will be increased by about 1.4 GW (turbine/pump) until 2015.[62]

4.3 Development of energy demand

4.3.1 Final energy consumption

As already discussed above in the context with carbon dioxide emissions and global warming risks, final energy demand is a close follower of the GDP and population developments. In 2007, the structure of final energy consumption by fuel was very different in the EU-27 member states. Overall, about 70% of it are direct use of fossil energy sources, e.g. in the industrial sector, in transportation and private households. The share of electricity in final energy also varies quite a lot, ranging from 34% in Sweden to only 14% in Hungary, and Austria being a little below the EU-27 average of 21%. The final energy shares by fuel are shown in the figure below:

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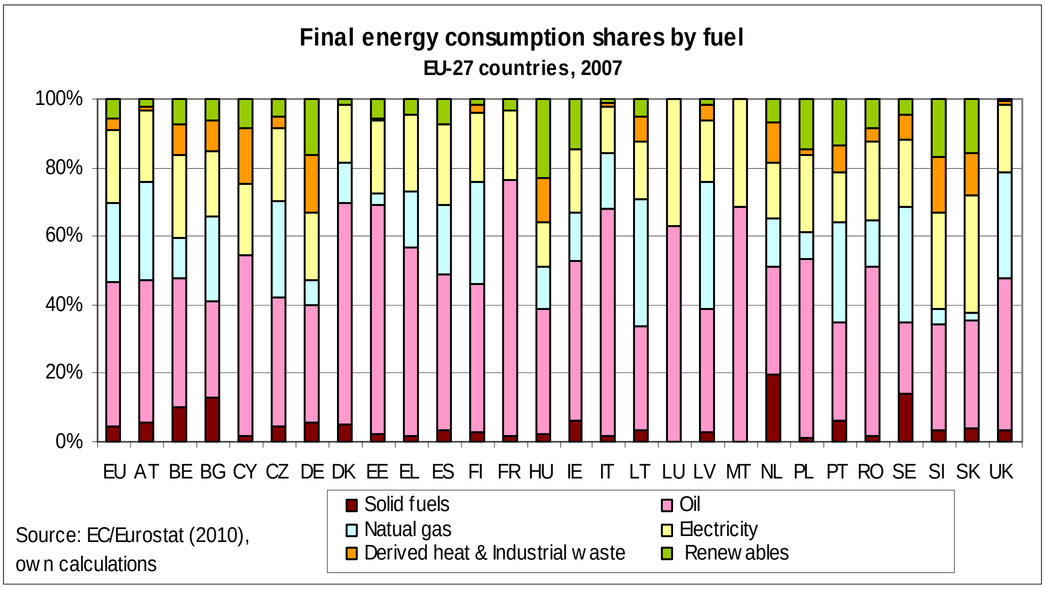
[61] Pieper (2010), p. 8

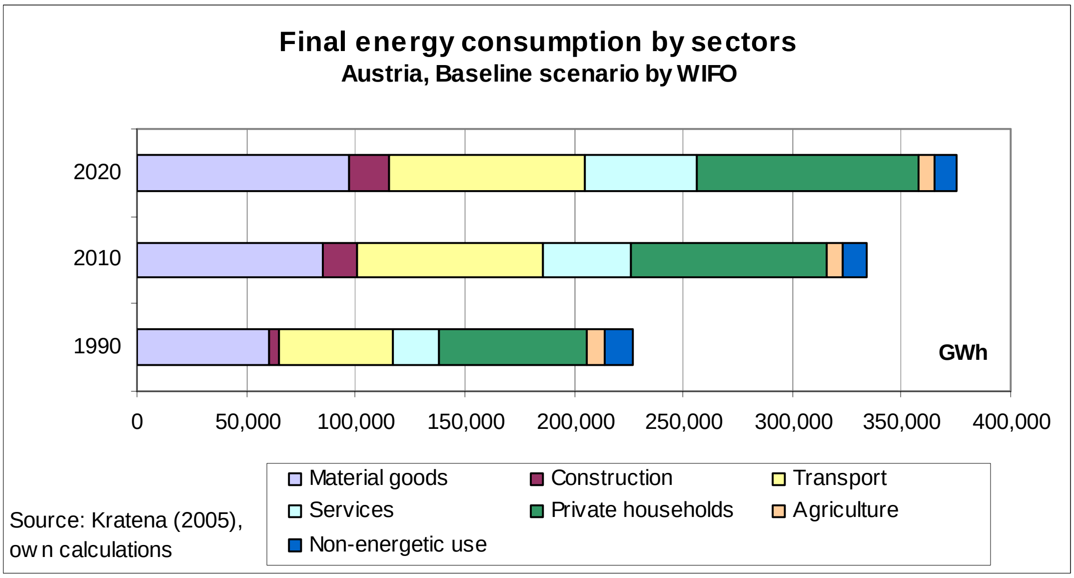
[62] Tretter (2010), p. 22



Source: EC/Eurostat (2010), own calculations

Figure 19: Final energy consumption by fuel, EU-27 countries, 2007

Final energy consumption needs to be analyzed by the sector structure of a country. This is important for finding adequate policies and measures to improve the energy efficiency in the sphere of final energy consumers. Final energy consumption in Austria was projected by WIFO until 2020 in the baseline scenario, which predicts strong demand increases for the case that no substantial energy efficiency improvements are achieved, see figure below:

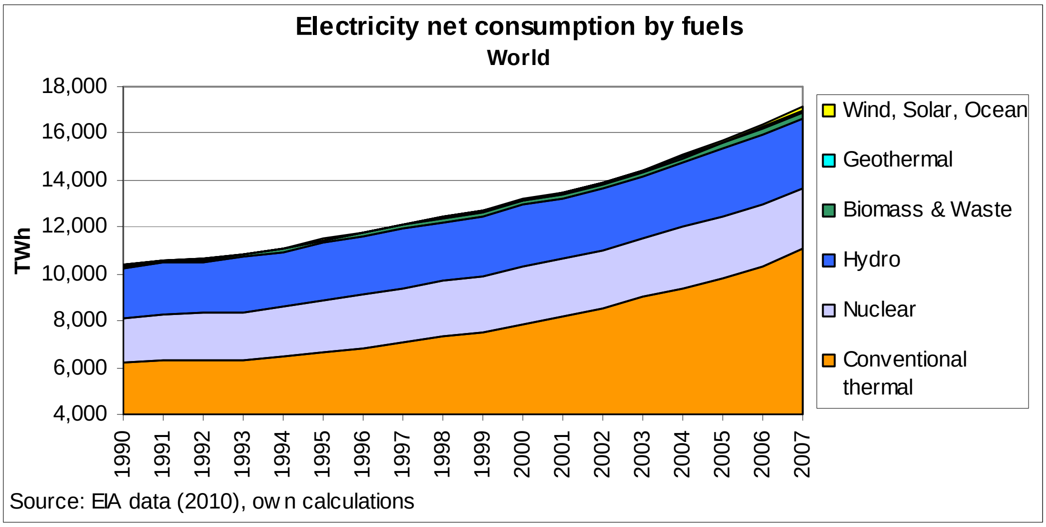


Source: Kratena (2005), own calculations

Figure 20: Final energy consumption by sectors, WIFO scenario, Austria

4.3.2 Electricity consumption

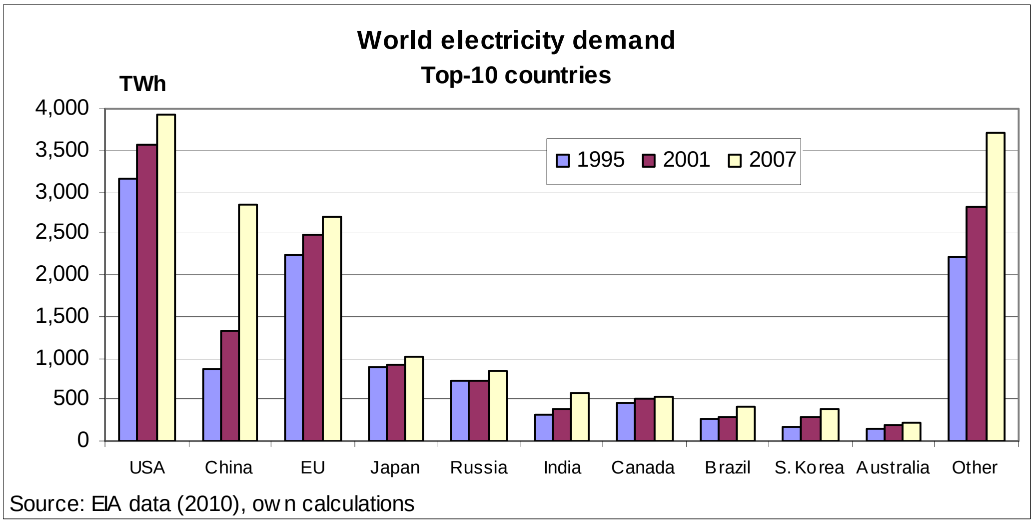
World electricity net consumption, which is defined as gross electricity generation reduced by electricity consumed at the generating stations for station service, auxiliaries, and pumped storage, grew 65% from 1990 to 2007. Almost the whole growth in energy demand was covered by conventional thermal power generation that increased 78% and its share went up from 60 to 65%. Hydropower grew only 40% and its share dropped from 21 to 18%; non-hydro renewables still only make up a fraction of 3% in 2007.



Source: EIA data (2010), own calculations

Figure 21: Electricity net consumption by fuels, world, 1990-2007

The next figure shows a split-up by countries for the world electricity demand. The demand in China is steeply growing and in 2007 the country was ranked already second, even ahead of the total EU.



Source: EIA data (2010), own calculations

Figure 22: World electricity demand, top-10 countries, 1995-2007

Within only six years, from 2001 to 2007, in China the electricity demand more than doubled. Other fast developing countries, like India, Brazil and South Korea, also show steep electricity growth. The industrialized countries kept down the increases, very much related to the much lower GDP and population growth rates than in developing countries.

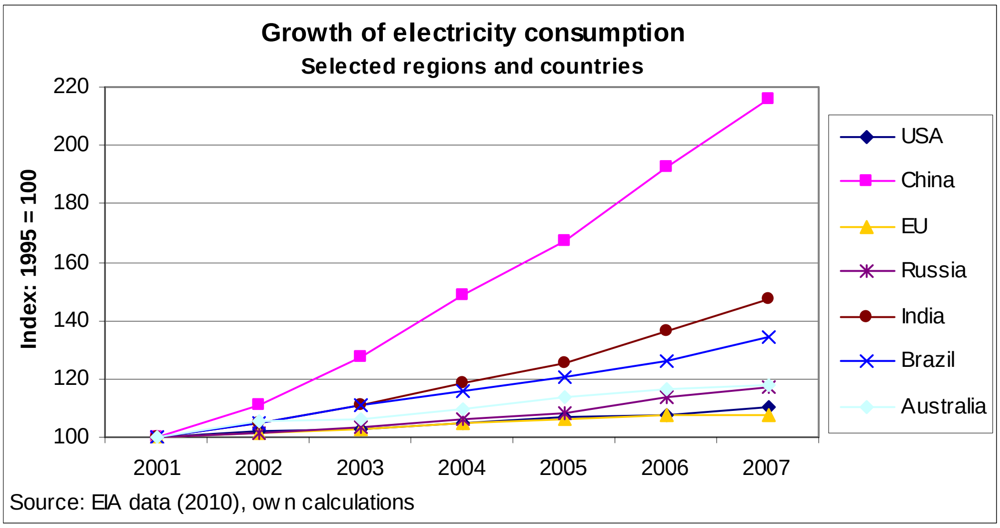


Figure 23: World growth of electricity consumption, selected regions, and countries, 2001-07

Growth of total non-fossil fuel-based electricity generation did not keep pace with the rising electricity demand. As a result, the worldwide share of non-fossil fuels in electricity production declined. The contributions from nuclear power and hydropower also dropped from 17% in 1990 to 14% and from 18% to 16% respectively. Electricity production from non-hydro renewable energy sources built up, but from a low base. The share of biomass and waste increased slightly from 1.1% in 1990 to 1.3% in 2007. Other renewables such as wind, geothermal and solar improved their share from 0.4% to 1.2% over the same period.[63]

In Europe, the share of conventional thermal power is lower because higher shares in nuclear and hydropower. In addition, biomass and other non-hydro renewables are gaining faster momentum than worldwide, but both linger at levels of around 3 % share of total electricity. Overall electricity consumption has increased by 32% from 1990 to 2007; conventional thermal electricity has grown 42%, nuclear power 19%, and overall power from renewables 53%, driven up mainly by biomass and wind energy.

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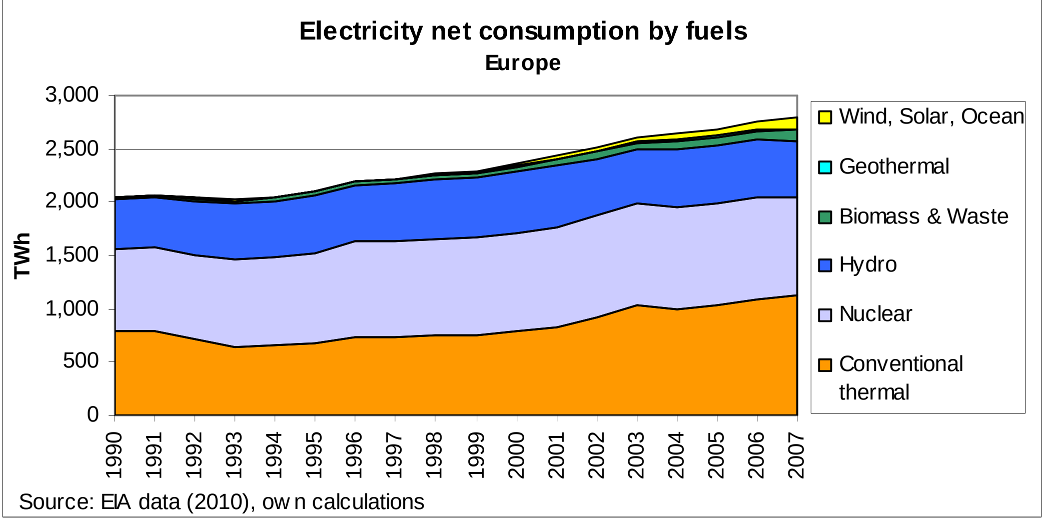
[63] IEA/ETP (2010), p. 103



Source: EIA data (2010), own calculations

Figure 24: Electricity net consumption by fuels, Europe, 1990-2007

Electricity production from renewable energy sources increased in both absolute and relative terms between 1990 and 2007, though partially offset by the pace at which the demand for electricity grew. Renewable energy contributed 15.6 % of the electricity consumed in the EU-27 in 2007, a 3.7 percentage point increase on 1990. Hydropower dominated renewable electricity production, followed by biomass, waste, and wind generation.[64]

The following chart shows that even with growing shares of non-hydro renewables the share of conventional thermal in the electricity generation is further growing. The reason is the on-going linkage between GDP growth and energy demand combined with falling shares of nuclear and hydropower generation.

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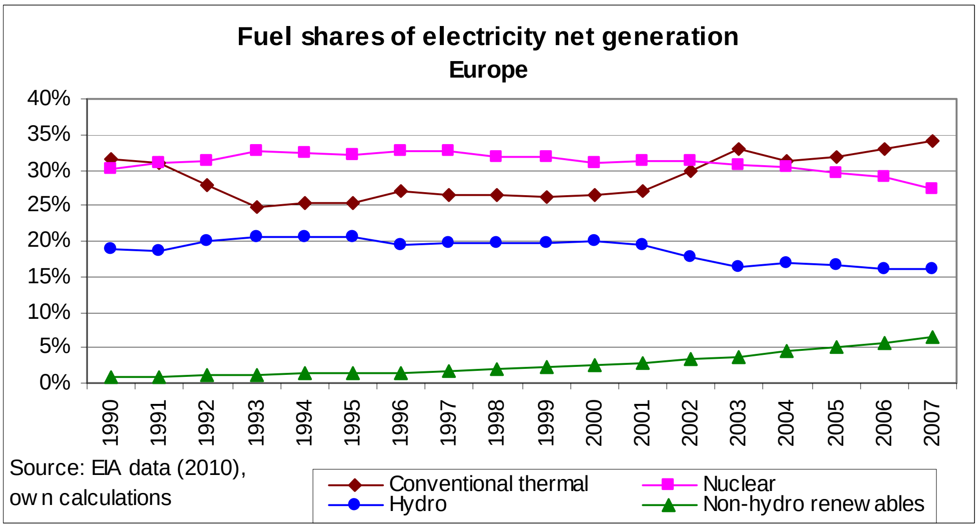
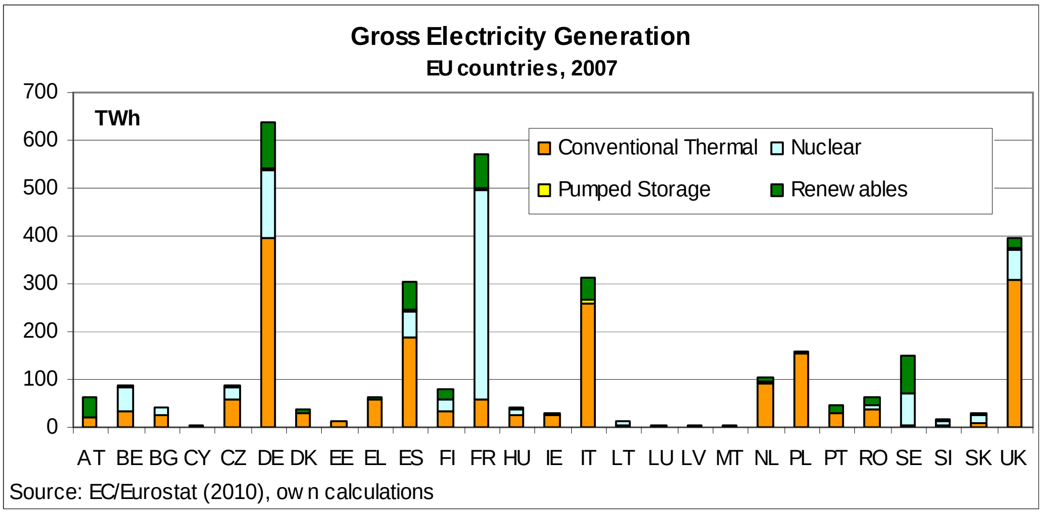
[64] EC/Eurostat (2009), p. 55



Source: EIA data (2010), own calculations

Figure 25: Fuel shares of electricity net generation, Europe, 1990-2007

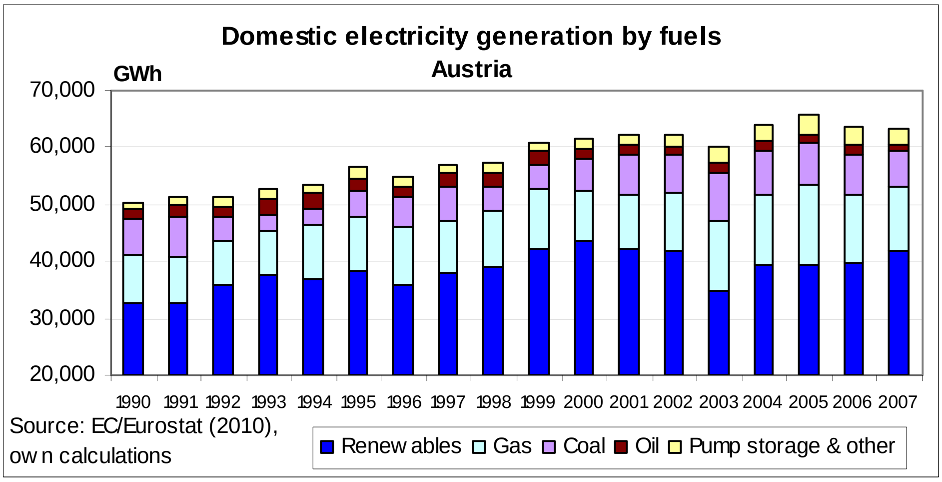
The EU member states have very different structures of gross electricity generation, what can be seen in the following figure:



Source: EC/Eurostat (2010), own calculations

Figure 26: Gross electricity generation, EU countries, 2007

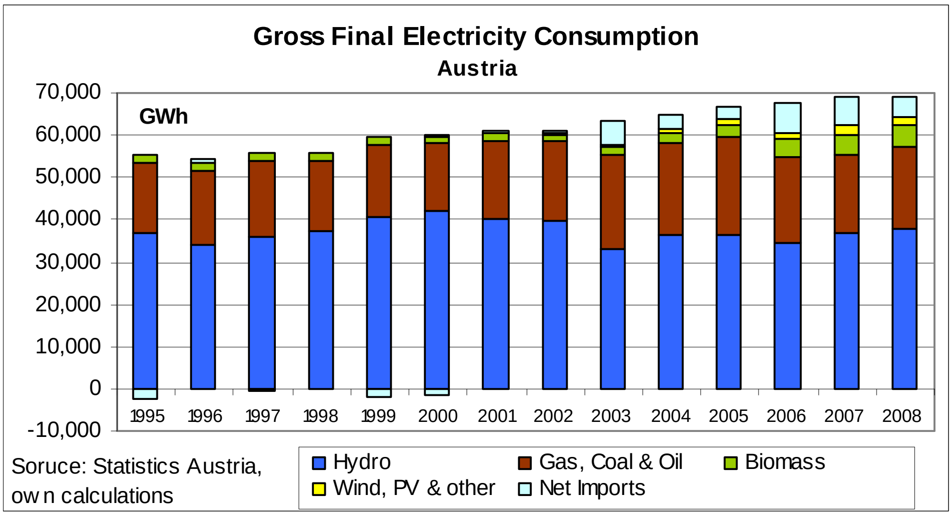
The structure of electricity generation in Austria is quite different to the world and European ones, because Austria has a large hydropower sector pushing up the share of renewables to more than 60%. Though, because of growing demand and relatively smaller extensions in hydropower generation, the share of fossil fuels in power generation increased from 1990-2007, see the following figure:



Source: EC/Eurostat (2010), own calculations

Figure 27: Electricity generation by fuels, Austria, 1990-2007

Gross final electricity consumption, including net electricity imports, has gone up by about 40% from 1990 until 2007. Since 2003, the non-renewable share was steadily increasing, but it could not generate enough electricity to compensate for necessary net imports.

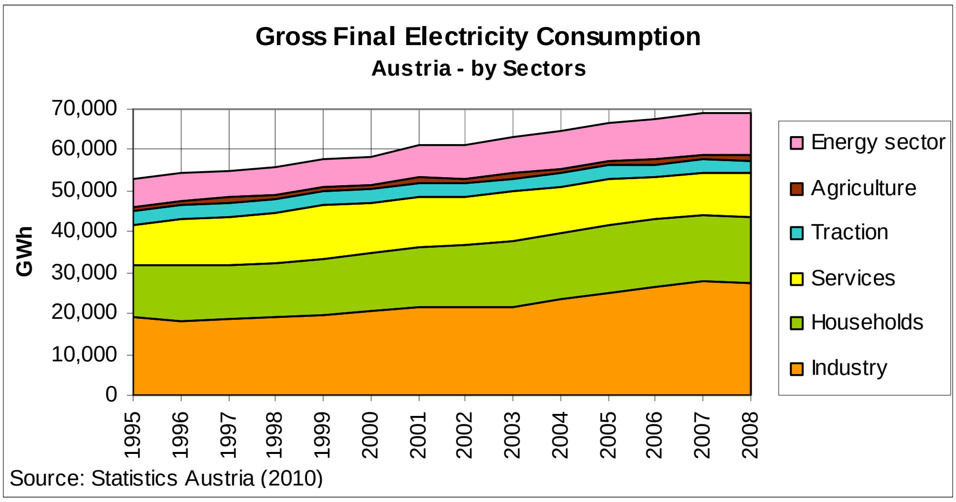


Soruce: Statistics Austria, own calculations

Figure 28: Gross final electricity consumption in Austria, 1995-2008

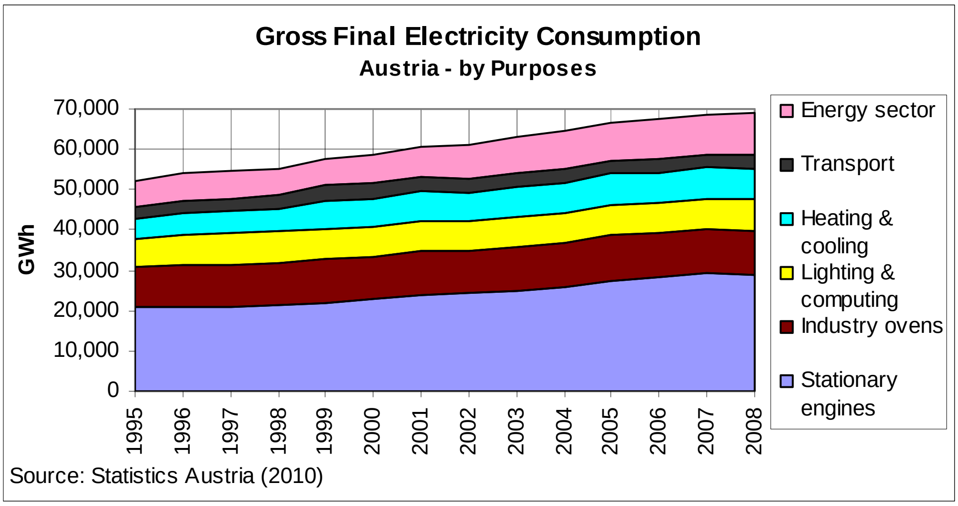
Industrial manufacturing has the largest sectoral share of gross final electricity consumption in Austria, and dominated electricity demand growth from 1995 to 2008. The transport sector still plays a subordinated role in electricity consumption, because traction is still dominated by the use fossil energy. Increasing electricity consumption within the energy sector reflects the growing importance of pumped storage hydropower.

The following two charts show the development of electricity demand since 1995 until 2008 by sectors and by purposes:



Source: Statistics Austria (2010)

Figure 29: Gross final electricity consumption by sectors, Austria, 1995-2008



Source: Statistics Austria (2010)

Figure 30: Gross final electricity consumption by purposes, Austria, 1995-2008

Analyzing the trend in electricity demand by utilization purposes displays that mainly stationary engines and heating & cooling are contributing to the overall growth, besides of the energy sector itself. Lighting & computing is rather stable in electricity consumption reflecting a positive trend in efficiency rates, because lighting and computing installation are strongly growing.[65]

4.3.3 Future electricity demand

World-wide growth of GDP and population leads to an increasing demand for energy sources of all kinds. Especially in developing countries the energy consumption is very much coupled with the economic development, and the dynamic growth in newly industrializing countries like China, India and Brazil, today is a huge climate change

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[65] Haas (2008), p. 30

challenge in addition to the very high energy and carbon intensity levels cultivated by the industrial nations. The need for more energy in growing economies remains the strongest driver for greenhouse gas emissions as long as fossil fuels are the main energy source.

This is why energy efficiency is such an important concept solving several problems at once. Lower energy intensity, measured per GDP or per capita, saves a lot of costs, mitigates the climate change and reduces import-dependence from fossil fuels. Higher efficiency in the transformation and in the utilization of energy is the pre-condition for at least a slight de-coupling of economic and social wealth from growing energy consumption. But on a world-wide scale, energy efficiency improvements do not cope with the fast growing energy demand.

In the reference scenario of the World Energy Outlook 2009 the IEA projects the future energy needs. Fossil fuels remain the dominant primary energy source, accounting for almost 77% of the overall increase in energy demand between 2007 and 2030. According to this outlook, the share of oil drops only marginally, but coal sees by far the biggest increase in demand. New renewable energy technologies see the fastest relative growth rates, but they linger at a low share of only two percent, as shown in the following table.[66]

Table 4: World primary energy demand by fuel, WEO 2009, reference scenario, 2007-30, TWh

PWh	**2007**	**2015**	**2020**	**2025**	**2030**	**Demand growth 2007-30**		**CAAGR**	**Share 2007**	**Share 2020**	**Share 2030**
Coal	37,030	44,520	47,974	52,591	56,836	19,806	53%	1.9%	27%	28%	29%
Oil	47,602	49,241	51,637	54,556	58,255	10,653	22%	0.9%	34%	31%	31%
Gas	29,215	32,576	35,297	38,367	41,414	12,200	42%	1.5%	21%	21%	21%
Nuclear	8,246	9,420	9,897	10,711	11,118	2,873	35%	1.3%	6%	6%	6%
Hydro	3,082	3,687	4,024	4,350	4,675	1,593	52%	1.8%	2%	2%	2%
Biomass & waste	13,677	15,561	16,608	17,585	18,655	4,978	36%	1.4%	10%	10%	10%
Other renewables	861	1,861	2,605	3,396	4,303	3,442	400%	7.2%	1%	1%	2%
Total	**139,711**	**156,865**	**168,042**	**181,556**	**195,256**	**55,545**	**40%**	**1.5%**	**100%**	**100%**	**100%**

Source: IEA/WEO (2009), own calculations

The reference scenario by IEA describes a future, in which governments are assumed to make no changes to their existing policies and measures affecting the energy sector. It provides a baseline projection of how global energy markets would evolve, if the underlying trends in energy demand and supply are not changed. But the IEA also emphasizes that these projections are not a real-life forecast, because the governments are not expected to do nothing. 'On the contrary, it is becoming increasingly likely that governments around the world will take rigorous action to address the central energy

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[66] IEA/WEO (2009), p. 74

challenges that we have identified in past Outlooks — climate change, energy security and energy poverty — and put the global energy system onto a more sustainable path. Climate change could become the main driver of policy in the coming decades.'[67]

The EIA projects in its reference case that world net electricity generation increases by 87 percent, up from 18,800 TWh in 2007 to over 35,000 TWh in 2035. 'Although the recession slowed the rate of growth in electricity demand in 2008 and 2009, its growth returns to pre-recession rates by 2015 in the Reference case. In general, in OECD countries, where electricity markets are well established and consumption patterns are mature, the growth of electricity demand is slower than in non-OECD countries, where a large amount of potential demand remains unmet. In the Reference case, total net generation in non-OECD countries increases by 3.3 percent per year on average, as compared with 1.1 percent per year in OECD nations.'[68]

World power generation from renewables grows by an average of 3.0 percent per year, and the renewable share of world electricity generation increases from 18 percent in 2007 to 23 percent in 2035. Coal-fired generation remains the biggest resource for electricity further growing by annually 2.3 in the projection. Electricity from natural gas and nuclear power increase by 2.1 and 2.0 percent per year, respectively, in the reference case of EIA.[69]

The following figure shows the projected development of world electricity generation until 2035:

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[67] IEA/WEO (2009), p. 75

[68] EIA (2010), p. 3 seq.

[69] EIA (2010), p. 4

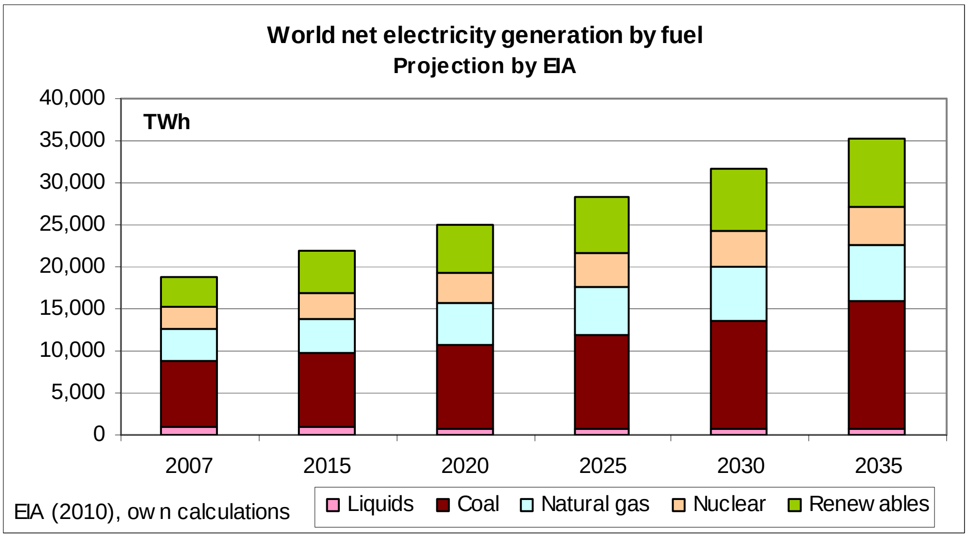

Figure 31: World net electricity generation by fuel, EIA projection, 2007-30

Most of the different scenarios drafted, project total world electricity generation somewhere in the range between 30,000 to 35,000 TWh per year, what is about twice the amount of today. The expected split-up between different energy sources used for electricity generation depends on the assumptions and targets of scenarios. Main criteria are for example the attitude concerning a possible extension of nuclear power and the assumptions about feasibility of low-carbon coal firing technologies.[70]

The main driver for future electricity consumption is the population number, because per capita demand for electricity in the world increases almost proportionally to income development, the expected rate of growth is 1.9% year between 2010 and 2030 and compared to an average of 1.7% per year between 1990 and 2010. In the industrialized countries, future electricity demand increases at a slower rate than in the past, at around 0.9% per year in North America and 2% per year for the Japan and Pacific region. In Europe the estimated rate of growth is 1.9% per year on average after 2010, which is only little below the yearly changes in the past due to the high growth potential in the new member states and accession countries of the EU. 'This does not mean that there is no improvement in energy efficiency, but rather that there is still a diffusion of new types of electrical appliances, as can be seen at present with ICT appliances. In some countries, electricity replaces fossil fuels for thermal uses, because of the lower cost. Electricity demand per capita grows much faster in the other regions, especially Asia, Africa and the Middle East (…). Ownership of basic household electrical appliances is still far from

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[70] Nienhaus (2009), p. 62

saturation; there is a diffusion of new end-uses such as air-conditioning and there is growing demand in the productive sectors.'[71]

According to the reference case drafted by the EC, annual generation of electricity in the world soars to nearly 60,000 TWh until 2050. The share of thermal power generation increases until 2020, because other sources cannot match the growth in demand. Power generation from nuclear and hydro sources only grows slowly. Concerning renewable electricity, growth rates exceed 10% per year until 2030 for wind and 15% per year after 2010 for solar, but come from low bases, so that it cannot match the absolute electricity demand growth.[72]

In its so-called carbon constraint case the EC expects that the contribution and share of electricity from non-fossil sources considerably increases and more than 30% of world electricity comes from renewable and almost 40% from nuclear energy by 2050. Until 2030, incremental generation in renewable electricity comes mainly from biomass and wind power, each providing about one fourth of a total that is still dominated by large hydro. In this scenario, it is assumed that solar would start only after 2030 to play a significant role, both PV and CSP technologies.[73]

In Austria, in the last 25 years electricity consumption grew yearly by 2.3% in average. Theoretically extrapolating this growth rate until 2030 would shift electricity demand to about 120 TWh, almost double the volume of today.[74] By taking into account the framework of international energy scenarios, total energy demand will most likely lie between 320 and 420 TWh by the year 2030, and the share of electricity will rise from 17% of today to a range between 21% and 29% depending on the scenario assumptions.[75]

The Austrian government determined in its energy strategy that energy efficiency must be the key to future energy policy. Upon this notion, it defined the target value for final energy consumption in the year 2020 to be 1100 PJ (306 TWh), virtually remaining at the same level as today for the coming decade.[76] Final net electricity demand is planned to go up to about 62 TWh until 2020, which is an increase of about 8% compared to 2005. Power

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[71] EC/WETO (2006), p. 42 seq.

[72] EC/WETO (2006), p. 36

[73] EC/WETO (2006), p. 59

[74] Haas (2008), p. 30

[75] Haas (2008), p.35

[76] BMWFJ (2009), p. 31 seq.

generation from renewable sources grow about 11%, and conventional thermal electricity drop 2%. The overall electricity share increases to approximately 21% of final energy demand in 2020.[77]

4.4 Renewable electricity potentials

4.4.1 Overall potential

The energy flows from renewable sources amount to about 3,000 times more than total present energy consumption of whole mankind. The main types of renewable sources are solar, wind, biomass, geothermal and ocean energy. 'In one day, the sunlight which reaches the earth produces enough energy to meet the current global power needs for eight years. For many centuries industrialised societies have not been able to grasp this incredibly rich source of energy. We have lacked the technology to reach out and make use of this vast source of energy, thereby letting it pass us by for many years. Today, we have the technology to largely harvest these resources and satisfy a planet hungry for energy.'[78]

When outlining the availability of renewable energy sources, it is important to define the potential that is considered. Three different types of potentials are distinguished:[79]

- Theoretical potential: Derived from general physical parameters, e.g. the determined energy flow resulting from a certain energy resource within a certain region. The theoretical potential identifies the upper limit of what can be produced from a theoretical point of view, based on current scientific knowledge.
- Technical potential: Consideration of technical boundary conditions, e.g. conversion efficiency of technologies, limitations such as the land area and raw material available. The technical potential has to be seen in a dynamic context, e.g. new research and development can increase the technical potential.
- Economical potential: Proportion of the technical potential that can be realised at cost levels that are considered to be competitive. The economical potential can be influenced by policy instruments.

Even in the case that the economical potential is attractive, relevant other factors influence the realization of power plant projects. 'The realizable potential represents the

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[77] BMWFJ (2009), p. 11

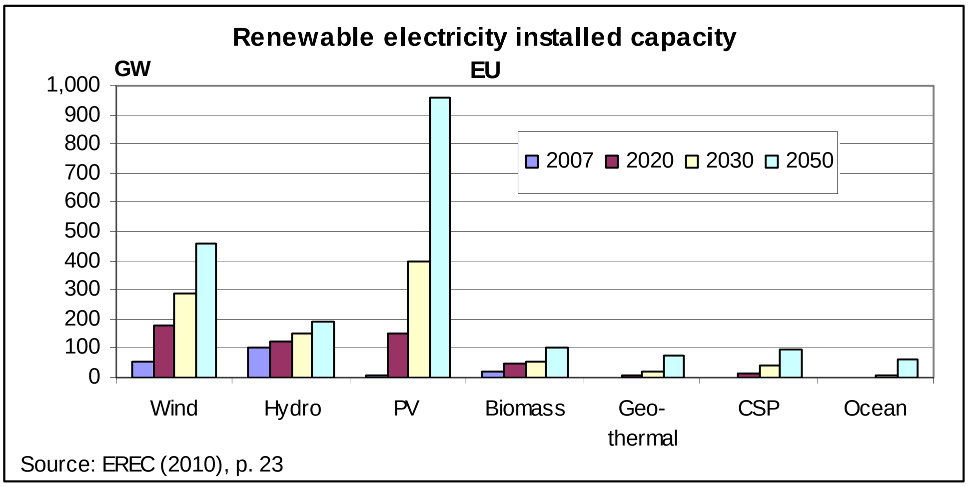
[78] EREC (2010), p. 16

[79] EREC (2010), p. 16 seq.

maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. Thereby, general parameters as e.g. market growth rates, planning constraints are taken into account. It is important to say that this potential must be seen in dynamic context - i.e. the realisable potential has to refer to a certain year.'[80]

For long-term projections, an exact definition of the type of potential is difficult, because the future technical and economical restrictions are not known. With an average annual growth rate of 14% between 2007 and 2020, the EU countries are expected to install renewable power capacities of about 520 GW by 2020. Between 2020 and 2030, geothermal electricity is predicted to see a high annual growth rate of about 44%, followed by ocean energy with about 24% and CSP with about 19%, closely followed by PV with 16%. The growth rates of wind, hydro and biomass will slow down because of already high potential utilization. By 2030, the total renewable electricity installed capacity amounts to 965 GW, dominated in absolute terms by solar photovoltaic, wind and hydropower. Until 2050, especially the solar potential is rapidly further growing.[81]

The following figure shows the EU's economical potentials for the utilization of renewable sources in the electricity sector:



Source: EREC (2010), p. 23

Figure 32: Renewable electricity installed capacity (GW), EU, 2007-50

The Renewable Energy Directive sets an overall target of a share of at least 20% renewable energy in the EU by 2020. For renewable electricity the target share is defined to 34%. But according to EREC's projections, renewable electricity generation technologies could contribute even 39% by 2020; and renewable power generation increases further until 2030, when the share of renewable electricity reaches around 65-

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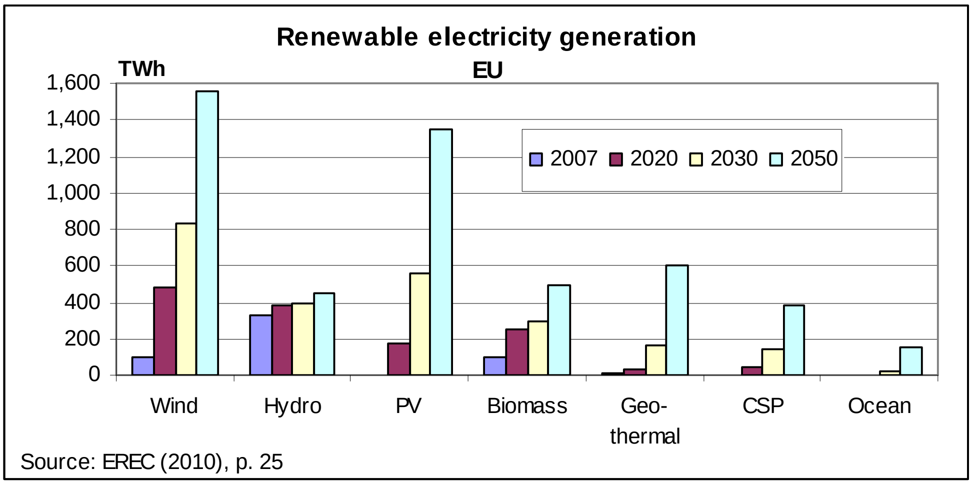
[80] Resch (2005), p. 41

[81] EREC (2010), p. 23

67%. By 2050, renewable electricity provides for 100% or even more of the EU's power demand.[82]

The following chart shows this long-term pathway towards a fully renewable power generation system in the EU:



Source: EREC (2010), p. 25

Figure 33: Renewable electricity generation (TWh), EU, 2007-50

Different scenarios for renewable electricity deployment span a wide range resulting from different concrete manifestations of influencing parameters, e.g. primary energy prices, CO_2 prices, electricity prices, support policies for renewables, electricity consumption. The following scenarios show the high relevance of assumptions about potentials and policies for deriving different transition paths to renewable electricity production:[83]

- Reference scenario: Renewable generation drops to a share of 57% until 2050. Hard coal plants constitute the majority of newly built generation capacities. Wind power, biomass, biogas, photovoltaic increase their share without support policies from 4% to 8% in 2050.

- CO_2 reduction scenario: Renewable generation stabilizes at 75% in 2050. Ambitious scenario in global climate change targets, but fossil fuelled central generation technologies remain significant. Only hard coal plants equipped with CCS are built. New renewables increase their share in electricity generation from 4% to 18%, with the highest growth rates in wind and bio energy until 2020, and PV reaching record high growth rates due to increasing economic viability from 2040 on.

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[82] EREC (2010), p. 25

[83] Haas (2009), p. 16 seq.

- Efficiency/renewable scenario: Renewable generation rises continuously up to 100% in 2040-2045. New renewables increase their share under support schemes to 31% in 2050. Record high growth rates for PV due to the support schemes and increasing economic viability from 2030 on.

In Austria, growth of renewable electricity is subdued because of the high level of expansion already achieved, largely dominated by hydropower and biomass. The utilization of additional potentials is not followed with the highest priority possible. 'The development of small hydro lags far behind the potentials that are seen for this source in Austria, due to lack of financial support but also the societal constraints at a regional level. A major share of the biomass electricity is attributed to industrial wastes, especially in the paper industry. In contrast to the European definition, the biomass plants based on industrial waste are not considered in light of the expressed targets in the Austrian Green Electricity Act. Only those RES-E technologies such as PV and wind energy where the use started basically from scratch could reach significantly higher growth rates. In the case of wind energy, a very strong growth could be observed in the period 2003 to 2005, an effect of the strong feed-in tariffs effective for new installations during these years. Since the phase out of the favourable support conditions (…) stagnation could be observed in recent years where almost no new RES-E projects were realized.'[84]

A common classification for renewable electricity technologies is the following:[85]

- Biogas, solid biomass, waste
- Large hydro, small hydro
- Geothermal power
- Wind on-shore, wind off-shore
- Solar photovoltaic (PV)
- Concentrated solar power (CSP)
- Tidal & wave

For the next decade the expectations for additional possible utilization of realizable potentials, but depending on sufficient policy instruments, are shown in the following figure:

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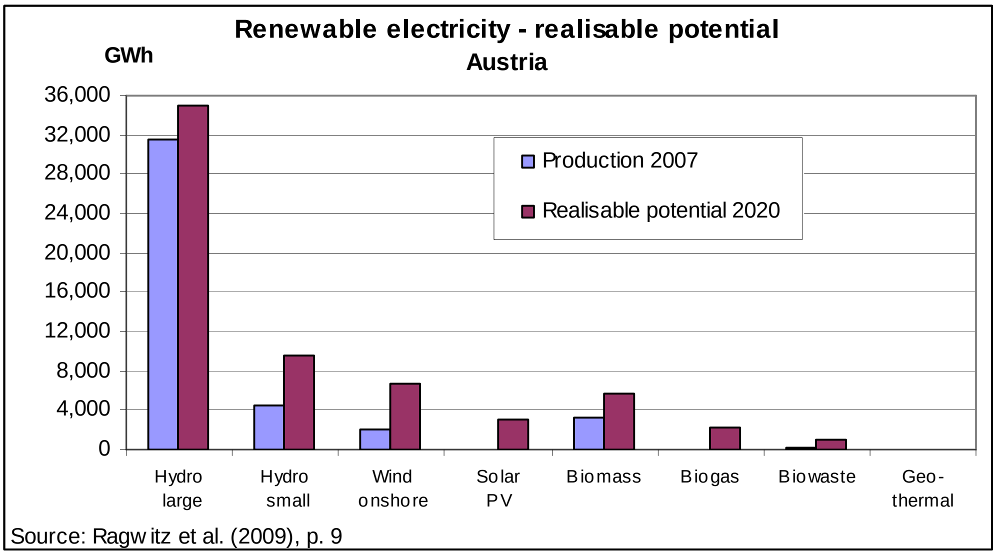
[84] Ragwitz (2009), p. 19 seq.

[85] Resch (2005), p. 4



Source: Ragwitz et al. (2009), p. 9

Figure 34: Realizable electricity generation potential, Austria, 2020

For the calculation of the future investments needed, a relevant up-side limitation is the technical potential of the energy source. For the scenario analysis in this paper, the main focus lies on renewable power generation in Austria, and the relevant types of technologies for that are: Hydro, biomass, wind, photovoltaic. In the following, a short description of the technology and its power production potential in Austria is given.

4.4.2 Hydropower

Hydropower is the mainstay of the Austrian electricity system and always has been a popular, clean and cheap energy source. The large water reservoirs in the Alpine regions are important for peak electricity production, and the run-of river stations for base load. In addition, pumped hydro storage and generation is important for load balancing, because a hydropower plant can react within 1 to 2 minutes to grid fluctuations.

The technical-economical hydropower potential in Austria is around 56.1 TWh of which about two thirds have already been opened for electricity production. The remaining potential splits into 1.4 TWh resulting from feasible optimizations of existing power station and the major share of 16.5 TWh is up to new developments. Due to the fact that some of the remaining potential is located in highly sensitive areas, e.g. national parks, cultural history sites, the realizable hydropower can be estimated with just 13 TWh, an addition of about 23% to the existing hydropower inventory.[86]

Power production from large-scale hydro stations was 32.5 TWh in 2008, about 50 % of final electricity demand in Austria. Because of the well-advanced stage of the

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[86] Pyöry (2008), p. 4 seq.

hydropower sector, new projects encounter growing resistance, and it gets more difficult to exploit the remaining potentials; thus the additional potential until 2020 is restricted to 4.5 TWh per annum. Small-scale hydro power, produced by approximately 2,500 plants with name-plate capacities of less than 10 MW peak, contributes 5.5 TWh yearly output of electricity. The potential for additional small-scale hydro power plants is 1.5 to 2.5 TWh, of which 1 TWh can be tapped by revitalization and retrofitting of existing plants.[87]

4.4.3 Biomass

Biomass is energetically used in many different ways and thus an important renewable energy source, especially for heating, liquid fuels and electricity. Biomass generates about the same amount of carbon dioxide as fossil fuels, but every time a new plant grows, carbon dioxide is actually removed from the atmosphere. Being the most diverse renewable energy source, many types of different utilization technologies have been developed. Electricity is generated from solid and liquid biomass, biological waste, and biogas. Biomass plants are either producing heat or electricity, but the most efficient way of technology for energy conversion from biomass are combined heat & power plants.[88]

The steam process is the most spread way of power generation from biomass. A boiler heats and evaporates water to steam. In a steam turbine part of the steam is transformed to mechanical energy, which is running the electricity generator. Some of the heat can be used for manufacturing or district heating. The main resources used are wood chips and waste. For electricity generation the efficiency rate is rather low between 20 and 40%, but in heat and power cogeneration plants an efficiency of up to 90% is possible.[89]

Biomass is used for different purposes, such as agriculture, forestry, and energy. Austria is one of the leading countries in growing and using biomass for energy generation, and a bulk of biomass plants are already in operation. In 2008, 1.9 TWh of electricity was generated from solid biomass and 0.5 TWh from biogas. Additional 1.5 TWh power are produced by exploiting the brine of wood pulp in the paper industry. The additional potentials until 2020 for power production are 2.9 TWh from biomass and 1.5 TWh from biogas.[90]

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[87] PV Austria (2009), p. 4

[88] Kranzl (2009), p. 41 seqq.

[89] Kranzl (2009), p. 66

[90] PV Austria (2009), p. 6 seq.

The land available for the energy sector is used either for fueling power and/or heat production, or for fuel components in transportation. Deriving the biomass potential for electricity generation thus depends on the assumption about the future structure of biomass usage, a question that is also interrelated with the development of the energy market prices. In this competitive environment a third, maybe the most important lever is policy making. Under the assumption of strong policies supporting the use biomass for combined heat and power production, until 2030 the electricity generation from biomass sources reaches around 9 TWh in an environment of low energy prices, and about 10% less of that amount with higher prices.[91]

4.4.4 Wind energy

Wind power generation is a relatively simple technology with calculable costs and has been rapidly spreading around the world in the last decade. The technology is already well developed and investment costs are attractive because of high cumulative installations achieved. The worldwide boom in wind energy brought a 29% growth in the capacity installed totaling 120 GW. In Europe 8.5 GW new wind power capacity was installed in 2008, an investment of about 11 billion €, and overall wind power plants are supplying four per cent of the electricity in Europe.[92]

In Austria, by now about 1000 windmills are producing 2.1 TWh yearly. However, the amendment of the eco power act in 2006 was unfavorable for new wind power projects so that the growth plummeted, and in 2009, zero new windmills were erected in Austria. The policy framework, i.e. the feed-in tariff level, was finally enhanced in 2010 and now new wind projects again are started. In Austria, the electricity generation potential until 2020 is about 7.3 TWh, representing 10 % of electricity demand. This electricity potential relates to only twice the number of wind towers necessary, because of retrofitting existing wind parks with bigger and more modern units.[93]

The wind power potential splits up in classes of different wind intensities available which determine the annual sum of full load hour hours, the structure of the wind power potential in Austria is shown below:

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[91] Kranzl (2009), p. 135, 148

[92] PV Austria (2009), p. 8

[93] PV Austria (2009), p. 9

Table 5: Wind power potentials by full load hour classes, Austria, 2006

Potential/ Class	**Power capacity**	**Electricity production**	**Full load hours**	**Capacity factor**
	MWp	GWh/a	h/a	%
1	160	369	2,306	26.3%
2	890	1,872	2,103	24.0%
3	196	380	1,939	22.1%
4	424	766	1,807	20.6%
5	387	645	1,667	19.0%
6	314	482	1,535	17.5%
7	324	463	1,429	16.3%
Total	**2,695**	**4,977**	**1,847**	**21.1%**

Quelle: Haas (2009), p. 220

The determination of economical wind power potentials depends on the expectations about future competitiveness of wind power. According to a study by EEA, the total technical wind potential in Austria is 466 TWh, out of which very little is competitive by 2020; however, 56 TWh is economically feasible by 2030.[94] This data indications shows that within two decades a large part of the electricity could be generated by wind.

4.4.5 Solar photovoltaic

The proportion of the sun's rays that reaches the earth's surface can satisfy global energy consumption 10,000 times over. On average, each square meter of land is exposed to enough sunlight to receive 1,700 kWh of energy every year, but only a certain part of solar radiation received can be used to generate electricity. If 0.71% of the European land mass were covered with PV modules, this would meet Europe's entire electricity consumption. Moreover, if only 4% of the world's very dry desert areas were used for PV installations, this would meet the whole world's total primary energy demand. Considering the vast areas of unused space (roofs, building surfaces, fallow land, deserts, etc.) the potential is almost inexhaustible.[95]

By 2030, solar PV systems will supply between 9 and 14% of the worldwide consumption of electricity. In advanced scenarios, electricity production reaches about 2,600 TWh produced from cumulative capacity installed of about 1.900 GW. 'Although the key markets are currently located mainly in the industrialized world, a global shift will result in a significant share – about 20% or an annual market of 56 GW – being taken by the developing world for rural electrification in 2030. Since system sizes are much smaller,

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[94] EEA (2009), p. 48

[95] EPIA (2010), p. 14

and the population density greater, this means that up to 3.2 billion people in developing countries would by then be using solar electricity.'[96]

There are two basic types of technologies for converting solar energy into electricity: Either by a thermal process running a generator (concentrated solar power) or by using the photovoltaic process. 'Solar photovoltaic (PV) generates electricity through the direct conversion of sunlight (…). Concentrating solar power systems (CSP) use concentrated solar radiation as a high temperature energy source to produce electrical power and drive chemical reactions. CSP is typically applied in large-scale plants under very clear skies and bright sun. The availability of thermal storage and fuel back-up allows CSP plants to mitigate the effects of sunlight variability.'[97]

For the case of Austria, primarily photovoltaic electricity generation seems feasible. The realizable electricity potentials from solar are restricted due to technological, economical, and environmental reasons. So, a solar PV potential can only be estimated by making assumptions. Today the most important restriction is still the investment costs for photovoltaic equipment, though in the last decade the costs have dropped significantly.

In the last decade, the diffusion of grid-connected PV systems has increased exponentially. This type of application accounts for around 90% of total global installed capacity, which amounts to 8,800 MW in 2007, compared to only 10% stand-alone systems. Currently, single and multi crystalline silicon technologies dominate the market, while thin-film technologies represent about 10% in terms of installed capacity. New concept devices, including ultra-low cost cells and ultra-high efficiency cells, are still in an early development state.[98]

Just three countries, i.e. Germany, Japan, and the USA, at present account for approximately 70% of global cumulative capacity installed. China, India, Australia, Spain, and Korea are expected to become important global players in PV in the near future, both in terms of installed capacity and in manufacturing. Global installed PV capacity has been growing at an average rate of more than 35% since 1998.[99]

For open-space PV parks, the energy yielded per unit of land is a function of the array power density (power per unit land area occupied) and the PV generation (energy

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[96] EPIA (2008), p. 9 seq.

[97] IEA/PVPS (2010), p. 6

[98] Krewitt (2009), p. 135

[99] Krewitt (2009), p. 135

generated per unit of power). 'For any given site and PV module, the energy density is ultimately a function of how the system is configured. If PV systems are tilted (or mounted on tracking arrays) the energy yield per unit of module power increases, but the spacing between modules needs to increase in order to avoid self- shading and to allow for maintenance. Ground-based arrays have the additional complication of requiring minimum spacing between rows to allow for service vehicles.'[100]

A higher tilt angle or deploying tracking arrays increase the yield per unit area by over 50%, moving from flat to 2-axis tracking. However, the increased yield from tilting does not make up for the significant additional land area required to avoid self-shading. 'The energy density for tilted- and single-axis tracking arrays are around half of the energy density of a flat, rooftop system, while 2-axis tracking system may produce about 1/3rd of the energy per unit of land area. Ultimately, this represents a tradeoff between land costs and PV-collector costs.'[101]

The PV potential in Austria is calculated with average values for module efficiency of 15%, solar radiation of 1000 W/m2, and a capacity utilization of 950 full load hours per year for roofs and land space, and 650 h/a for building facades. The solar PV potential is estimated upon half of the suitable area on roofs (in total 140 km^2) and facades (52 km^2), plus assuming that solar parks could be erected on a land area of 150 km^2.[102]

The total solar PV electricity generation potential is about 20 TWh by 2030, as shown in the table below:

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[100] Denholm (2008), p. 1

[101] Denholm (2008), p. 2

[102] Fechner (2007), p. 43

Table 6: Solar PV potential in Austria until 2030

Parameters	**Units**	**Roofs**	**Facades**	**Open spaces**	**Total**
Surface area	km2	70	26	150	246
Average efficiency	%	15%	15%	5%	15%
Average solar radiation	W/m2	1,000	1,000	1,000	1,000
Full load hours	h/a	950	650	950	897
Capacity installed	GWp	10.5	3.9	7.5	21.9
Electricity produced	**GWh/a**	**9,975**	**2,535**	**7,125**	**19,635**

Source: Fechner (2007), Denholm (2008), own assumptions

Compared to EREC's projections of electricity generation by solar PV shown further above, the Austrian potential represents a share of about 3 % in Europe by 2030, for the case of full development of this potential.

Beyond using rooftops and facades on buildings, if large-scale ground based PV systems are deployed, then land-use impacts should be considered, for which other land-use applications provide a useful comparison. For example, in the USA, golf courses and airports each currently occupy about 35 m^2 per person, while land used to grow corn for ethanol production exceeds 200 m^2 per person.[103] Using 150 km2 for solar PV in Austria would result in a land-use of just 18 m^2 per capita, what also demonstrates that the potential of solar PV is even much higher in the long run.

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[103] Denholm (2008), p. 4

5 Modelling and analyzing the investment needs

5.1 Methodical introduction

5.1.1 Scenario concept

Thinking in scenarios about the future development differs from projecting trend paths in two ways. First, it is a future-open way of thinking that includes uncertain markets and industries as well as technological and general environment by describing and developing several, conceivable future perspectives. Second, it is an inter-connected way of thinking that integrates the concurrence of variety and dynamics, so-called complexity, requesting the management to consider the overall development and behaviour of systems. The combination of future-open and inter-connected thinking leads to scenario definitions. A scenario is understood as one of several images that are based upon a logical combination of thinkable assumptions for the future development. In practice, the majority of scenario concepts do not use probabilities, and the main methodical distinction of scenarios is made by the procedure of constructing the scenario construction:[104]

- Inductive scenarios are constructed by systematic and complete connection of possible developments of key factors.
- Deductive scenarios are built by firstly defining the subject, and then alternative developments of the key factors are assigned to it.

Due to the fact that the author cannot integrate into his master thesis all possible factors and developments in an inductive way, the scenario is constructed deductively. It can be described as a scenario model for planning and simulation of different developments and results over a period of time. The probability of the single scenarios is not known, but only such information and data is assigned to the model that can be derived from sources that were analyzed before. This methodical approach also gives room to scenario alternatives, which by tendency connect more extremely the key factors to open up a broader angle of possible futures.

5.1.2 Model definition

The scenario model developed in this paper puts together information from different areas of influence to approach the range of possible future developments of the electricity generating system in Austria. The information and data used is based on general

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[104] Fink (2006), p. 15 seq.

literature, research studies and data bases. The main components of the scenario model are shown in the following diagram:

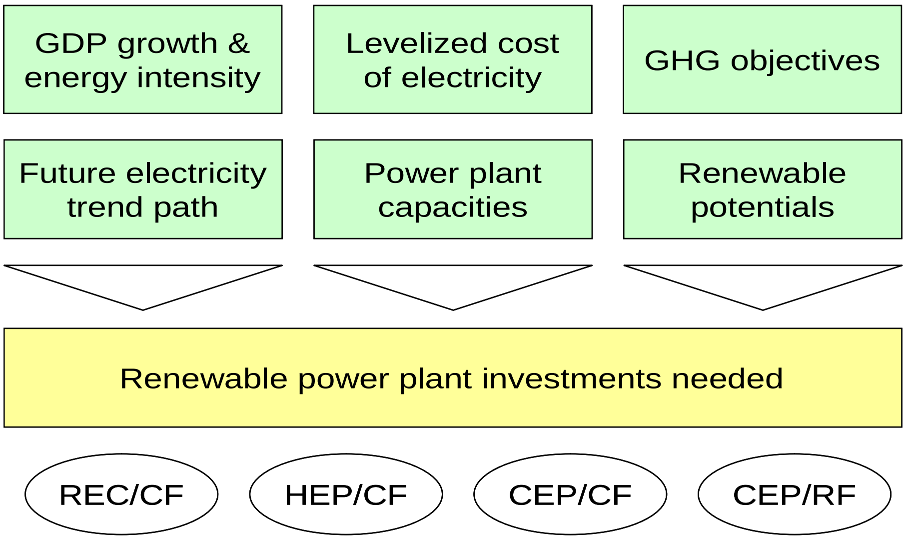

Figure 35: Components of the scenario model

The need of urgent greenhouse gas mitigation is an inherent motivation for writing this paper. The framework conditions are assumed to be favorable for utilization of renewable potentials. The model includes, especially for wind and solar energy, scenarios which reach beyond more conservative scenarios, depending on the technological progress and the economical and political framework conditions in the years to come. The future electricity trend paths are estimated with the intention to cover a growing share of final energy demand by producing electricity from renewable sources. Countries like Austria, with little own fossil fuels reserves, are able to diminish import dependence by increasing the renewable electricity generation.

The LCOE (levelized cost of electricity) calculation shows how the costs of electricity generation compare between different technologies today, and how this cost structure changes over the next two decades. The cost development is an important factor of influence for deriving the needed volume of investments. Because the investment costs of renewable power technologies are higher than for fossil plant, a higher share of renewables in new plant installations also causes higher investment volumes.

The investment scenarios are based on three electricity trend paths (REC, HEP, CEP). The basic assumption is that fossil plants are not replaced by renewables (CF), but that the yearly growth is covered only by new renewable installations. Additionally, for the clean energy policy scenario (CEP) also a scenario variation is determined, in which the fossil plants are linearly reduced to zero over the next twenty years (RF). The names of the renewable electricity scenarios are:

- REC/CF Reference case
- HEP/CF High energy prices
- CEP/CF Clean energy policy
- CEP/RF Clean energy policy, plus replacement of fossil plants

CF: constant fossil production capacity; RF: reduced fossil production capacity (linearly by 5% per year)

The single parameters of the different scenarios are defined in the chapter further below concerning the model assumptions. For the clean energy policy scenario the basic assumption is that the legal and financial framework is optimized for increased consumption of electricity generated from renewable sources. Today, numerous policy concepts and practices exist, but a detailed assessment of the different instruments and its efficiencies is not in the scope of this paper.

5.1.3 Constant values

Economic analyses can use either current values by including the effect of inflation or constant values by not including inflation. Utility engineering analyses normally are made in current values, because the figures approximate the actual costs when they occur. Constant values are normally used in analyses for comparing technologies to recognize the potentials of technical advancements, performance improvements and cost reductions in a longer time-frame. Disadvantages of constant-value computations are that it presents cash flows in reference-year figures, which are lower than actual values in the future, and it understates capital carrying charges. On the other hand, constant-value analysis, which is also applied in this paper, does not incorporate inflation effects into capital carrying charges and operating cost projections. The main advantages of using constant values are:[105]

- Generally preferred by economic analysts
- Figures appear close to today’s values
- Clarifies real cost and revenue trends
- Enables a better intuitive understanding of results
- Present value calculated with the real discount rate

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[105] Ramachandran (2009), p. 1-10

The variety of parameters in a scenario model for electricity production is evident, and assumptions and simplifications are necessary to reduce complexity. By doing so, no important aspects must be neglected. The sources have been analyzed carefully for relevant information and data, which partly had to be transformed for reasons of consistency and comparability, e.g. concerning the base years of investment costs, the used currency, and energy units. In general, cost figures, and change rates are expressed in constant values. For transforming current values or rates, the Austrian consumer price index is used.[106]

5.1.4 Uncertainties

'As the power generation technologies are quite capital intensive, there are several technical, economic and financial factors that influence the variations in capital cost from one technology to another and from one project to another. Higher uncertainty with respect to performance of a key component in a new technology will result in more significant impact on the cost estimate. Many factors contribute to the overall uncertainty of an estimate. They can generally be divided into four generic types:'[107]

- Technical: Physical phenomena, small sample statistics, scaling errors
- Estimation: Less-than-complete designs, planning and execution over several years, capital expenditure spread over several years, project and construction schedule depending on environmental permits
- Economic: Unanticipated cost changes, financing costs linked to project duration, recession impacts
- Other: Permitting, licensing and other regulatory actions, labor disruption, weather conditions

The analysis of present and future costs of electricity generation, as briefly described in the following chapter, is linked with a lot of uncertainties concerning the underlying assumptions about the key factors. The main aspects influencing the economic optimum for power plant decisions are:[108]

- Future development of fuel prices: Higher market prices make investments for higher efficiency levels affordable.

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[106] OeNB Statistics (2010)

[107] Ramachandran (2009), p. 1-5

[108] Schneider (1998), p. 14

- Depreciation period and interest rates: Short depreciation periods and/or high interests lead to an overweight of investment costs which is compensated by lower efficiencies.

- Capacity utilization of the plant: For peak load plants fuel costs are subordinate to capital costs which are minimized by reducing the efficiency (base load vice versa).

- Level of possible eco taxes: Energy and/or carbon taxes are variable running costs, so higher efficiency rates are thrived for.

5.2 Key factors of influence

5.2.1 Investment costs

The investment costs of new power plants depend upon a row of factors, e.g. efficiency rate, location of the plant site, size, and number of blocks, planning and construction time. Specific investment costs are related to a certain net capacity installed (block size) and a certain net efficiency rate. Specific investment costs are benchmarks from which actual plant realizations can substantially differ. The total investment costs comprise the following main components:[109]

- Costs of the turnkey plant
- Contributions of building owners
- Interest during the construction time

To obtain an actual overview of cost and performance data for conventional and renewable power generation technologies, a number of literature sources was screened and analyzed. The cost indications found are real prices from different years, ranging from 2003 to 2009. The values are taken unchanged, assuming that real price changes in the short term are not significant, except for new renewable technologies. The two tables inserted below show power plant data from different sources, upon which generic assumptions for the LCOE calculation model applied are derived for the scenario model.

Besides of necessary currency conversions (1€ equals 1.30 US-$), some of the original data is streamlined, e.g. heat rates are transformed into efficiency rates, and operating staff needed is included to specific O&M costs. Concerning investment and O&M costs, most of the information found is not specified in detail, causing uncertainties in

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[109] Schneider (1998), p. 14 seq.

comparison and interpretation of the data used. The following literature sources are underlying:

- EPRI 2009: 2008$, service date 2015, all-in costs (total capital requirement), including project-site specific and owner's costs[110]
- EPRI 2006: 2004$, service date 2010, overnight costs (without owner's costs)[111]
- Lazard 2009: Total capital cost (owner's cost included)[112]
- RWI 1997: Only conventional plants, specific investment costs (excluding construction interest)[113]
- EIA 2010: 2008$, order date 2009, total overnight costs[114]
- Green-X 2009: 2009€, data only for RES-E[115]
- Haas 2008: Cost data for renewable technologies, base years 2005-10[116]
- LUT 2008: Price level of 2008, investment costs including construction interest and owner's costs[117]
- BEI 2004: Investment costs as of 2003, fixed O&M incl. personal costs[118]
- IEA 2010: No indication of base year[119]

The following two tables summarize the cost and performance data found in the sources listed above for conventional and renewable power plants:

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[110] Ramachandran (2009), p. 1-15 seqq.

[111] Bedard (2006), p. 30 seq.

[112] Lazard (2009), p. 9, 13 seqq.

[113] Hillebrand (1997), p. 12 seqq.

[114] EIA (2010a), p. 91, 160 seq.

[115] Resch (2010), no p.

[116] Haas (2008), p. 220 seqq.

[117] Tarjanne (2008), p. 3 seqq.

[118] Pfaffenberger (2004), p. A-3 seqq.

[119] IEA/ETP (2010), p. 118

Table 7: Cost and performance data of conventional power generation plants

	Plant type	Data Source	Capital Costs €/kW	O&M fixed €/kW.a	O&M variable €/MWh	Plant Size MW	Plant Life Years	Efficiency %	Capacity Factor %
Hard Coal	SCPC	EPRI 2009	2038			660-750		38	80
	PC	EPRI 2006	962			600		39	80
	SCPC	Lazard 2009	2154	15.7-24.3	1.5-4.6		20		
	Dry firing	RWI 1997	1866	56.0	1.8			48	
	Scrubbed	EIA 2010	1710	21.7	3.6	600		37	
	PC	LUT 2008	1300	19.2	5.6	500	25	42	91
		BEI 2004	850-1000	19.8-22		600	40	45	
	SCPC	IEA 2010	1615	32.3				42	
Hard Coal	IGCC	EPRI 2009	2277			800		38	80
	IGCC	EPRI 2006	1062			600		37	80
	IGCC	Lazard 2009	3135	20.3-21.7	5.2	580	20		80
	Gas & steam	RWI 1997	2352	70.6	1.8				
	IGCC	EIA 2010	1976	30.4	2.3	550		39	
	IGCC	IEA 2010	1846	55.4				42	
Natural gas	CTCC	EPRI 2006	677					47	80
	NGCC	EPRI 2006	354			600		46	80
	NGCC	Lazard 2009	731-904	4.2-4.8	1.5-2.7	550	20		40-85
	Gas & steam	RWI 1997	974	19.5	1.0			58	
	CC advanced	EIA 2010	745	9.2	1,6	400		51	
	CCGT	LUT 2008	700	14	3.3	400	25	58	91
	Gas & steam	BEI 2004	400-550	9.2-11.8		2x400	30	57	
	NGCC	IEA 2010	692	20.8				57	
Nuclear	advanced	EPRI 2009	3738			1400		33	90
	ABWR	EPRI 2006	1231						85-90
		Lazard 2009	4865-6442	9.8	8.5	1100	20		90
		RWI 1997	2840	88	0.5			34	
	advanced	EIA 2010	2938	70.8	0.4	1350		33	
	PWR or BWR	LUT 2008	2750	40	5	1500	40	37	91
	Gen. III+	IEA 2010	2308-2846	69.2-85.4				36	

The investment costs of fossil and nuclear power generation are in a broad range, related to the full scope of different conditions and options possible in setting up a power plant investment. The specific investment costs are in the lowest range for power plants using natural gas. Coal generation largely depends on the conversion process applied, with the combined gas and steam cycle being more costly than the conventional steam process. Nuclear plants are the most capital-intensive power plant technology.

Table 8: Cost and performance data for renewable power generation plants

	Plant type	Data Source	Capital Costs €/kW	O&M fixed €/kW.a	O&M variable €/MWh	Plant Size MW	Plant Life Years	Efficiency %	Capacity Factor %
Small hydro	medium size	Green-X 2009	1275-5025	40		2	50		
		IEA 2010	2308						
Large hydro	conventional	EIA 2010	1762	1.9	10.7	500			65
	medium size	Green-X 2009	1125-4875	35		75	50		
		IEA 2010	1538	30.8					
Geothermal		Lazard 2009	2635-3519	0	19.2-23.1	30	20		70-80
		EIA 2010	1345	129.5	0	50		10	90
		Green-X 2009	2575-6750	113-185		5-50	50	11-14	
		BEI 2004	2000-6000	80		5	30	6-11	
		IEA 2010	1846-1923	169.2					
Wind	US average	EPRI 2009	1808			100			35
	class 3-6	EPRI 2006	846						30-42
		Lazard 2009	1462-1923	30.8-38.5	0	100	20		28-36
	onshore	EIA 2010	1353-1512	30.8	0	100			43
	onshore	Green-X 2009	1125-1525	35-45		2	25		
		Haas 2008	990	37.5					
	onshore/coast	LUT	1300	52.8	16	3	25		25
	onshore	BEI 2004	900-1200	37.8-50.4		1.2	20		
	onshore	IEA 2010	1115-1692	39.2					
Biomass	CFB	EPRI 2009	2754			75		28	85
	CFB	EPRI 2006	1538					25	85
	direct	Lazard 2009	2423-3077	63.8	8.5	35	20		80
		EIA 2010	2961	50.7	5.3	80			83
		Green-X 2009	2225-2995	65-95		1-25	30	26-30	
	wood chips	Haas 2008	2000	29		30		30	
		LUT 2008	2700	43.2	3.6	30	25	33	91
	steam turbine	BEI 2004	2700	54		20	35	30	
		IEA 2010	1923	85.4					
Solar thermal	trough	EPRI 2009	3732			125		13.5	22
	Par. Trough	EPRI 2006	2423						33
	trough	Lazard 2009	3462	50.8	0	200	20		26-29
		EIA 2010	3165-3948	44.7	0	100			31
		Green-X 2009	3600-5025	150-200		2-50	30	33-38	
		IEA 2010	3462-5385	23.1					
Photovoltaic		EPRI 2009	6139			20		10	26
	crystalline	Lazard 2009	2500-3846	19.2	0	10	20		20-27
		EIA 2010	4206-4747	9.2	0	5			21
		Green-X 2009	2950-4750	30-42		<1	25		
		Haas 2008	4465-6065	50				13	10
		IEA 2010	2692-4302	38.5					

Compared to conventional power generation, the data and information found is even more heterogeneous; and detailed descriptions often are missing. Investment costs for hydropower naturally depend a lot on size and location of the plant. Wind energy offers the lowest specific costs, but also the load factors are lower than for hydropower or biomass plants. The investment costs of biomass plants have a similar range like advanced coal combustion, what is not very surprising due to the similarity in the conversion processes. The most capital-intensive renewable power technologies are geothermal, solar thermal and solar photovoltaic with specific costs reaching even above nuclear power plants.

The broad range of data found demonstrates that there certainly is not just one correct definition of costs and performance for different power plant technologies. The main differences origin form the choice of energy conversion technologies leading to different net efficiency rates, from the competitive market situation for technology providers in different regions, from different start dates of the power plant service, and from changing currency relations causing purchasing power shifts.

Investment costs normally are linearly depreciated over a period shorter than real plant lifetime expected, and the yearly accounted interest expenses are based on the amount still not depreciated. The annual total costs of the investment are the sum of the depreciation and interest amounts of each year. The depreciation period is an important factor of influence for the capital costs, with the distinction to be made between depreciation recognized for tax purposes and depreciation reported for accounting. The imputed depreciation is oriented towards the economic life of a power plant, whereas the tax-deduction is not relevant because of pre-tax character of cost calculation. The optimal economic life-time of the plant is at the point where the total of average investment and O&M costs reaches the minimum. Investors may have reasons to reduce the depreciation period compared to the economic life time for purposes of comparison different plant types:[120]

- Competitiveness of aged plants: For continued operation of an aged plant the actual marginal costs have to compare with the full costs of a new plant. Over time repair costs and fuel prices could be increasing, so that the aged plant could get uneconomical.
- Future electricity prices: Due to the liberalized electricity industry the uncertainties about the future market situations are increasing, e.g. the electricity prices could fall towards the short-term marginal costs due to overcapacities.

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[120] Schneider (1998), p. 51 seqq.

5.2.2 Load factor

Power generation by different energy sources depends on the merit order, which is defined according to ascending variable operating costs of power plants for dispatch. The number of hours per year a plant operates depends on fuel costs and plant efficiency. Concerning fuel costs, a gradual deterioration of competitiveness of natural gas relative to coal is expected with important consequences for the structure of the merit order. The competition among fossil power plants within the merit order concerns primarily natural gas and coal plants. Older plants are less efficient than new ones and so they lose ranks in the merit order, as capacity replacement and expansion progresses over time.

The following load scheme of plant operation will be predominant in the future electricity generation system:[121]

- Low variable cost plants, such as nuclear, hydro run-of river and lignite plants, rank first in the merit order but their capacities are limited for various reasons.
- Intermittent generation from renewable sources is absorbed by the system according to prevailing regulations, such as the feed-in tariffs which are widely applied in the EU.
- Hydropower plants with reservoirs operate according to regular annual cycles and ensure generation in peak hours. They are also the main contributors of ancillary services, such as voltage regulation.
- Peak devices are also used for such purposes and contribute mainly as reserve units in peak hours.
- Operation of plants with a strong cogeneration component is usually driven by steam/heat demand and its load pattern.

The average load factors of power capacities in different areas of resources are shown in the following table:

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[121] EC (2008), p. 64 seq.

Table 9: Load factors in electricity generation by type of resource, 2000-2030

	2000	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Nuclear	0.75	0.80	0.83	0.84	0.84	0.92	0.93
Solid fuels	0.51	0.53	0.59	0.65	0.71	0.73	0.77
Large gas	0.40	0.47	0.42	0.45	0.45	0.44	0.40
Small gas & oil	0.28	0.26	0.24	0.26	0.30	0.32	0.33
Biomass	0.46	0.58	0.48	0.48	0.55	0.52	0.54
Hydro	0.37	0.32	0.34	0.33	0.33	0.34	0.34
Wind	0.20	0.20	0.23	0.25	0.26	0.26	0.27
Other RES	0.57	0.37	0.26	0.22	0.20	0.19	0.18

Source: EC (2008), p. 65

In Austria, the load factors in fossil power plants are different to the values indicated in the table above. In 2008, for natural gas plants on average it was only 0.27 and for coal plants 0.48. The load factors used in most literature sources seem to overstate the operating of fossil plants in practice. Thus, in the LCOE calculation model lower load factors are used, reflecting the real situation in the Austrian electricity system.

5.2.3 Operations & maintenance

The running costs of electricity generation are the sum of fuel expenses, including carbon costs and/or other eco levies, and operation and maintenance costs. The running costs of electricity generation are relatively higher for fossil, nuclear and biomass energy sources. Renewable electricity production using solar and wind energy is operating with zero cost fuels, and O&M costs normally, with the exception of biomass, are also low in renewable power production compared to fossil-based plants. In the case of cogeneration plants the revenue gained form selling heat is deducted from the running costs.[122]

Fuel costs are fluctuating over time in dependence of the primary energy prices. O&M costs are annual expenditures that are either fixed, depending upon type and size of the plant, or variable in relation to the electricity output. O&M costs are increasing in the course of life time, especially maintenance and servicing, but also real price increases in personal costs might occur. The main components of O&M costs are:[123]

- Fixed O&M costs: Personal costs, maintenance & servicing, taxes & insurances.

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[122] Resch (2005), p. 36 seq.

[123] Schneider (1998), p. 23 seqq

- Variable O&M costs: Procurement of consumables, operating fuels, variable maintenance & servicing.

Based on the plant information found in the literature, the average total O&M costs in relation to power plant capacity, and its fixed and variable shares, are estimated as shown in the table below:

Table 10: Average O&M costs of main power generation technologies

Type of power plant	**O&M total costs**	**O&M fixed costs**	**O&M variable costs**
	€/kWp	share	share
Hard Coal	50	59%	41%
Natural Gas	25	46%	54%
Nuclear	80	63%	37%
Hydro	35	69%	31%
Biomass	60	66%	34%
Wind onshore	40	100%	0%
Solar PV	30	100%	0%

The main part of O&M costs is fixed, and often in sources only total O&M costs per unit of capacity are indicated. This is the reason that in the two tables above with power plant data often the column for variable O&M costs is empty. Variable O&M costs in most cases have a relatively lower level, so the total O&M costs are related to the power plant capacity installed.

5.2.4 Learning rates

In history, learning effects have been proven for various technologies. Spreading utilization of new technologies leads to growing experience, which is expressed by higher safety and quality, lower costs, and improved efficiency. Future projections concerning the development of technology costs are uncertain; and they need to be calculated and interpreted carefully. Notwithstanding, it is necessary to take into account cost reductions and efficiency improvements when analyzing future scenarios. Two methodical approaches to technological learning are distinguished:[124]

- Exogenous learning, expressed by yearly cost reductions
- Endogenous learning, expressed by experience curves and learning rates

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[124] Haas (2008), p. 19

In the most common approach, the future cost reductions are defined through a function of cumulative production, i.e. the capacity installed, and a constant learning rate over a certain period of time. Other models consider research & development expenditures as a second factor, which also causes technological progress. If the influence of research & development is not considered, the influence of cumulative production is over-estimated, especially in early markets, showing that research expenses cannot be substituted by production.[125]

In the electricity sector, technological progress is substantially determining the future development and comparison of LCOE. Not only for still quite nascent technologies like wind and solar, but also for fossil and nuclear power plants progress potentials are given, e.g. improvement of efficiency rates, reduction of generating costs, mitigation of pollutant emissions, enhancement of safety. The efficiency rates of coal power plants are expected to rise to above 60%, those of natural gas power plants even more than 70%. The third generation of nuclear power plants is now developed, and reactors of the fourth generation are announced until 2030. But the most dynamic technological progress is expected for the relatively new renewable energy technologies.[126]

Renewable energy technologies, with exception of hydropower, are still in rather early market phases and need legal and financial subsidies to be competitive with incumbent power production. Due to the globally and locally growing interest in clean energies, a rapid expansion process has emerged over the last one to two decades, which leads to declining production costs and to significant improvement in quality and efficiency of the predominant renewable options. For example, wind turbines at inland sites had a size of 95 kW peak and electricity generating costs of above 11 c€ per kWh in 1987. Until 2006, the turbine sizes grew to 2 MW, and the generating costs dropped to about 6 c€ per kWh. The specific costs of wind power production shows a progress ratio between 0.83 and 0.91, meaning that doubling the cumulative installed capacity leads to specific costs reduced by 9 to 17%.[127]

For the future, the highest learning rate is expected for solar photovoltaic electricity generation. The investment costs of different PV module technologies vary, but these module cost differentials are less significant at the system level, which are expected to converge in the mid and long term. The future cost reductions for PV systems are

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[125] Haas (2008), p. 20

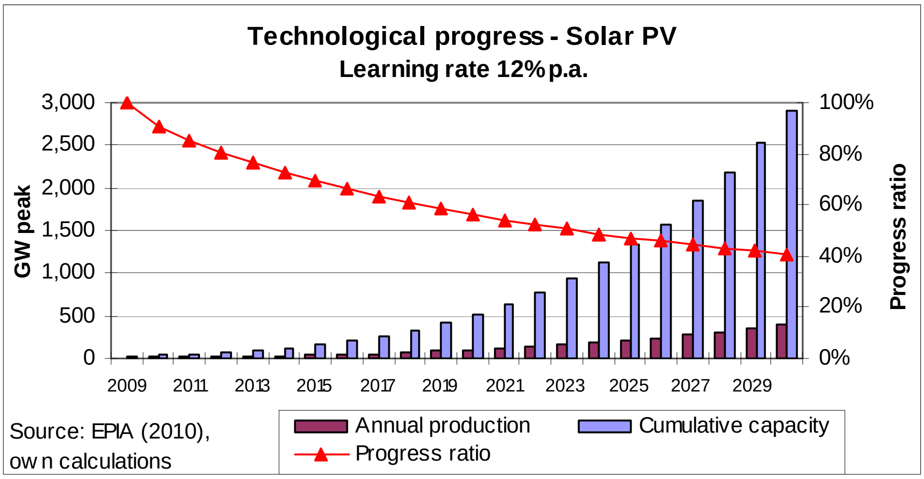
[126] EWI (2005), p. 23

[127] Krohn (2009), p. 10 seq.

assumed to continue along the historic PV experience curve, with average learning rates of 15 to 22% for every doubling of cumulative installed capacity. The primary progress goal is to reduce turnkey PV system prices and electricity generation costs by more than two thirds by 2030.[128]

Historical data of the last two decades indicate a fairly constant learning rate for PV systems at 20%. Different assumptions are made from 2011 onwards, assuming specific learning rates for the various PV components and different speeds of technology diffusion. For PV modules a fixed learning rate of 20% continues under the assumptions that after 2010 thin film PV penetrates the market, and then after 2025 a major technological shift occurs to third generation devices. For the electrical and mechanical balancing of PV systems, the learning rates will drop by 5 to 10% during the next 10 to 20 years.[129]

EPIA estimates that solar PV cumulative capacities installed grow from 23 GW in 2009 to about 128 GW until 2014.[130] Using this forecast data and assuming a growth rate of 25% for the year 2015, which then declines by 5% yearly in each of the subsequent years, the investment costs for solar PV systems decrease to about 41% of the costs in 2009, as shown in the following chart for a learning rate of 12% annually:



Source: EPIA (2010), own calculations

Figure 36: Technological progress in solar PV power generation, 2000-30

For analyzing the future LCOE development, valid learning rates are an important assumption. For the LCOE calculation model, the learning rates origin from the Green-X model. The respective experience curves are depicted in the following figure:[131]

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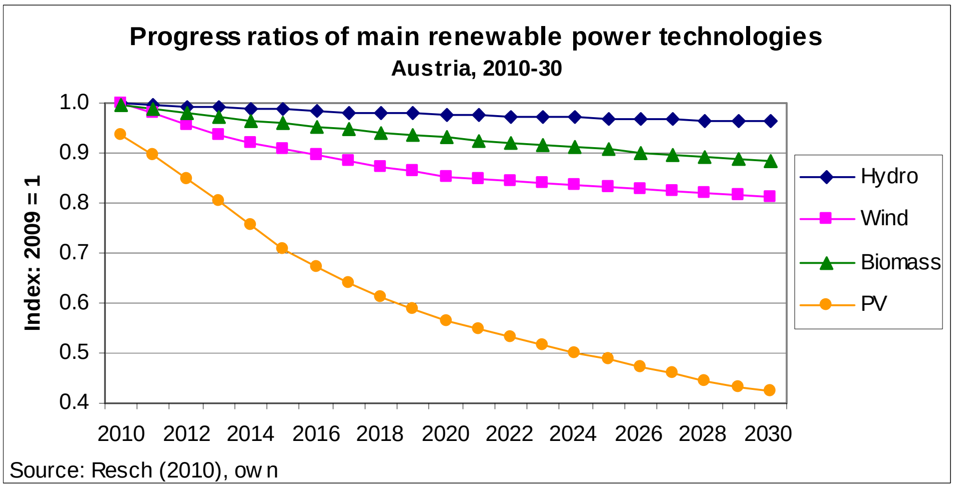
[128] IEA/PVPS (2010), p. 18

[129] Krewitt (2009), p. 137 seq.

[130] EPIA (2010), p. 9

[131] Resch (2010), no p.



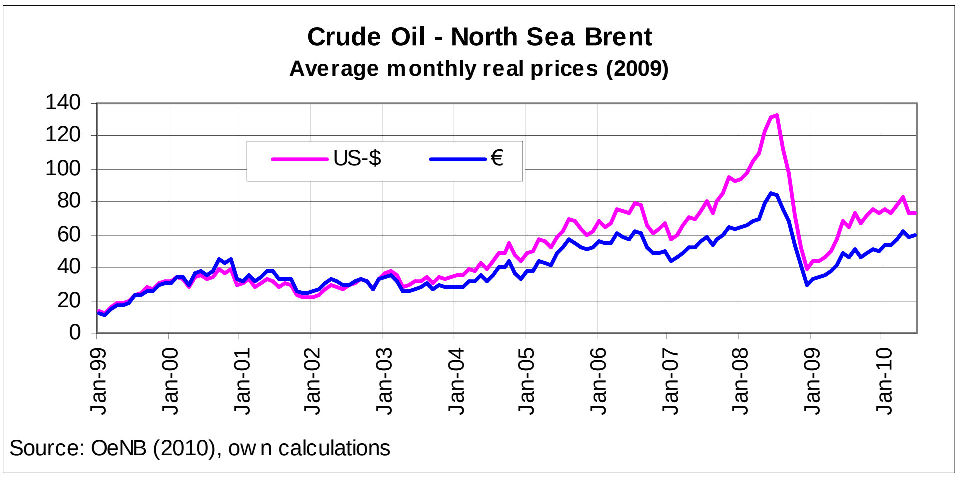
Source: Resch (2010), own

Figure 37: Progress ratios of main renewable power technologies, Austria, 2010-30

5.2.5 Fossil fuel prices

Fossil fuel prices are of large influence for the economic development. Criticizing the negative impacts of greenhouse gas emissions caused by fossil fuels must not disregard the huge growth of population and its progress in wealth that was possible since the beginning of the industrial revolution, especially in the so-called developed countries. Fossil fuels are the blood in the modern economies' veins and they need to flow with high reliability. Unfortunately, besides of global warming threats, the costs of fossil fuels are increasing over time and fluctuate heavily.

The historical development of the crude oil real prices is shown in the following figure:



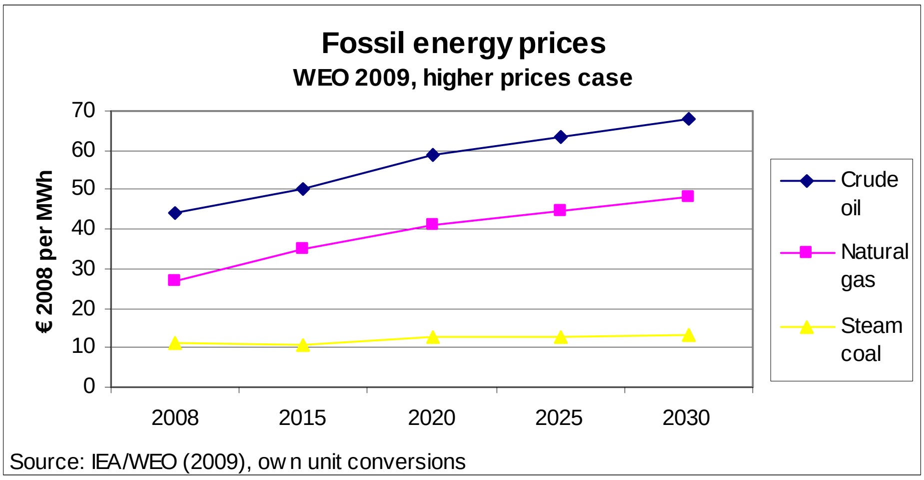
Source: OeNB (2010), own calculations

Figure 38: Crude oil real price development, North Sea Brent

For comparison of renewable with conventional power generation costs, it is necessary to make assumptions about future fuel prices. The problem in the real world is that fuel prices are not predictable, no long-term insurance is available, and long-term future markets for fuels do not exist, because market risk is too large. 'But you cannot sensibly deal with real risk in an economic calculation by assuming it does not exist. The unpleasant corollary of this is that engineering-economics cost calculations simply don't make sense because future fuel prices - just like stock prices - are both uncertain and highly unpredictable.'[132]

The EIA expects high uncertainty in world oil markets in its Annual Energy Outlook 2010. The future development of world oil prices spans a broad range reflecting the inherent volatility and uncertainty. The price paths are not intended to reflect absolute bounds, but rather to allow an analysis of the implications of world oil market conditions that differ from assuming a continuation of current trends in terms of economic access to non-OPEC resources and OPEC market share of world production. In the high oil price case, a future world oil market is depicted by the EIA, 'in which conventional production is restricted by political decisions and economic access to resources: use of quotas, fiscal regimes, and various degrees of access restrictions by the major producing countries decrease their oil production, and consuming countries turn to high-cost unconventional liquids production to satisfy demand.'[133]

The IEA is projecting in its reference case only a slow increase of fossil real prices, but in the higher prices case an acceleration of prices is forecasted. The graphs in the following picture are derived by transforming the price projections given in the World Energy Outlook 2009 into specific costs, denoted in 2008 € per MWh:[134]



Source: IEA/WEO (2009), own unit conversions

Figure 39: Fossil energy prices, WEO 2009 higher prices case, 2008-30

The figure shows that, according to IEA's projections, the coal price development decouples from crude oil and natural prices from now until approximately the year 2020. The

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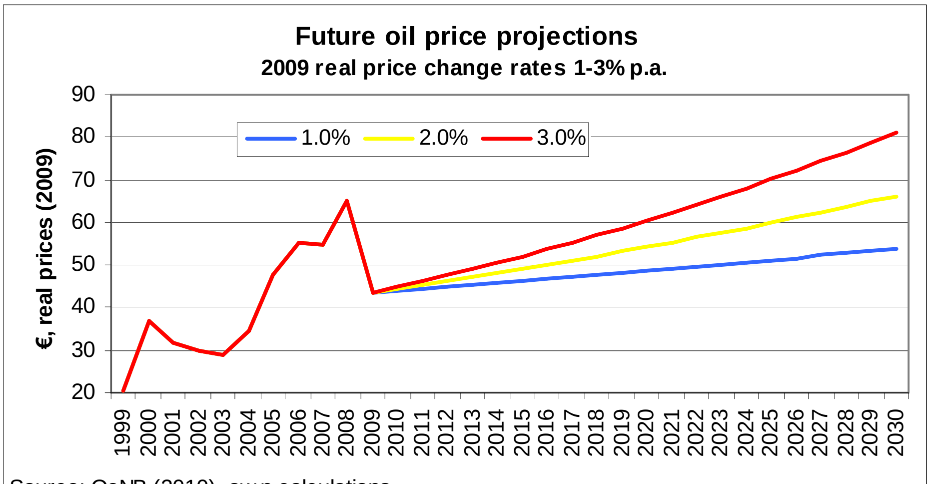
[132] Krohn (2009), p. 116

[133] EIA/AEO (2010), p. 54

[134] IEA/WEO (2009), p. 660

most valuable fossil fuel remains crude oil with higher specific costs than natural gas and coal. After 2020, the relation between the three main fossil commodities is kept in a close range. Roughly, the IEA assumes that specific cost of natural gas is 70% of crude oil and specific cost of steam coal is 20% of crude oil.[135]

In 2009, the average world market oil price was about 44 Euros (61 US dollars). From this starting point, in the following chart possible oil price projections are depicted:



Source: OeNB (2010), own calculations

Figure 40: Projections of future oil prices

Europe relies on fossil-fuel fired plants, with high economical risk of volatile and unpredictable fuel prices. There is only little incentive for power generating to mitigate the risk, unless governments use taxes or subsidies to rectify the market distortion due to ignored external costs and benefits. The benefit to society of using stable cost of electricity, e.g. generated by wind, to displace volatile fossil fuels cannot easily be sold in the market because the major beneficiary of such a policy change is society at large.[136]

Between the market prices for different energy commodities exists a close inter-relationship, as can be seen in the following chart:

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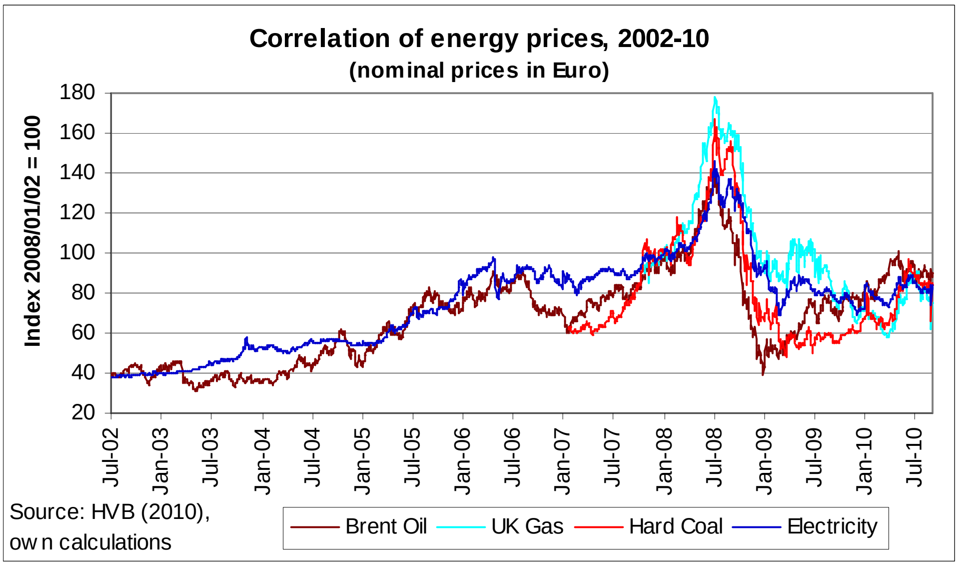
[135] IEA/WEO (2009), p. 660

[136] Krohn (2009), p. 113



Source: HVB (2010), own calculations

Figure 41: Correlation of energy market prices, 2002-10

The historical analysis of market data shows that, converted into nominal Euro values, energy prices approximately have doubled since 2002. Though, much more interesting is that the development in the long-term is quite similar, and the main energy carriers tend to stay in a narrow range if they are depicted and compared as indices. Also the price of electricity correlates closely with the fossil energy prices, because the main part of electricity is generated from conventional sources. Consequently, it can be expected that further increasing fossil prices, will also increase the relative cost-competitiveness of renewable power generation.

5.2.6 Carbon costs

With the liberalization of electricity markets, the pricing of electricity on the wholesale level has fundamentally changed. At present the prices are no longer established on the basis of average costs of electricity production as in the regulated monopoly market. The pricing in liberalised electricity markets takes account of the short-term marginal costs of electricity production, which would arise if the electricity demand marginally rises and additional capacity is needed. ‘In principle, pricing on the electricity markets is based on short-term marginal costs, i.e. the additional costs for the production of additional electricity. For the area of electricity production the short-term marginal costs up to the introduction of the EU Emissions Trading Scheme consisted above all of fuel costs. The last plant used (the so-called marginal generation unit) is thereby in a position to cover its fuel costs. If the market price lies below these costs, there would be no economically feasible reason for operating the power plant. Should the market price lie above the short-term marginal costs of a power plant, so-called contribution margins arise. These contribution margins can be used to cover fixed operation costs, to re-finance investments and to make profits.'[137]

Greenhouse gas emissions are an externality caused by fossil fuel consumption and its impact is a fundamental one: Long-term, global impact, major uncertainties, potentially of huge scale. Liberalized market mechanisms are failing if their main coordinating system, i.e. prices, gives the wrong signal to the market participants. Because of the widely accepted recognition that greenhouse gas emissions threaten the prospects of others, an appropriate response to fix this market failure is necessary, e.g. through taxes, other forms of price corrections, or regulation.[138]

The level of CO_2 prices has to be seen in relation with the external costs possibly caused by climate change. The assessment of such cost effects depends on a wide range of assumptions, so that the cost range spans from 15 to 280 € per tonne, with a medium estimate of 70 € per tonne CO_2 equivalent.[139] The CO_2 market price at the ETS has fluctuated around the lower end of this range in the last 18 months, but the maximum fine for power generators not fulfilling the obligation is 100 € per tonne. This shows that in the future higher carbon costs are likely, especially if external costs really are internalized.

In 2005, the European Union introduced the Emissions Trading Scheme (ETS) for greenhouse gas certificates, which changes significantly the economic conditions for electricity production. Carbon dioxide emissions have become a cost factor for electricity production. The power plant operators have to surrender the corresponding amount of emission allowances for their CO_2 emissions to the responsible authority. The total quantity of available emission allowances for all of the European Union is limited, and the emission allowances are tradable. If the quantity of the available emission allowances falls short of the expected demand, a shortage arises and the emission of CO_2 takes on a price within the emission allowance market. With the introduction of market prices for carbon emission, also substantial windfall profits have arisen, because the CO_2 costs are passed through to the wholesale market price. The revenues from electricity production thereby increase, although the emission allowances predominantly are allocated to the operators for free.[140]

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[137] Matthes (2008), p.7

[138] Stern (2010), p. 11

[139] Haas (2008), p. 17

[140] Matthes (2008), p. 5 seq.

For the third phase from 2013 to 2020, the EU has adapted the legal framework of the ETS. Until 2020 and beyond, the EU-wide cap is decreasing by a linear factor from the mid-point of the period 2008 to 2012, providing greater predictability for industrial sectors when planning investments. The scope of the EU-ETS is extended to other GHG; and all big industrial emitters are covered, including aviation and international maritime shipping. The allocation of certificates is harmonized, so that in the long run, all installations will have to buy their allowances on the market, through auctioning procedures. 'The electricity sector (except a transitional clause for new Member States) will start in 2013 with full auctioning, while other sectors will receive a substantial share of free allowances which will decrease over time. These free permits will be allocated on the basis of ex ante benchmarks, set at European level, which should help avoid market distortions.'[141]

The global CO_2 market is still nascent. In addition to the European ETS, only few other market places have been established by now. The global market size was 125 billion US dollars in 2009, only a small increase of +5% to the year before. The weighted average EUA price was 24€ per ton in 2008, and downward pressure on carbon prices was caused by the economical recession, which brought the CO_2 price to a low of 8.2 € per ton in February 2009, and the weighted average was as low as 14 € in 2009. Nevertheless, the global carbon turnover in carbon markets is predicted to grow to 1.3 trillion US dollars by 2020, once other relevant regions of the world will have agreed to join this market.[142]

The development of the CO_2 certificate contract prices in the ETS is shown in the following chart:

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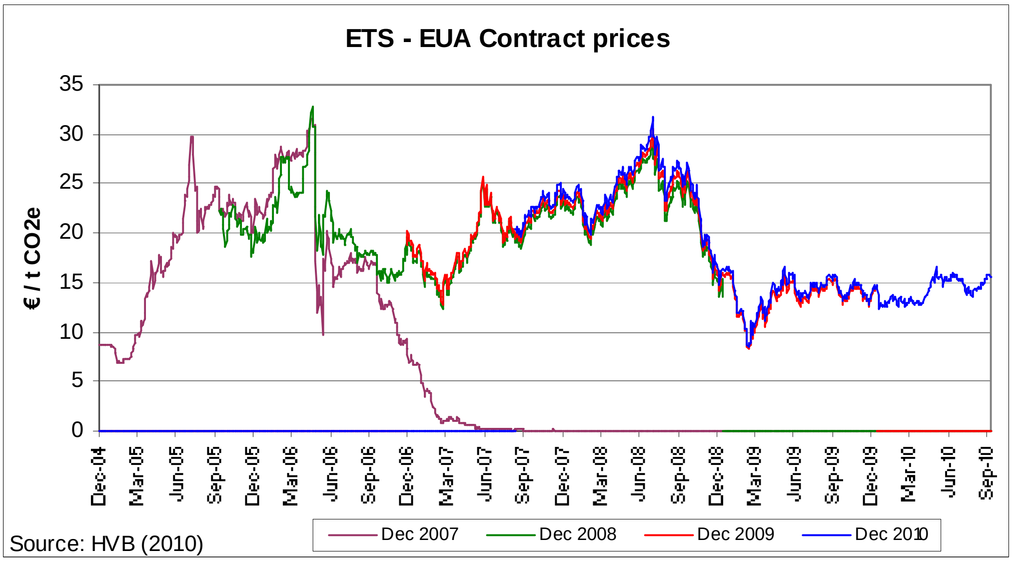
[141] WEC (2009), p. 65 seq.

[142] NEF (2010), no p.



Source: HVB (2010)

Figure 42: European Trading System (ETS), prices of EUA contracts

The carbon market prices can be compared to other costs for reducing greenhouse gas emissions, such as energy saving and renewable power generation. The CO_2 abatement curve reflects the annualized costs of different options in a given year in comparison with business-as-usual. 30% of the technical abatement options generate net economic benefits and another 50% would involve costs of below 20 € per tonne CO_2 equivalent. On average, the costs to abate all 38 Gt of CO_2 equivalents, forecasted by the year 2030, amount to approximately 4 € per tonne.[143] This comparison suggests that there is a large potential for mitigating GHG emissions in a very cost-efficient way, once the external costs are priced in correctly.

5.2.7 Discount rate

For calculating levelized costs of electricity, it is necessary to discount the future cost streams and sum it up to the total present value. The discount rate chosen for this computation is heavily influencing the LCOE, because for different technologies the costs are not spread in the same way over lifetime. Higher discount rates reduce the impact of future expenses in comparison with capital costs. Capital-intensive power generation technologies, like wind and solar, use free energy sources, but the initial investments are higher than for fossil power stations. For the time being, and continued until progress ratios sufficiently reduce the initial costs, a careful consideration of the discount rate is important, so that a correct and fair comparison of LCOE is guaranteed.[144]

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[143] McKinsey (2009), p. 39

[144] Schneider (1998), p. 50 seq.

Comparing power generating costs must take into account fuel and carbon price. Wind, solar, and hydro power generation are more capital-intensive, but the running costs are relatively low. Conventional thermal power generation is more expense-intensive, and the running costs, including as the largest component the fuel costs, are significantly higher than for renewable power. Due to the fact that fuel prices fluctuate and are unpredictable, the investment risk is relatively higher.[145]

Individual agents are demanding or supplying electricity on price-driven interactions in markets. Therefore, discount rates applied are reflecting the yield curve in financial markets. Discount rates pertaining to individual agents are usually based on the concept of cost of capital, which is termed weighted average cost of capital (WACC) for companies or subjective discount rate for individuals. In both cases, the rate used to discount future costs and revenues involves a risk premium, which reflects business practices, various risk factors or even the perceived cost of lending. The discount rate for individuals also reflects an element of risk averseness. This financial market-oriented approach leads to relatively high discount rates ranging in real terms from 8% applicable to large utilities up to 20% applicable to individuals. From the perspective of a social long-term planner, who does not follow a short-term cost optimization of the electricity system, the discount rates are much lower in a range of 4-5% in real terms.[146]

The LCOE of capital-intensive technologies, e.g. wind and solar, is highly sensitive on the discount rates used.[147] A high discount rate underestimates the attractiveness of predictable future cost streams. By tendency, it leads to an investor’s preference for power plant technologies that shift expenditure risks into the future, e.g. costs for fossil fuel or nuclear waste. This is possible until now, because cost risks are socialized in the way that the electricity market prices incorporate changes in running outlays of the utility, if no cheaper alternative exists. When the abundance of renewable electricity is steadily growing, it will be more difficult to adjust prices to fuel cost hikes, and consequently the risk for power generation from fossil sources goes up.

‘The finance concept of risk is well understood by investors, although not as it relates to renewable energy technologies. (…) Any projected cost stream associated with a particular electricity resource contains some degree of risk. While projected fossil fuel outlays clearly present the greatest risk, other cost streams, such as projected labor costs

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[145] Krohn (2009), p. 115

[146] EC (2008), p. 23 seq.

[147] Heptonstall (2007), p. 14

associated with O&M outlays also carry an element of risk. Compared to traditional evaluation methods, the inclusion of risk tends to raise the electricity cost estimate for conventional technologies, whose principal cost inputs are risky fuel and maintenance streams.'[148]

O&M costs in case of capital-intensive technologies, such as wind, and PV, are nearly risk-free in a financial sense. Maintenance of renewable power plants is just as risky as those of fossil technologies, but being rather small, it contributes little to overall risk. Fossil fuels are high-risk cost streams, unpredictable over time, and they fluctuate in a negative systematic manner relative to the economy and to the returns on other assets. 'This important relationship has significant implications for both electricity cost estimation and for energy security. These have gone largely unnoticed. Other cost-streams are less risky. Fixed maintenance and various contractual obligations fluctuate less on a periodic basis (…).Capital-intensive renewables, such as photovoltaic and wind turbines, exhibit low systematic risk (…) because their costs are almost entirely in the form of up-front capital outlays and their yearly operating costs are small and predominantly fixed.'[149]

The IEA is setting a rate of 3% in one of its scenario variants to explore the impact on the electricity sector of using a single lower discount rate to reflect social time preferences, rather than the market rates of between 8% and 14%. This assumption results in much higher levels of renewables and in fossil fuels in end-use sectors being replaced increasingly by electricity. The CO_2 emissions in this variation decrease more quickly compared to those of other scenarios with higher discount rates.[150]

Due to the high relevance of the discount rate applied, the effect of risk-adjustment is part of the LCOE sensitivity analysis. For the baseline LCOE model the real discount rate is set at 6%. From the standpoint of private investors, this might seem low, but with risk-free government bond rates near 2%, the consideration of renewable power investments at 6% internal rate of return is an attractive alternative to other financial investments with comparable risk profiles.

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[148] Awerbuch (2005), p. 5

[149] Awerbuch (2005), p. 9

[150] IEA/ETP (2010), p. 113

5.3 Cost of electricity

5.3.1 LCOE concept

Electricity is a commodity that is produced from different primary energy sources using different kinds of technology. Whatever the upstream production process is like, electricity cannot be differentiated by the final user, even if the market prices are different. The main economical attribute for competition in the electricity markets is the unit cost of electricity produced. From the profit of an electrical utility to the investment decision of a private homeowner, the costs of electricity are the main financial parameter.

Thinking about a transition from fossil to renewable sources for electricity generation, means to change the cost conditions of electricity in a substantial way. If electricity supply and demand meets in a competitive market environment, this is the predominant factor influencing the decisions and actions of market participants. Such behaviors can only be changed by the legal framework or by individual willingness to pay more, e.g. for green electricity.

In the scenario analysis model used in this chapter to calculate the investments needed for future renewable electricity generation, the concept of levelized costs of electricity (LCOE) has a core role. Only by comparison of LCOE resulting from different technologies used, a possible path of transition and the related financing needs can be determined. Policy measures can accelerate or slow down the development, but the underlying economical factors of electricity production must be known and become acceptable for the society over time.

The LCOE is calculated in two steps. First, for all future cost streams the total present value is determined. Beside of initial investment costs, and running costs (O&M, fuel, etc.), also the demolition and remediation costs at the end of the operating period are included in the cost calculation. Second, the equivalent annual costs, calculated by multiplying the present value of the costs with the annuity factor, are divided by the average annual electricity output, which is the product of net capacity times full load hours.[151]

5.3.2 Cost components

The main cost components of electricity production are capital costs, including planning and site work, operating and maintenance costs (O&M), fuel costs, and if applicable the

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[151] Schneider (1998), p. 50 seq.

cost of carbon emissions.[152] However, implicit in these variables are a whole range of detailed estimates and assumptions, each of which being open to analysis, critique and debate. The most important ex ante decision in cost calculation is about what is included and what is excluded from it.

Normally included in electricity cost calculations are the following components:[153]

- Capital costs
- Fuel cost and fuel taxes
- Operating and maintenance costs
- Waste management costs
- Decommissioning costs
- Site-specific R&D and insurance costs
- Costs of emissions regulations, e.g. cost of carbon
- Economic plant lifetime
- Plant load factor
- Discount rate
- Build schedule
- Shape of the learning curve

The following components often are not captured by levelized electricity cost calculations. Some of these factors possibly can be incorporated by adjusting the elements described above, so that they act as a proxy for the missing parameter. There are three groups of missing LCOE components:[154]

- Externalities, e.g. value of government funded research programmes, residual insurance responsibilities that fall to government, external costs of pollution damage, inter-temporal and inter-generational cost issues

- System factors, e.g. impact on power system balancing, impact on system level energy security, flexibility and controllability of power station output

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[152] Krohn (2009), p. 12

[153] Heptonstall (2007), p. 9

[154] Heptonstall (2007), p. 10

- Business impacts, e.g. cost of the irrevocability of investments, actual versus economic plant lifetime, fuel price and future revenue volatility, future changes to tax regimes, environmental legislation, government support mechanisms

‘Looking at the list of what is potentially not captured by levelized cost estimates, there are two striking points. Firstly the sheer number of factors that this approach either struggles to incorporate or ignores completely, and secondly, the importance of these excluded factors in the investment decision process. Given this, it is not surprising that levelized costs are only one of the indicators that companies may consider when assessing their investment options.’[155]

For the design and development of a power plant, different optimization goals are followed, e.g. low costs, high availability, high safety and reliability, low environmental impacts. Some objectives partly cannot be harmonized, so normally minimum standards are defined for availability, safety, reliability and environmental impacts, upon which the cost of electricity is minimized. The investor must balance the initial investment with the future operating costs by deciding about the type of technology and the efficiency rate. The cost minimum usually lies somewhere between the low and high ends of efficiency rates, e.g. given cheap fuel supply, highly efficient power plants are not built, because higher investment costs are not compensated by fuel cost savings. Higher fuel prices, lower interest rates, and increased eco taxes push the economic optimum towards more efficient power plant solutions.[156]

Because of the uncertainties in the underlying definitions and assumptions, any comparison of LCOE between different technologies only opens up the window for a first view on results, which must be challenged and recalculated for single investment decisions. The LCOE calculation model developed in this paper is used for estimating the investments needed for renewable electricity installations. The main economic factors influencing the LCOE comparison between different electricity generation technologies are briefly described and discussed in the preceding chapter.

5.3.3 LCOE calculation

The LCOE calculation method is rather precise for deriving electricity generation costs just for a single power plant, where most input parameters are well-known and alternations for future fluctuations, e.g. fuel prices, can be applied quite easily. Calculating average LCOE

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[155] Heptonstall (2007), p. 10 seq.

[156] Schneider (1998), p. 12

for distinct power production technologies in different countries and regions leads to a broad range of results, depending on the input assumptions used, concerning variation of plant conditions, such as the following:

- resource conditions, e.g. solar and wind availability
- demand conditions, e.g. full load hours in case of CHP
- technology options, e.g. plant size, conversions technology

The general level of LCOE varies strongly between the different technologies for power generation. Conventional thermal and cost-efficient renewable options, like large hydropower and biogas, generate electricity below market prices. Onshore wind power and solar PV still cannot deliver electricity at market prices even at the best sites. The minimum, maximum and average LCOE for wind and photovoltaic scatter considerably. To a lesser extent, this can be ascribed to different investment costs between countries, but more crucial are site-specific resource conditions as well as different technical options for applications.[157]

The transition of the energy system from conventional to renewable sources concerns all areas of society and economy. The goal of clean and sustainable electricity production stands in conflict with economical interests of suppliers and consumers that have to be balanced by a well-conceived framework of policy instruments. The costs of electricity are an important factor to be considered in any transition scenario, so that overall cost burdens for the society and the economy are optimized.

The calculation and comparison of electricity generation costs is depending on many input factors, which are described further above. Annualized investment costs play a significantly higher role in renewable power technologies that in fossil ones. On the other hand, fuel costs are much more relevant for gas, coal, and biomass plants. For running costs, including fuel prices, no valorization is incorporated in the model. Because of the fact that CO_2 certificates needed in the electricity sector will be fully auctioned after 2012, carbon costs are included in the LCOE calculation to show the future impact of carbon costs.

The LCOE calculation model set up for this master thesis paper takes into account the following baseline parameters for seven generic power plant types:

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[157] Resch (2010), no p.

Table 11: Baseline input parameters for LCOE calculation

Parameters	**Units**	**Nuclear**	**Gas**	**Coal**	**Hydro**	**Biomass**	**Wind**	**Solar**
Investment data:								
Electric power	MW	1,200	500	600	200	40	100	10
Specific investment costs	€/kW	3,500	700	1,800	2,000	2,700	1,400	3,500
Investment costs	M€	4,200	350	1,080	400	108	140	35
Economic lifetime	a	40	25	30	50	30	25	25
Interest rate, real	%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Annuity factor	%	6.6%	7.8%	7.3%	6.3%	7.3%	7.8%	7.8%
Production data:								
Efficiency rate	%	33%	50%	40%	100%	30%	100%	100%
Capacity factor	%	90%	30%	50%	40%	60%	25%	11%
Full load utilization	h/a	7,884	2,628	4,380	3,504	5,256	2,190	964
Specific O&M costs	€/kW	80	25	50	35	60	40	30
O&M costs	M€/a	96.0	12.5	30.0	7.0	2.4	4.0	0.3
Carbon intensity	g CO_2/kWh	0	440	882	0	0	0	0
Carbon price	€/t CO_2	0	20	20	0	0	0	0
Fuel price	€/MWh	2	27	11	0	20	0	0
Electricity output	GWh/a	9,461	1,314	2,628	701	210	219	10
LCOE (2009)	**€/MWh**	**46**	**93**	**86**	**46**	**115**	**68**	**315**

The reference case comparison of the generic plants shows that LCOE of hydro and nuclear power are the lowest, and the existing fossil plants are operated in the low-cost range. Wind power is the cheapest new renewable technology close to conventional plants. Biomass electricity generation is rather cost-intensive in the case of mere electricity production with a bad efficiency rate. The biomass cost-efficiency can be improved by constructing combined heat and power plants, because the sale of the heat allows for extra revenues. Solar photovoltaic at present does not come near to grid parity because of high specific investment costs and low load factors.

The baseline LCOE results are shown in the figure below:

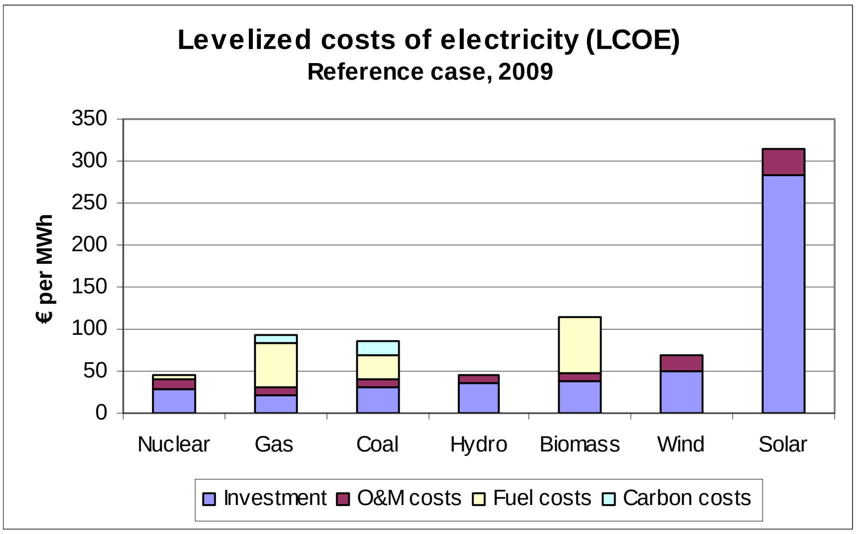

Figure 43: Levelized costs of electricity (LCOE), reference case, 2009

5.3.4 Sensitivity analysis

By variation of the key input factors, the LCOE sensitivities are calculated and analyzed to find out about the competitiveness of the different power technologies in the years to come. Very important for the future LCOE changes are the progress rates that will reduce investment and O&M costs in different patterns. For fossil and nuclear, in the model no progress is entered, because of its wide-spread utilization and high stage of technological development. For renewable power technologies, the progress rates are applied according to the projections about cumulative capacity development. The sensitivity analysis shows the highest learning impact for solar PV, bringing down the LCOE near to grid parity.

The impact of technological progress on the future LCOE, excluding any other possible cost changes, is shown in the following chart:

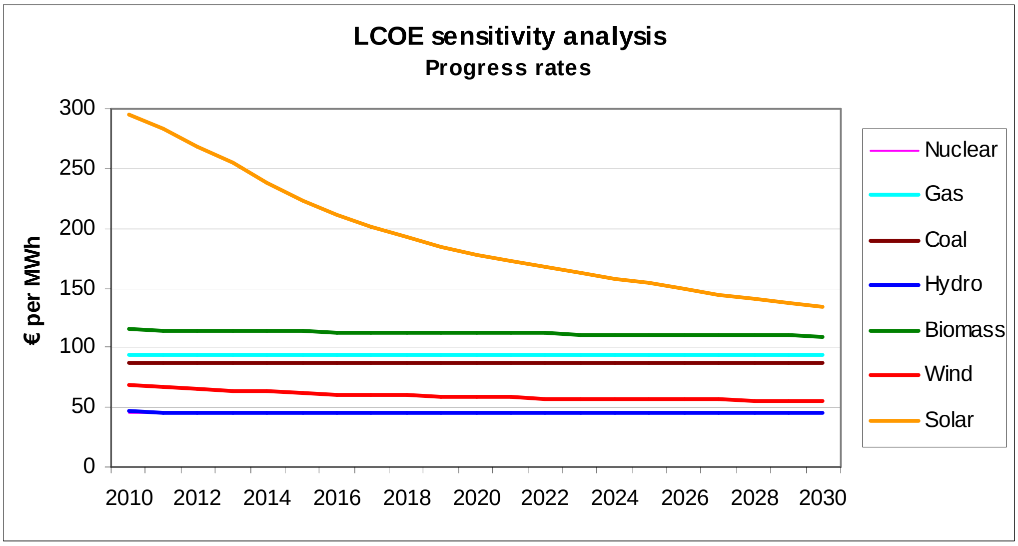

Figure 44: LCOE sensitivity analysis - progress rates

The impact of real fuel prices changes on the LCOE is calculated based on average fuel costs in 2009. The figure below shows that a strong hike in market prices of fossil and biomass sources is an imminent threat for profitability and competitiveness. Hydro and that wind power get quickly more attractive in such an environment, demonstrating that the electricity prices are much more predictable compared to fuel combustion plants. In the short-term, without positive learning impacts, solar PV remains more expensive than conventional power, even in the case of very high price surges, as can be seen in the figure below:

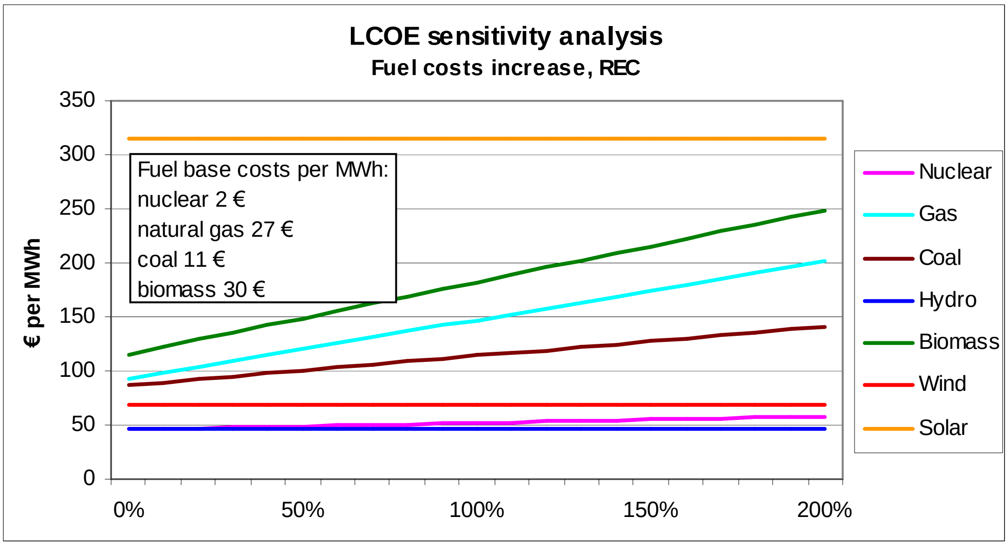

Figure 45: LCOE sensitivity analysis - fuel costs increases

Adding increased carbon prices to the data shown in the last figure does not change the picture significantly. First, carbon prices are only relevant for gas and coal power generation, second the actual CO_2 price level is rather low, and even tripling it, does not affect much the overall result, compared to other factors of influence, see figure below:

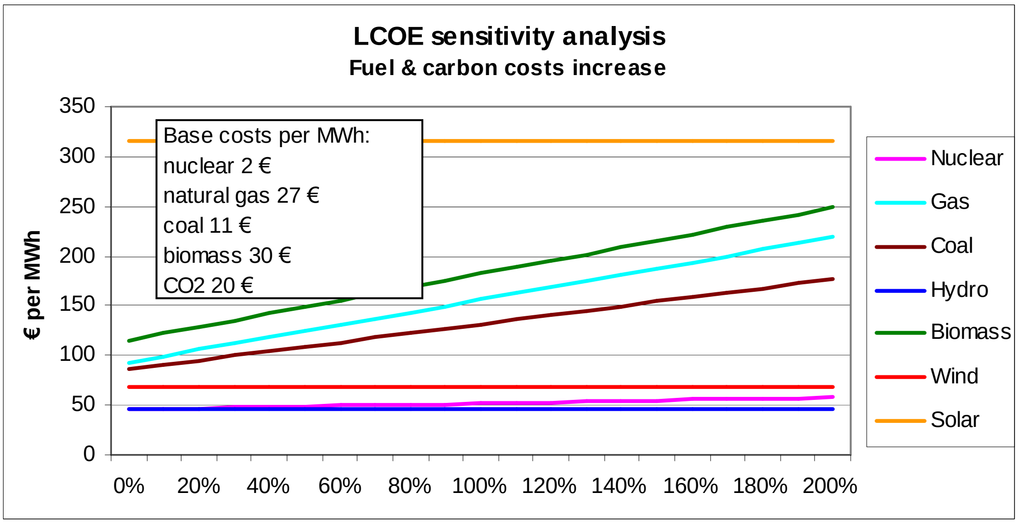

Figure 46: LCOE sensitivity analysis – fuel & carbon costs

The last sensitivity analysis is made for the discount rate, which is of high importance for LCOE results. The effect of diverse discount rates is related to the technology's character of being more capital-intensive, like e.g. wind and solar, or more expense-intensive, like fossil plants. The sensitivity impact is best demonstrated by just using natural gas and wind energy as examples. For capital-intensive technologies, lower interest rates lead to reduced LCOE, which by tendency reflects the private investors' yield expectations. For gas power plants, the variation of the discount rate does not matter in the same magnitude, because the main part of LCOE is variably caused by fuel prices, see figure below:

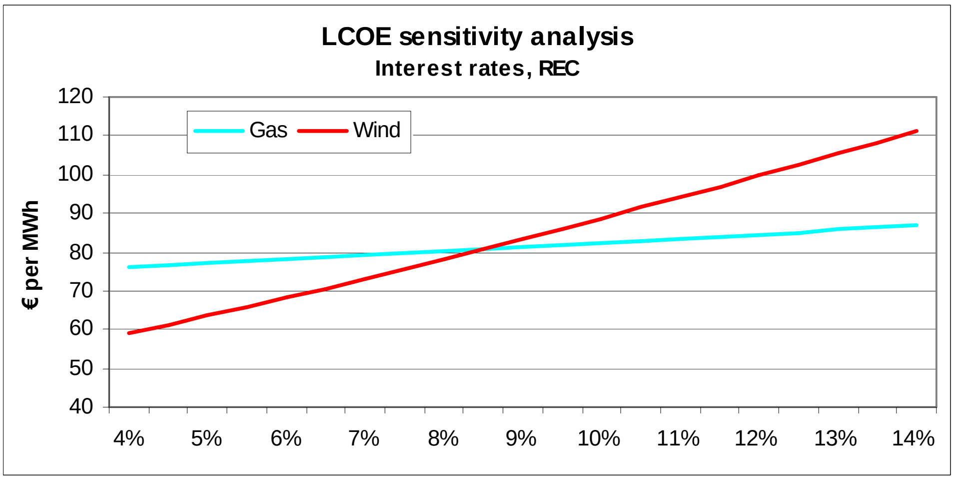

Figure 47: LCOE sensitivity analysis - discount rate variation

5.4 Model assumptions

5.4.1 Scenario definition

The relevant components for analyzing the investments needed for renewable power generation are described above in the methodical introduction to this chapter. The parameter definition in detail for the three scenarios is done in three parts:

- General assumptions about the development of the economy, energy intensity and policy framework
- Specific assumptions about the development of the key factors influencing the levelized costs of electricity
- Scenario variation for the replacement fossil & nuclear power plant stock (only in the Clean Energy Policy scenario)

The core assumptions for the development of the general environment for electricity generation are shown in the following table:

Table 12: Scenario definition - general development of energy market

General development	**Unit**	**REC Reference Case**	**HEP High Energy Prices**	**CEP Clean Energy Policy**
Policy framework	qualitative	baseline	baseline	improved
GDP growth	% p.a.	2%	1%	2%
Energy intensity	% p.a.	-1%	-1%	-2%
Electricity demand	% p.a.	1%	1.5%	2%

In the CEP scenario, for the policy framework is assumed that legal and financial support is optimized for enhanced production, distribution, and consumption of renewable electricity. The baseline GDP growth is assumed with 2% real change per annum, but in the HEP scenario only half because of negative impacts from the higher energy prices. Energy intensity is expected to improve by 1% yearly in REC and HEP scenarios, and by 2% yearly in the CEP scenario, because of strong energy efficiency measures undertaken. Electricity demand grows in all three scenarios, caused by new devices and applications, substituting the use of other energy carriers. High market prices for primary energy sources are expected to speed up this trend (HEP), as well as new policies to support the transition to clean electricity (CEP) in all demand sectors.

The yearly change rates for key factors influencing the future LCOE of competing power technologies are shown in the table below:

Table 13: Scenario definition - key factors of influence for future LCOE development

Key factors of influence	**Unit**	**REC Reference Case**	**HEP High Energy Prices**	**CEP Clean Energy Policy**
Fossil prices	% p.a.	2%	5%	2%
Carbon price	€/MWh	20	40	60
Discount rate	%	6%	5%	4%

Fossil real prices are expected to increase by 2% yearly in the REC and CEP scenario, and 5% yearly in the HEP scenario. The same change rates are applied for coal, gas, and uranium. The reason for relatively lower increases in the CEP scenario is that clean energy policies probably will emerge not only in Austria but also worldwide, thus slowing down the worldwide demand growth and depletion of fossil sources. Carbon price levels will be driven either by stronger fossil demand or by clean energy policies. The real discount rate is set at 6% in the reference case and a little lower in the high-energy scenario assuming that higher energy prices retard the economic development. In the CEP scenario, the discount rates are lower, because of general insight that the technological and financial risks for renewable power investment are rather minor; and investors distinguish risk margins between fossil, nuclear, and renewable energy.

In the CEP scenario, the accelerated growth of clean energy options is expected subduing the economical conditions for operating fossil plants. Because of higher risk awareness and improved policies, the following variations to the LCOE input parameters are taken into account:

Table 14: Scenario definition - fossil & nuclear variation

Fossil & nuclear variation	**Unit**	**REC Reference Case**	**HEP High Energy Prices**	**CEP Clean Energy Policy**
Risk adjustment	% points			5%
Load factor	%			-20%
Lifetime	%			-20%

The risk adjustment is assumed in combination with generally lower discount rates; it is added for fossil and nuclear generic plants to calculate the possible impact of changed risk awareness leading to more differentiated rate of return expectations. For prudence reasons, investors might also calculate new fossil projects with lower load factors reflecting the merit order effect, as well as shorter plant lifetimes considering changing conditions, which could lead to earlier shut-downs, e.g. in case of non-competitive operating costs, new legal regulations, etc.

5.4.2 Generic plants

The investment needs for renewable electricity generation are calculated in a simplified model reducing the power capacity mix to the four main renewable sources with relevant potentials for future up-take. The LCOE of renewable technologies are compared with those of nuclear, gas and coal power plants. To get a good overview result on the LCOE comparison seven generic power plants are defined representing the different technology types.

The key data and information for these generic power plants is stated in the following table:

Table 15: LCOE calculation - generic power plant data

Energy source	**Plant size**	**Life time**	**Capital costs**	**Laod factor**	**O&M**	**Efficiency**	**Emissions**
	MW	Years	€/kW	%	€/kW.a	%	g CO2e/kWh
Nuclear	1200	40	3500	90	80	33	-
Gas	500	25	700	30	25	50	440
Coal	600	30	1800	50	50	40	882
Hydro	200	50	2000	40	35	-	-
Biomass	40	30	2700	60	60	30	-
Wind	100	25	1400	25	40	-	-
Solar PV	10	25	3500	11	30	-	-

Nuclear power is also included in the comparison, although it is not actively produced in Austria. Due to the high relevance in the European electricity mix, which is traded across all regions in Europe, it makes sense to understand its LCOE in comparison with fossil and renewable power generation. The plant data above is derived from different sources in the literature as listed in the chapter about LCOE calculation. The load factors found for wind and solar PV are adjusted to the lower levels of Austrian potentials.

5.4.3 Electricity demand

In Austria in the last 25 years electricity consumption grew by yearly 2.3% in average. Theoretically extrapolating this growth rate until 2030 would rise the electricity demand to about 120 TWh, almost double the volume of today.[158] The Austrian government concluded in its energy strategy that energy efficiency must be the key for future energy policies and defined the target value for final energy consumption in the year 2020 to be 1100 PJ (306 TWh), virtually remaining at the same level as today.[159] Final electricity demand, excluding losses and own consumption in the energy sector, is strategically planned to go up to 62 TWh (223 PJ) until 2020, which is an increase of about 8% compared to 2005. Power generation from renewables is planned to grow 11%, and conventional thermal electricity falls 2%.[160]

For the scenario model, it is necessary to make assumptions about the development of gross final electricity demand. The yearly growth of electricity demand adds to the capacity needs resulting from necessary replacements of aged power plants. Based on the literature found concerning energy and electricity projections the baseline assumption is that electricity demand will grow by 1% per annum at average until 2030. With an annually GDP growth rate expected in the range between 1.5% to 2.0% and under the

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[158] Haas (2008), p. 30

[159] BMWFJ (2009), p. 31 seq.

[160] BMWFJ (2009), p. 11

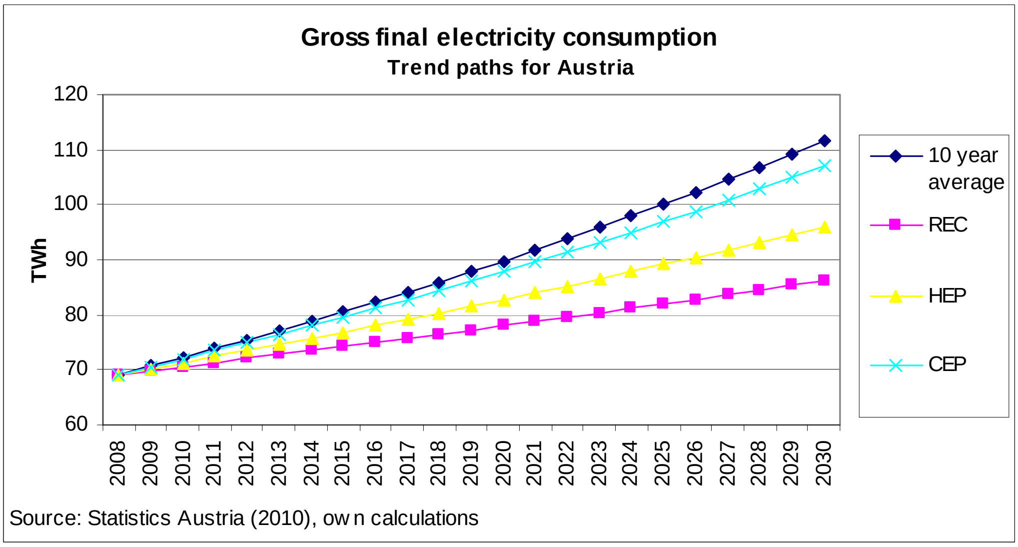
pre-condition that the share of electricity in final energy demand continues to grow, a yearly 1% growth rate for electricity consumption is a trend path that also is only realistic with successful energy efficiency measures.

1% yearly growth of electricity generation lies close to the projections concluded in the Austrian energy strategy, which does not consider other trend paths, maybe because of the character of this document to determine political objectives. But higher fossil prices could shift final energy demand towards electricity; and climate change awareness could also cause more growth. Scenarios with higher electricity demand growth induce declining demand for other energy sources, reducing energy import dependency and helping to achieve the greenhouse gas targets.

The following trend paths for electricity demand are used in the scenario model:

- 10 year average (2.19% p.a.): Extrapolation of the historic growth from 1998-2008, only for comparison purpose
- Reference case (1% p.a.): Improved efficiency of electric applications and electricity saving measures as determined in the Austrian energy strategy
- Higher energy prices (1.5% p.a.): Same as reference case with increased shift to electricity using products because of higher fossil energy prices
- Clean energy policy (2% p.a.): Additional policies and incentives to transition more quickly to renewable power to achieve higher greenhouse gas mitigation targets

The outcomes of the trend paths in means of future gross final electricity consumption are shown in the following chart:



Source: Statistics Austria (2010), own calculations

Figure 48: Gross final electricity consumption, Austria, trend paths 2008-30

In relation to total final energy consumption, remaining at the level of 306 TWh (1100 PJ) until 2020, and assumingly also in decade thereafter, the share of electricity will increase in the REC scenario from 23% in 2008 to 25% in 2020 and 28 % in 2030. In the HEP and CEP scenarios the shares go up to 27% and 31% by 2020, and 29% and 35% by 2030 respectively. Strongly increased shares of electricity bear the chance to further mitigating greenhouse gas emissions - under the pre-condition that it is produced domestically from renewable sources - and should also be considered for the next revision of the long-term energy strategy in Austria.

5.4.4 Renewable sources

The estimated potentials found in diverse studies diverge quite substantially, depending on the definition and application of technical, economical, and political factors of influence. Thus, the potential estimation must be seen against the backdrop of uncertainties growing with the time horizon ahead. The following sources are the basis for the potential estimations by the author:

- Long-term scenarios of the societal optimal energy supply in the future[161]
- Renewable energy policy country profiles (RE-shaping project)[162]
- 100 % clean electricity in 2020 (brochure of renewable energy associations)[163]
- Europe's onshore and offshore wind energy potential[164]

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[161] Haas (2009), p. 63 seqq.

[162] Ragwitz (2009), p. 9 seqq.

[163] PV Austria (2009), p. 4 seqq.

- Water power potential study Austria[165]
- Strategies for the optimal development of biomass potentials in Austria[166]
- Technology roadmap for photovoltaic in Austria[167]

Out of the four main renewable electricity sources in Austria, the remaining hydropower potential is significant, but its development is limited, because the actual stage of hydropower expansion is quite advanced in Austria. The utilization of additional biomass potentials for electricity generation is an obvious alternative to coal and gas plants, though the competition about agricultural land area is an important aspect for evaluation. For wind and solar the main factor of influence is the future development of investment costs. With lapse of time, wind and solar potentials economically are growing, because of its declining specific costs.

As discussed in the chapter on LCOE and its sensitivities, very relevant for the opening of renewable potentials is the comparison of its costs with incumbent power technologies. The LCOE development, depending on a wide range of influencing parameter, is shown in the following table for the CEP scenario, which assumes a climate-friendly policy framework:

Table 16: LCOE range for CEP scenario, 2010-30

LCOE range - CEP Scenario			
€/MWh	2010	2020	2030
Nuclear	77	78	80
Gas	131	143	158
Coal	152	158	165
Hydro	37	36	35
Biomass	138	156	180
Wind	59	50	48
Solar	247	149	112

The lowest LCOE are related to hydro and wind resources, so its further development has the highest priority. In addition, the biomass potential quickly can be opened, but the attention must be directed on CHP stations, because pure electricity generation is inefficient and expensive. Biomass prices tend to follow fossil market prices, which could

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[164] EEA (2009), p. 18 seqq.

[165] Pyöry (2008), p. 3 seqq.

[166] Kranzl (2009), p. 121 seqq.

[167] Fechner (2007), 40 seqq.

be a limiting factor for further plants, especially after breaking even with solar PV. Starting from 2020 at the latest, the continued cost decline of solar PV changes the comparison picture. Within the next ten years, solar PV will become the most attractive electricity source, and other renewable potentials are more limited in Austria.

Overall, the potentials for renewable electricity generation are sufficient, and most likely a shift towards higher solar and wind potentials will occur, depending on the policy framework as well as market price conditions. The below values for 2020 and 2030 are estimated by the author, for which the different approaches in the sources listed above are taken into account. Especially wind and solar potentials are expected to increase largely over time. The renewable potentials assumed are shown in the following table:

Table 17: Renewable electricity potentials in Austria, until 2030

Energy source	**Electricity production (TWh)**			**Capacity installed (GW)**			**Load factor**	
	2008	2020	2030	2008	2020	2030	2008	2020/30
Hydro	38.9	44.7	50.0	11.1	14.6	16.3	40%	35%
Biomass	2.5	8.8	10.0	0.5	1.7	1.9	60%	60%
Wind	2.0	6.7	15.0	0.9	3.5	7.8	25%	22%
Solar	0.0	3.0	20.0	0.0	3.4	22.8	11%	10%
Total	**43.4**	**63.2**	**95.0**	**12.5**	**23.2**	**48.8**	**40%**	**31%**

Until 2030, the total renewable electricity potential surpasses by far the actual total electricity generation in Austria, which was 67 TWh in 2008. About half of electricity generation from renewable sources will come from non-hydro sources, which at present contribute a dominant share of almost 90%. Besides the remaining hydro potential, until 2020 biomass and wind potentials will be the mainstay for increased clean electricity production. Solar PV is expected to speed up its up-take in the near future, but until 2020, its share will remain near 5%. In the following decade, solar PV will rapidly grow because of better cost efficiency boosting its share to above 20% of electricity supply in Austria by 2030.

The average capacity utilization is expected to decline for hydro, wind, and solar due to the exploitation of less attractive potentials, which will be developed over time, when the cost of electricity generation from renewable sources continues to fall alongside its learning curves. In case of enforced policy instruments, the capacity factors decrease for the same reason that less attractive sites get used for new wind or solar power plants. In the LCOE calculation generally constant load factors as of 2008 are applied. For the scenario model analyzing the future need of capacities and investments the reduced load factors are used, as shown in the column 2020/30 in the table above.

5.4.5 Fossil plants

For determining the future volume of renewable electricity generation and the investments needed to establish the necessary power plant park, a very relevant scenario assumption has to be made about the ageing fossil power plants today in operation. On the one hand, the question is to be asked, whether Austria needs any more fossil capacities to cover additional electricity demand. In the scenarios defined for this paper, this question is generally assumed to be answered negatively. On the other hand, the existing power plants have to be replaced in due course of time, and it can be considered either to do so by new investments in fossil, especially natural gas, power plants, or not to build new fossil capacities but rather enlarge renewable electricity production.

For the REC and the HEP scenarios, a one-to-one replacement of fossil generation capacity (CF: constant fossil) is assumed without consideration in depth when the single reinvestment projects will take time. Thus the yearly electricity demand growth is assigned directly to the coverage by additional renewable generation capacity. For the CEP scenario this is done in the same way, but in a second scenario variant the fossil capacity as of 2009 is linearly reduced over the next 20 years. This scenario variation is called CEP/RF (RF: reduced fossil); the growth trend for renewables is much faster in this case, for which optimal support policies are necessary.

The basic data of the fossil plant, excluding mixed fired stations, is shown in the following table:

Table 18: Linear replacement of fossil plants until 2030

	Units	**2009**	**Reduction** per year (1/20)
Power capapcity	MW	6,274	314
Electricity generation	GWh/a	17,612	881

Obviously, a linear approach to the replacement of aged power plant is only theoretically possible. But not knowing when and where the replacements really will take place, this approach intends to establish a virtual transition path to full-scale renewable electricity generation by 2030 in Austria, even under the assumption of 2% annual demand growth in the clean energy policy scenario. Such a constellation forms the upper end of the range of investments needed to build a 100% renewable electricity economy and society.

5.5 Scenario model

5.5.1 LCOE development

The different impacts of key factors on the LCOE can be combined and used as an overall framing condition for the scenarios analyzed in this paper. The scenario parameters are defined in the first part of this chapter. The LCOE sensitivities depending on different scenario settings are shown in the following three figures.

In the REC scenario the LCOE change is mainly driven by progress ratios and to a lesser extent by slowly increasing real market prices. In such an environment, solar PV costs drop more than by half, but it cannot break even with fossil power technologies, because solar irradiation levels and weather conditions are not enough favourable. Also discount rates remain the same as for conventional power, and no risk differentiation is applied. Other technologies remain more or less in the same order in such a low-dynamic environment, as shows the figure below:

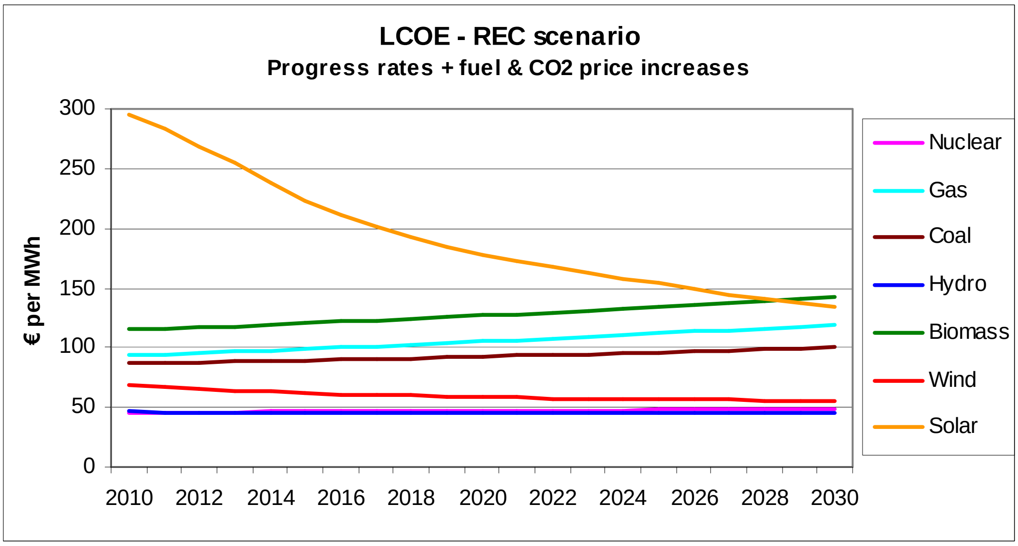

Figure 49: LCOE simulation - REC scenario

In the HEP scenario, it is assumed that higher energy prices also might cause a slower GDP growth and a little lower interest levels. In this constellation, fuel combusting technologies would become less competitive. Hydro, wind and nuclear remain in their most competitive position, very closely sitting together with real LCOE in the area around 50 € per MWh. Solar PV electricity costs decline a little faster due to lower discount rates, and reach cost levels similar to biomass, gas and coal power plants in 10 to 15 years from today, see next figure:

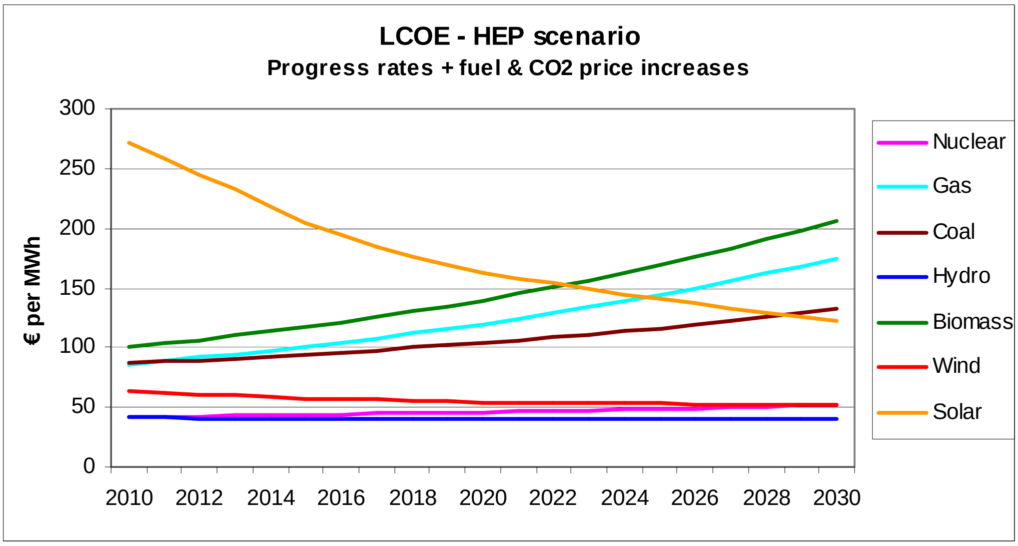

Figure 50: LCOE simulation – HEP scenario

The CEP scenario is defined in a way of establishing the best surrounding conditions for a clean and sustainable electricity future, but as in the other scenarios, it does not include any financial support measures. In the case of a high-speed transition to renewable sources, less upward demand pressure on fossil and carbon prices is expected, so that in the CEP scenario primary energy prices only increase moderately. Progress ratios are kept constant as an input factor that originates largely from outside of Austria, assuming that the clean energy policy will not necessarily take place in all countries at the same time. Also interest rates are adjusted by risk-margin reflecting the investors' willingness to lower rate of returns expected from safe and domestic renewable electricity generation in comparison with high-volatile fossil fuels dependent on sufficient imports.

In this scenario can be seen that hydro and wind are the most cost-efficient way to produce clean electricity, the biomass and solar PV graphs cut each other around 2020, and LCOE of fossil technologies will become step-by-step less attractive over the years to come, see figure below:

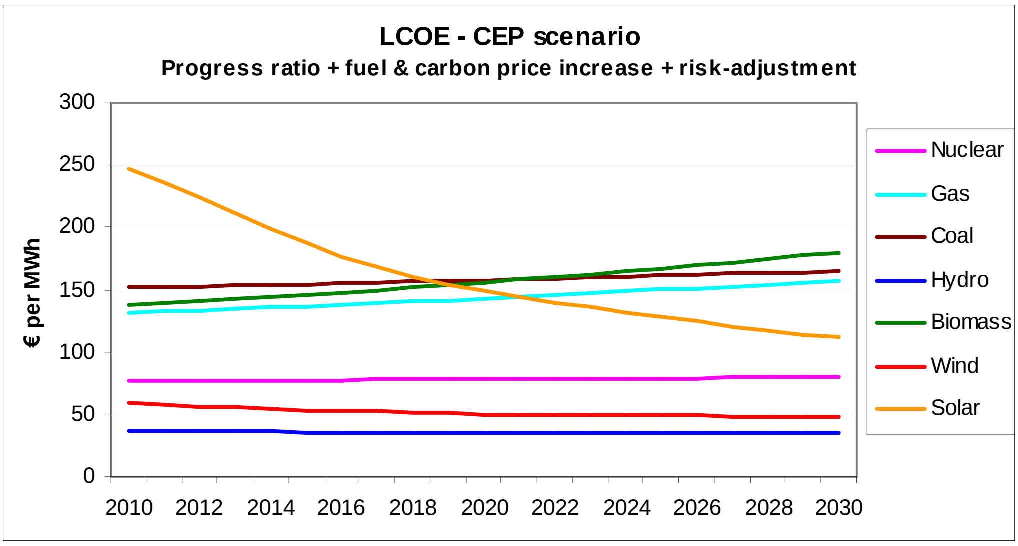

Figure 51: LCOE simulation - CEP scenario

The LCOE price simulations depending on different scenarios are needed to find out whether a transition to 100% electricity from renewable sources is feasible for Austria. One of the main conditions for such a transition path is that renewable potential are opened in an economical way and the existing fossil power plant park is used as bridging technology. Solar PV has very high potentials, which at present can only be developed with high financial support from the public or from the electricity consumers. Looking at the figures above it seems most of all feasible to open and develop hydro and wind potentials for replacing ageing fossil plants and closing the import gap in the years up to 2020. In parallel the development of solar PV should be continuously enhanced, leading to near grid parity conditions around 2020.

5.5.2 Power generation gaps

Depending on the power demand growth rates set for the three scenarios, the additional demand has to be fulfilled either by higher utilization of existing fossil plants or by installing new power plants. The basic notion underlying the scenario model is to close future electricity demand and to replace step-by-step existing fossil capacities by renewable sources. The additional yearly demand, calculated upon the scenario definitions set further above, are depicted in the following chart in comparison with a trend projection of the average demand growth over the last 10 years:

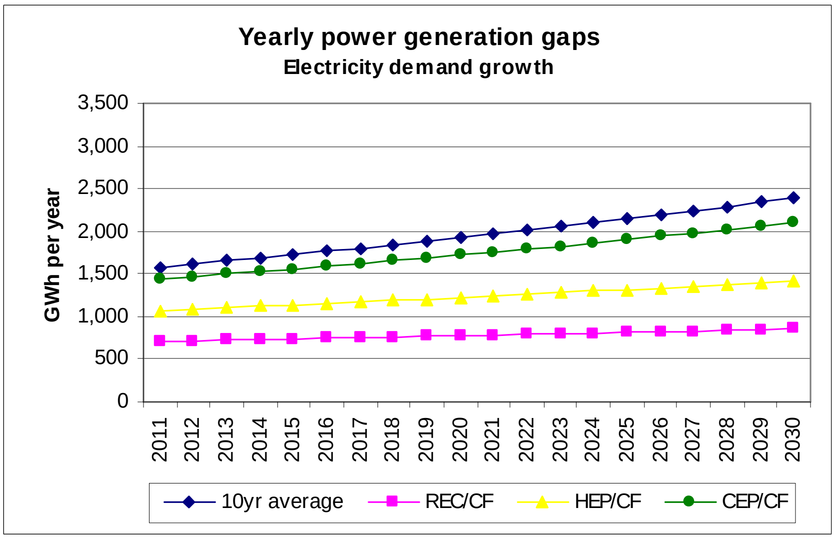

Figure 52: Power generation gaps - electricity demand scenarios, 2011-30

In 2009, 17.6 TWh of electricity was generated in pure fossil power stations (excluding mixed fired units).[168] Under the assumption that power generation in fossil plants is linearly reduced over the next 20 years the yearly power generation gaps to be filled by renewable sources rise by about 880 GWh. The development is shown in the next chart:

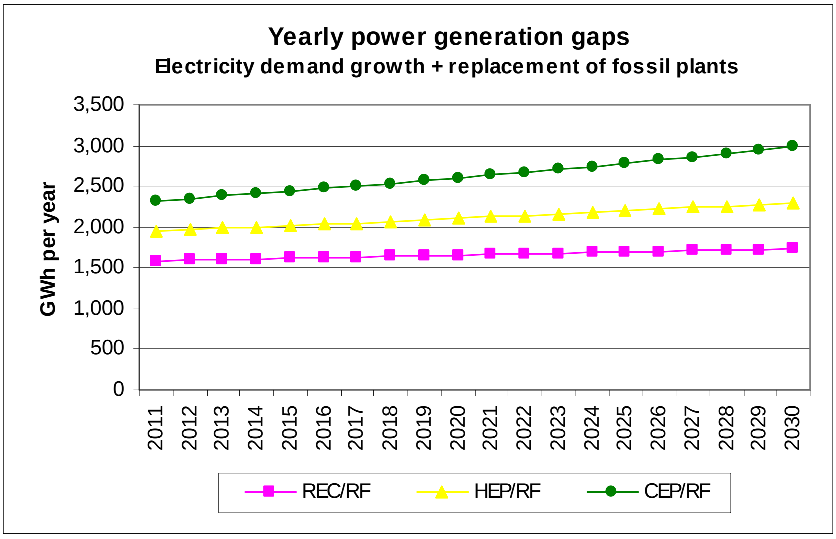

Figure 53: Power generation gaps - electricity demand scenarios and fossil plant replacement, 2011-30

It is obvious that the future electricity demand will not exactly follow a straight line calculated with constant growth and replacement rates. Nevertheless, these projections are necessary for estimating the renewable potentials and capacities needed for additional power generation as well as to calculate the investment costs based on the development of specific investment costs of the different plant types.

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[168] E-Control (2010)

5.5.3 Plant capacities mix

For calculating the plant capacities needed, it is necessary to make assumptions about how to fill the electricity generation gaps. The renewable electricity potentials are described and determined in the preceding chapter. Additional hydro, wind and biomass potentials are more limited in Austria than solar PV. On the other hand, solar PV is the most expensive power generation technology by now and will remain in the upper range at least for the next 10 to 15 years. Under these pre-conditions, the author follows the principle to use up primarily hydro, wind and biomass resources by the same amount yearly added, and close the remaining gap by increasing the share of solar PV over time.

For covering the demand growth as defined in the scenarios, enough potentials are available to be developed, so the renewable capacity mix in dominated by hydro, wind and biomass for the full period until 2030. The share of solar PV in the capacity growth goes up until 2030, caused by the low load factor in comparison with power from hydro and biomass. The development of additional capacities needed is shown in the figure below:

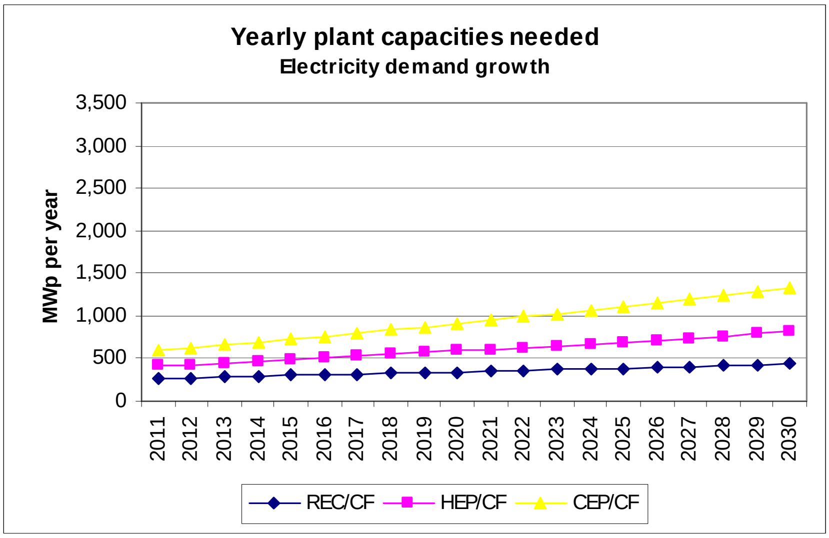

Figure 54: Plant capacities needed - electricity demand scenarios, 2011-30

A different situation arises for the target to reduce and replace fossil plant capacities. Fossil power plants have higher load factors than renewable ones, especially in the case of wind and solar power. In such a case, the renewable power potentials deplete much faster, so that in the HEP scenario after 17 years and in the CEP scenario already after 14 years the only remaining renewable potential is solar PV. Due to the low load factor, a big jump in the capacity needed occurs as is shown in the next figure:

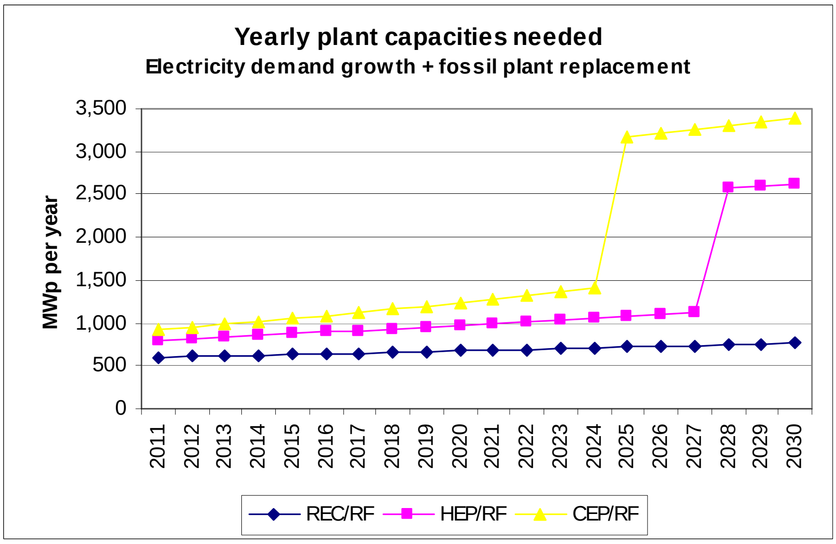

Figure 55: Plant capacities needed - electricity demand scenarios and fossil plant replacement, 2011-30

In the HEP scenario about half of the solar PV potential in Austria is used up until 2030, in the CEP all of it. The full replacement of fossil plants in the CEP scenario is only possible if in the years from 2025 to 2030 a solar PV capacity of over 3 GW peak is installed each year. This is a huge amount compared to installations as of today, with global new installation of around 15 GW forecasted for 2010 and 30 GW for 2014.[169] On the other hand, yearly new installations will grow with CAGR of 20% or more so that until 2030 the yearly solar PV capacity added could reach a global level of around 280 GW (advanced scenario).[170] In such an environment, it seems indeed realistic that all power generation gaps in Austria, including the full replacement of ageing fossil plants, can be filled by renewable sources.

5.5.4 Investment costs

Finally, after determining and combining the most relevant factors of influence are setting up scenarios for the future development, it is possible to calculate the range of investments needed to achieve the target of a fully renewable electricity system in Austria. The figures derived, as all data used in the model, are computed in 2009 Euros; and in reality will be higher in nominal terms due to inflation. As stated before, such calculations' uncertainties grow with the number of years, but they are helpful for estimating future market volumes, upon which the market participants can conceive own strategies and business planning.

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[169] EPIA (2010), p. 9

[170] EPIA (2008), p. 32

The specific investment costs of power generation technologies are very different, and always have to be considered in relation to the plants' efficiency rates and load factors. A pure comparison of investment volumes needed cannot replace a detailed analysis of the LCOE and its influencing factors. The determination of investment sums over the coming years, and decades, gives an indication for economic activities needed in various other sectors, such as manufacturing and financing. The financing volumes are calculated with the specific investment costs derived in the LCOE model by applying the expected progress ratios, as shown in the following table:

Table 19: Specific investment costs of renewable power technologies, 2010-30

Specific investment costs			
€/kWp	2010	2020	2030
Hydro	2,000	1,953	1,926
Biomass	2,688	2,512	2,387
Wind	1,400	1,194	1,138
Solar	3,282	1,976	1,481

In the scenarios with constant fossil capacities, the investments needed for renewable power capacities are lower, but new investments in non-renewable plants are not included in this figure. Depending on the electricity demand scenario, the yearly investment needed is growing, but slower than capacity demand due of decreasing specific investment costs, especially for wind and solar technologies. The development of the total investment costs per year is shown in the following figure:

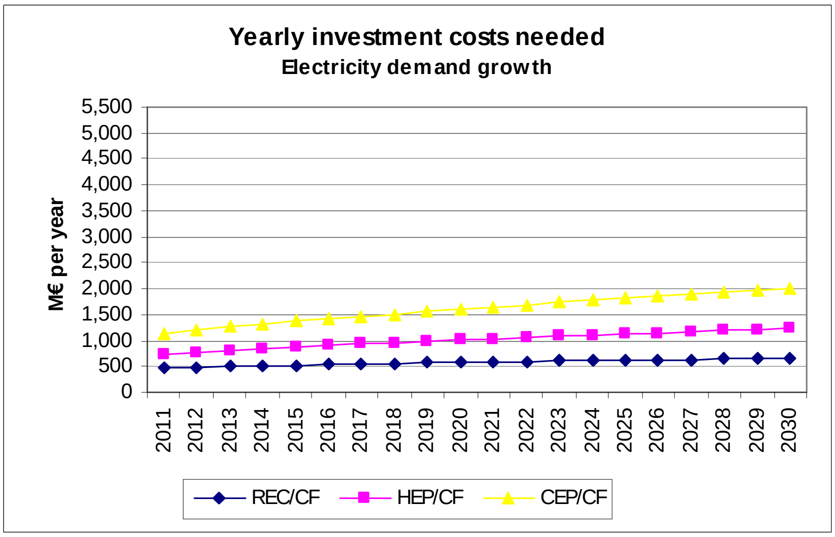

Figure 56: Investments needed - electricity demand scenarios, 2011-30

In reality, the development of yearly investments naturally cannot follow straight graphs, and for this, the investments are summed up for five-year periods and the range for all scenarios is calculated. For the first period 2011-15, the total investments needed range from 2.5 to 6.3 billion €; and this range goes up to 3.2 to 9.7 billion € in the period 2026-30. The table below shows the key results of the electricity scenario model, without replacement of existing fossil capacities, for five-year phases from 2011 to 2030:

Table 20: Overview of investments needed, constant fossil capacity, 2011-30

	2011-15	**2016-20**	**2021-25**	**2026-30**
Electricity gap (TWh)				
REC/CF	3.6	3.8	4.0	4.2
HEP/CF	5.5	5.9	6.4	6.9
CEP/CF	7.5	8.3	9.1	10.1
Capacity need (GW)				
REC/CF	1.4	1.6	1.8	2.1
HEP/CF	2.2	2.7	3.3	3.8
CEP/CF	3.3	4.2	5.2	6.2
Investment costs (G€)				
REC/CF	2.5	2.8	3.0	3.2
HEP/CF	4.1	4.8	5.4	5.9
CEP/CF	6.3	7.5	8.7	9.7

To replace all fossil power plants until 2030, much higher investment in the renewable power capacities is necessary, because these figures include the investment shift from fossil to renewables. In the HEP scenario in 2028, and in the CEP scenario already in 2025, the total yearly investment costs more than double. The reason is that the potentials of hydro, wind, and biomass are utilized by then, and only solar energy is left to cover the additional yearly electricity demand. The specific costs of solar are quickly declining due to the technological learning effect, but they remain on a level much above relatively cheaper hydro and wind power technologies. Most likely, the only remaining, cheaper alternative will be to import renewable power from regions with more cost-efficient resource conditions, e.g. solar power form the South, wind power from off-shore. Under the assumptions of full domestic self-supply, the development of the investment needs is shown in the next figure:

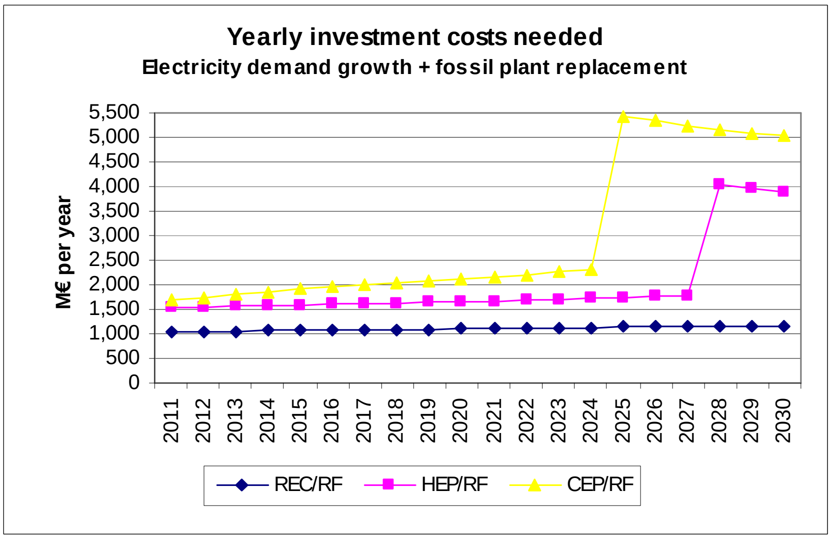

Figure 57: Investments needed - electricity demand scenarios and fossil plant replacement, 2011-30

For five-year phases, the investments needed are between 5.3 and 9.0 billion € in the beginning, and they steeply surge in the HEP and CEP scenarios in the second decade observed, as shown in the table below:

Table 21: Overview of investments needed, reduced fossil capacity, 2011-30

	2011-15	2016-20	2021-25	2026-30
Electricity gap (TWh)				
REC/RF	8.0	8.2	8.4	8.6
HEP/RF	9.9	10.3	10.8	11.3
CEP/RF	11.9	12.7	13.5	14.5
Capacity need (GW)				
REC/RF	3.1	3.3	3.5	3.7
HEP/RF	4.2	4.7	5.2	10.0
CEP/RF	4.9	5.8	8.5	16.5
Investment costs (G€)				
REC/RF	5.3	5.4	5.6	5.8
HEP/RF	7.8	8.1	8.5	15.4
CEP/RF	9.0	10.2	14.3	25.9

High cost increases in the wake of using up domestic hydro and wind potentials can be avoided by either keeping down the dynamics of electricity demand growth or by importing renewable electricity from other regions, e.g. wind power from the European sea shores or solar electricity from the South Europe or North Africa. A pre-condition for such an energy strategy certainly is the further extension of the long-range and cross-border power grid in Europe. No investments needed for grid development projects have been included in the calculations above.

5.6 Interpretation of results

5.6.1 Core result

The core result of the scenario model is that electricity production fully from renewable sources is possible in Austria by 2030. A main input assumption for the transition to a renewable electricity system is the issue of energy efficiency in the electricity sector. The Austrian government postulates in its energy strategy that overall energy consumption, remains on the level as of today until 2020. If this objective is continued also during the decade afterwards until 2030, electricity demand growth leads successively to a higher share in the final energy mix, but uncertainties remain in the mid and long term about the speed of a possible shift of final energy consumption towards electricity.

Under the scenario definitions set in this paper, the renewable power potentials – hydro, biomass, wind, and solar – are sufficient for coping with demand growth as well as for the full replacement of ageing fossil power plants. However, in case of a steeper growth of electricity demand, i.e. 2% p.a. in the CEP scenario, more cost-efficient potentials will be quickly used up during the next 10 to 15 years, and in the longer term, solar radiation must become the main renewable source. Fortunately, the point of time for this transition coincides with significant LCOE improvements of solar PV in comparison with other renewable and fossil technologies in the first half of the 2020's.

Initial investment costs of renewable power plants are substantially higher than for fossil ones, especially natural gas stations. On the other hand, with the exception of biomass, the fuel for hydro, wind, and solar electricity generation is free of charge. Higher investment costs also mean that the capital-intensity of power generation increases, which creates a great business potential for financiers and investors. Such investments will become very attractive over time, when technological risks decline by increasing market diffusion and revenues from electricity output are calculable with high reliability.

In a short-term horizon, the continued production of electricity in existing fossil power plants might seem economically attractive. As long as the short-term marginal costs, i.e. the fuel, O&M, and carbon costs, remain on today's levels, renewable electricity generation must be subsidized, e.g. by contracting feed-in tariffs. If the volume of such supporting instruments is not sufficient, either conventional power production is continued or the supply gap has to be filled by additional imports.

5.6.2 Financing

The transition from fossil to renewable power causes higher investment volumes to be financed front-off. So, in comparison with conventional power technologies, e.g. natural gas plants, the financing of higher initial investments is required. The following table shows the difference in investments needed for the three scenarios, including the replacement of fossil plants:

Table 22: Difference of investments needed for renewable and natural gas plants, billion €, 2011-30

Billion €	**2011-15**	**2016-20**	**2021-25**	**2026-30**
Natural gas				
REC/RF	1.9	2.0	2.0	2.0
HEP/RF	2.4	2.5	2.6	2.7
CEP/RF	2.8	3.0	3.2	3.5
Renewable sources				
REC/RF	5.3	5.4	5.6	5.8
HEP/RF	7.8	8.1	8.5	15.4
CEP/RF	9.0	10.2	14.3	25.9
Difference				
REC/RF	3.4	3.5	3.6	3.7
HEP/RF	5.4	5.7	6.0	12.7
CEP/RF	6.2	7.1	11.1	22.4

The difference in investments needed is substantial; and it demonstrates the high relevance of finding attractive financing solutions. In the five-year period 2011-15, a total investment volume of 5.3 to 9.0 billion € is necessary, which is 3.4 to 6.2 billion € more than for natural gas plants. The difference increases successively until 2020, and afterwards, so that a main issue for realizing the transition to renewable power generation is the availability of sufficient capital for investments in renewable power capacities.

The importance of financing models quickly gains importance and creates an additional business opportunities for financial institutions and private investors. Step by step, the operating outlays for electricity generation, especially fuel and carbon costs, diminish in means of, and instead of it, depreciation and debt service will go up. Thus, part of the value generation shifts from the energy to the financial sector, which in future fuels the renewable electricity generation by handing out low-risk credits to all kinds of renewable power producers.

6 Conclusions

Greenhouse gas emissions and global warming have been discussed and disputed for many years, and finally the awareness about possible negative consequences for the Earth is widely spreading, and many governments are considering and establishing mitigation targets and policies. Renewable energy sources are poised to play a major role in the blueprint of a low-carbon world, in combination with higher energy efficiency and behavioral changes.

The growth of population and GDP in the industrialized world was largely fueled by fossil energies, and the developing and emerging economies rush to develop in the same way. The limits of growth and the depletion of resources are calculable and foreseeable, so that sustainable alternatives to today's fossil energy sources are urgently needed. Fortunately, renewable energy technologies have been developed for years and are now available in advanced quality and industrial scale. Due to the still early stage of market diffusion, most renewable technologies remain less cost-efficient than conventional power technologies, but the cost gaps are rapidly decreasing. Most of the externalities of fossil energy sources are still not priced in, and the acceptance for higher energy prices in society and economy stays low for the time being.

The purpose of this master thesis was to analyze and combine the number of relevant factors of influence on the future development of electricity generation, with the particular focus on investments needed for a renewable power system in Austria. As a side condition, a supportive policy framework is assumed in the CEP scenario, which, for the period of transition, closes the economical gaps between conventional power plants and the still emerging technologies for renewable power. Subsidies and feed-in tariffs will most likely be needed for some more years. The amount and duration of financial supports needed depends strongly on the growth and progress rates of renewable technologies, and on political decisions concerning the implementation of ecological taxes, especially concerning a correct cost internalization of greenhouse gas emissions.

Public budgets must be used economically, and private investors and consumers are optimizing their decision by cost arguments. Thus, in this paper the future LCOE development of renewable power generation was analyzed and compared with its conventional alternatives. Due to technological learning, the costs of renewable electricity will decline quickly, and in compound with increasing fossil energy and carbon costs, the LCOE gaps are successively going down. The full utilization of a range of diversely cost-efficient technologies can be secured in the easiest way by applying of feed-in tariffs based on the LCOE development.

The scenario model developed in this paper shows as the main result that a full-scale renewable power system is in reach for Austria. The renewable energy potentials are sufficient, at least in an energy-efficient environment also slowing the historic growth rate of electricity demand, though further shifts of final energy consumption towards electricity will happen. The electricity share in gross final energy consumption increases to between 28 and 35 per cent by 2030, depending on the scenario settings. For the top end of this range, all hydro, biomass, wind, and a big part of solar potentials have to be developed over the next 20 years. The domestic solar PV potential as determined in this paper must also be considered as a kind of opportunity cost for achieving import independence, but economically it might be recommendable to consider imports of cheaper renewable power from other regions.

The investments needed for renewable power generation in Austria naturally vary according to the scenario variations. In the case of full replacement of fossil power plants until 2030, the investment costs start from below 1 million € yearly in an energy-efficient environment in the first five-year period. The investment costs go up to around 5 billion € yearly after using up hydro, wind, and biomass potentials, because the remaining capacity gaps need to be filled by more costly solar PV installations.

Units

%	per cent
°C	degree Celsius
€	Euro
bbl	barrel
c€	Euro cent
g	gram
€	Euro
G€	giga € (billion €)
GWh	gigawatt hour
J	Joule
kg	kilogram
km	kilometre
km^2	square kilometre
kW	kilowatt
kWh	kilowatt hour
l	liter
m	metre
m2	square metre
m^3	cubic metre
M€	mega € (million €)
MBtu	million British thermal unit
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt hour
p	peak
PJ	petajoule
PWh	petawatt hour
t	tonne
TJ	terajoule
toe	tonne of oil equivalent
TWh	terawatt hour

Abbreviations

AAU	assigned amount unit
ABWR	advanced boiling water reactor
AEO	annual energy outlook
APG	Austrian Power Grid
BAU	business as usual
BEI	Bremer Energie-Institut (Institute for Energy, University Bremen)
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (Federal Ministry of Agriculture, Forestry, Environment and Water Management)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMVIT	Bundesministerium für Verkehr, Innovation und Technologie (Federal Ministry for Transport, Innovation and Technology)
BMWA	Bundesministerium für Wirtschaft und Arbeit (Federal Ministry of Economy and Employment)
BMWFJ	Bundesministerium für Wirtschaft, Familie und Jugend (Federal Ministry of Economy, Family and Youth)
BWR	boiling water reactor
CAAGR	compound average annual growth rate
CAIT	Climate analysis indicators tool
CCPP	combined cycle power production
CC	combined cycle
CCS	carbon capture and storage
CDM	clean development mechanism
CEP	clean energy policy (scenario type)
CER	certified emission reduction
CF	constant fossil capacities (scenario variant)
CFB	circulating fluidized bed
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
CO_2e	CO_2 equivalent
COP	conference of the parties
CRF	capital recovery factor
CSP	concentrated solar power
CTCC	combustion turbine combined cycle
DG	Directorate-General (of the European Commission)
ed., eds.	editor, editors
EEA	European Environment Agency
EEG	Energy Economics Group
eq	equivalent

EREC	European Renewable Energy Council
ERU	emission reduction unit
ETP	energy technology perspectives
ETS	Emissions Trading Scheme
EU	European Union
EU-27	European Union of 27 Member states from 1 January 2007
EUA	European Union allowances
EUR	Euro
EWEA	European Wind Energy Association
EWI	Energiewirtschaftliches Institut an der Universität zu Köln
F-gases	fluorinated gases
FiT	feed-in tariff
FLH	full load hours
GDP	gross domestic product
GHG	greenhouse gas
GTCC	gas turbine combined cycle
GWP	global warming potential
HEP	high energy prices (scenario type)
HFC	hydro fluorocarbon
HVB	HypoVereinsbank
ICT	information & communication technology
IEA	International Energy Agency
IER	Institute of Energy Research
IETA	International Emissions Trading Association
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
JI	joint implementation
JRC	Joint Research Centre
LCOE	levelized cost of electricity
LRMC	long-rung marginal costs
LULUCF	land use, land-use change and forestry
LUT	Lappeenranta University of Technology
M&A	mergers and acquisitions
N_2O	nitrous oxide
NEF	New Energy Finance
NGO	non-governmental organization
no.	number
NOAA	National Oceanic and Atmospheric Administration
nop.	no page number
NREL	National Renewable Energy Laboratory

O&M	operations and maintenance
OeNB	Österreichische Nationalbank (Austrian National Bank)
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
p., pp.	page, pages
ppmv	parts per million by volume
PC	pulverized coal
PPS	purchasing power standard
PV	photovoltaic
PWR	pressurized water reactor
R&D	research & development
RE	renewable energy
REC	reference case (scenario type)
RED	Renewable Energy Directive
RES	renewable energy sources
RES-E	electricity form renewable energy sources
RET	renewable energy technology
RF	replacement of fossil capacities (scenario variant)
SCPC	supercritical pulverized coal
seq., seqq.	sequens, sequentes
T&D	transmission and distribution
TGC	Tradable Green Certificates
TU	Technische Universität (University of Technology)
UBA	Umweltbundesamt (Environment Agency)
UCTE	Union for the Co-ordination of Transmission of Electricity
UN	United Nations
UNEP	United Nations Environment Programme
UNEP SEFI	UNEP Sustainable Energy Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
vol.	volume
WACC	weighted average cost of capital
WEC	World Energy Council
WEO	World Energy Outlook
WI	Wuppertal Institute for Climate, Environment and Energy
WIFO	Österreichisches Institut für Wirtschaftsforschung (Austrian Institute of Economic Research)
WRI	World Resources Institute
ZfE	Zeitschrift für Energiewirtschaft (Magazine for Energy Industry)
ZSW	Zentrum für Sonnenenergie- und Wasserstoffforschung (Centre for Solar Energy and Hydrogen Research)

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