Energy for Sustainable Development IV

Evidence from Czech Republic and Austria

Jaroslav Knápek, Amela Ajanovic, Reinhard Haas et al.

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Content

Preface

The energy system has been changing considerably in recent years. Especially the electricity markets have started to undergo fundamental changes in the supply structures.

A core focus of the work of the joint Czech-Austrian Energy Expert Group (CZ-AT EEG) is to analyse the effects of these changes and to deal with them with a special focus on the Czech Republic and Austria.

The CZ-AT EEG was established in 2002 by an initiative of the *"Protocol on the Negotiations between the Czech and the Austrian Governments"*, led by Prime Minister M. Zeman and Federal Chancellor W. Schüssel with the participation of European Commissioner for Enlargement G. Verheugen from the EU, generally known as the *Melk Protocol*. The adoption of this document was led by a goodwill of both the parties for the further development of neighbourly relations. With respect to the basic differences between the national policies on energy in general and on electricity specifically in the two countries, it is evident that the activities of such an expert working group are exceedingly important from the point of view of the development of new energy technologies as well as an open debate on the energy policies of both the countries.

Since the AT-CZ research group was established in 2002, a series of activities on energy research has taken place. A core activity was a permanent timing of two standard meetings carried out each year (one in each country). The main agenda of those meetings has consisted of an assessment of previous activities and the preparation and adjustment of the action plan for the future. Scientific seminars and conferences have been arranged by the group every year. The discussion has concentrated predominantly on the questions of renewable sources of energy, especially biomass, reshaping electricity markets, environmental matters in energy, retrofitting of buildings, possibilities of reductions to energy spending, and other connected topics.

Another important point is the fact that, in the last eight years, more than 160 students of Czech and Austrian universities have participated in joint winter/summer schools on "Energy systems and the environment", introduced among the expert group's activities in the recent years. This success is further conditioned by organising winter and summer schools for students of economic, environmental and energy study programmes.

Another impressive activity has been the publication of a series of books.

The first publication of the group's expert reports was edited in 2005. Now we are presenting the 4th issue of publications presenting the results of joint research. This book is the 4th in this series focusing on the most recent developments in the energy sectors of these countries with an additional attempt to provide a comparison with overall EU developments.

A significant part of these contributions comprises the joint reports of both the countries' experts. The reader can find not only some non-traditional views on new technologies for energy sources, but an open discussion of approaches to their utilisation in the light of national policies as well.

In conclusion of this short foreword to the publication, it should be emphasised that all the activities of the CZ-AT EEG have been supported by funding of the Ministry of Foreign Affairs of the Czech Republic and the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. Certain students' activities have been supported by the AKTION programme and by own resources of the participating universities. The members of the CZ-AT EEG hope that the promising activities done over the past 13 years will continue to be maintained and developed in the future.

This book is organized as follows:

In chapter 1 a general overview on energy supply, energy consumption and the environment in the Czech Republic and Austria is given in an international context.

The following four chapters focus on development of renewables. Chapter 2 analyzes the recent trends in renewable electricity and corresponding support costs in the EU-28 with a special focus on the Czech Republic and Austria. Chapter 3 and 4 discuss the potentials of biomass and biofuels in the Czech Republic and Austria. Chapter 5 provides a specific analysis of the Competitiveness of intentionally planted biomass for energy purposes.

Chapter 6 to 8 focus on issues of electricity generation. Recent changes and future challenges on European electricity markets are analysed in Chapter 6. In Chapter 7 the modelling and forecasting of spot electricity prices and their volatility is investigated. Chapter 8 provides an economic evaluation of energy storage.

Finally, chapter 9 and 10 provide contributions from the end-use sectors Heating and Transport. Chapter 9 discusses the energy demand and corresponding greenhouse gas emissions of buildings in Austria. The major trends in passenger car transport in Austria and the Czech Republic are compared in Chapter 10.

Prague and Vienna, June 2015: Jaroslav Knápek, Amela Ajanovic, Reinhard Haas

1

Energy Supply, Energy Consumption and the Environment: the Czech Republic and Austria in an International Context

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Abstract

Energy consumption, fuel mixes, energy intensities and energy-related greenhouse gas (GHG) emissions have developed quite differently in various EU countries in recent years. The core objective of this chapter is to provide comparisons for major energy and environmental features, patterns and indicators between the Czech Republic (CR), Austria (AT) and the EU-28.

The major results of our investigations are as follows. The development of the structures of primary and final energy consumption in the EU-28, the CR and AT in recent decades have been quite different. The major difference was that the trend was rather decreasing in the CR and quite stable in the EU-28, while energy consumption has been increasing in AT in all the categories investigated. Regarding the environmental performance GHG emissions decreased in the Czech Republic but are still on a higher level than in Austria where they remained constant since 1990. Eventually, the major conclusion is that both the countries still have a potential for further improvements in their energy and environmental performance.

Key words: energy consumption, environment, indicators, Austria, Czech Republic

1.1 Introduction

Energy consumption, fuel mixes, energy intensities and energy-related greenhouse gas (GHG) emissions have developed quite differently in various EU countries in recent years. Huge differences are observed especially between the Czech Republic and Austria. In this chapter, we provide some comparisons for major energy and environmental features, patterns and indicators. The core objective is to extract corresponding differences between the Czech Republic (CR) and Austria (AT) in a European context.

In detail, the following analyses are conducted:

– documentation of major basic facts and figures on historical development and the current state of primary and final energy consumption in the CR and AT broken down by energy carriers (coal, biomass, district heating, electricity, etc.);
– analysis of indigenous energy shares vs. imports;
– extraction of trends in final energy consumption by end use sectors;
– comparison of major energy indicators;
– comparison of major environmental indicators.

1.2 Development of energy consumption

The first objective is to compare and identify differences in primary and final energy consumption between the CR and AT in an EU-28 context.

1.2.1 Development of primary energy use

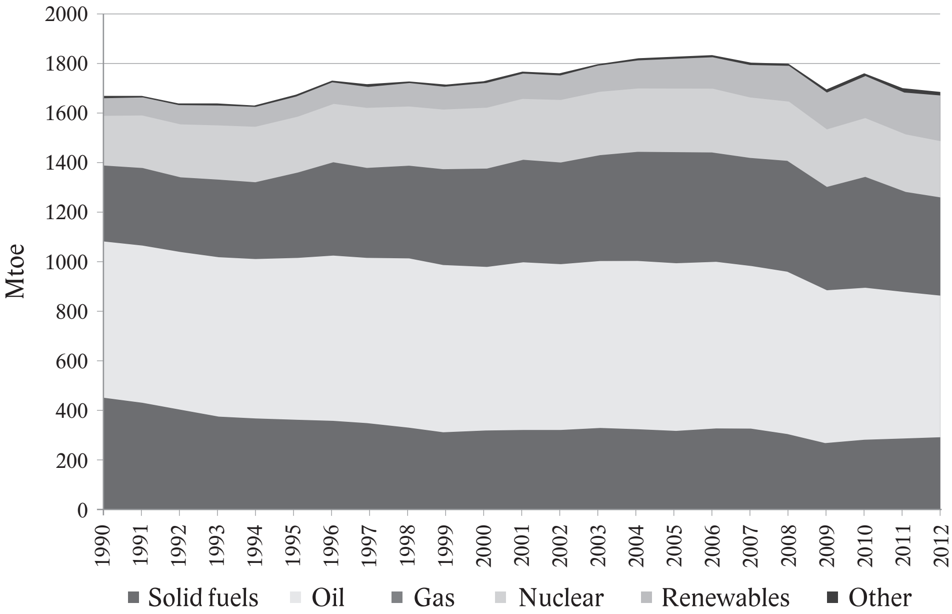
First, we analyse developments and differences in primary energy use in the EU-28, the CR and AT. Primary energy consumption in the EU-28 from 1990 to 2012 by energy source is shown in Fig. 1. It can be seen that there was some volatility but the total consumption did not change considerably over the whole period. Regarding the fuels, renewables and gases increased while solid fuels dropped remarkably. Nuclear and oil products remained quite stable.

The corresponding picture for the CR is shown in Fig. 2. The major findings are by and large the same as for the EU-28 but nuclear and renewables increased.

The development of primary energy consumption in Austria from 1955 to 2012 by energy carrier (incl. electricity imports) is depicted in Fig. 3. The major findings are quite different because the total primary energy consumption increased from about 1100 PJ in 1990 to about 1400 PJ in 2012. Especially the consumption of gas and renewables increased.

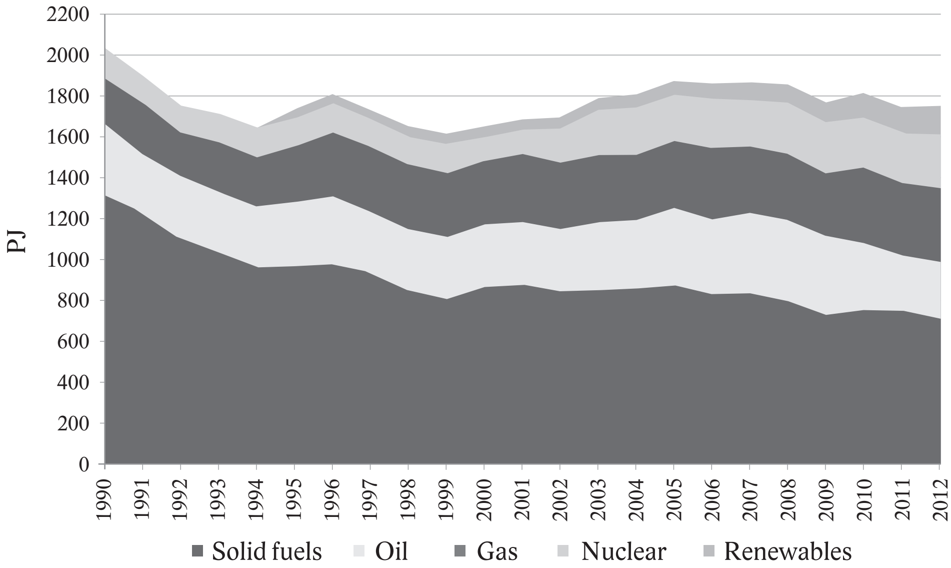
1.2.2 Development of indigenous primary energy supply and imports

A comparison of the development of indigenous primary energy supply and imports in the CR and AT is given in Fig. 4 and 5. The differences are tremendous. In the CR, the share of indigenous supply has been constant at about 75% (incl. nuclear) since 1990. In Austria, it was only about 30%.



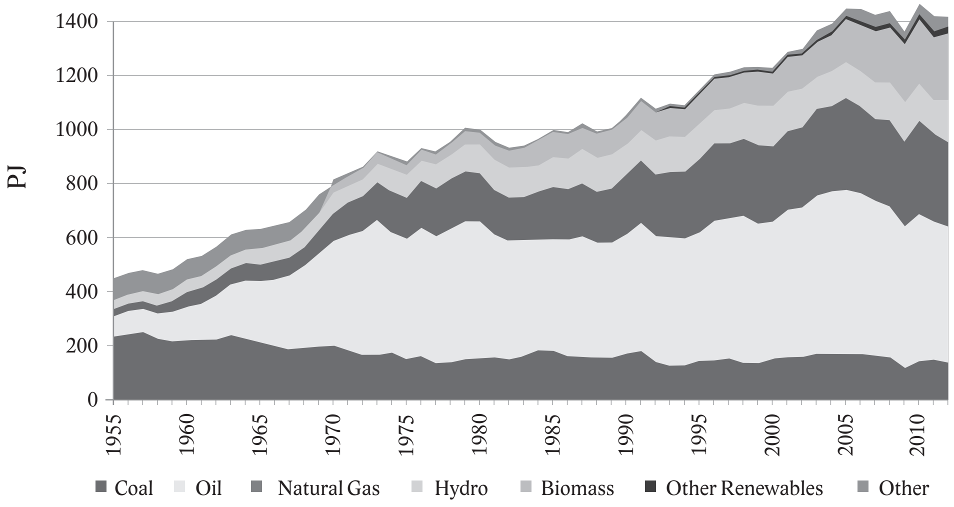
Source: EU Energy pocket book 2014

Fig. 1: Primary energy consumption in the ***EU-28*** *from 1990 to 2012 by energy sources*



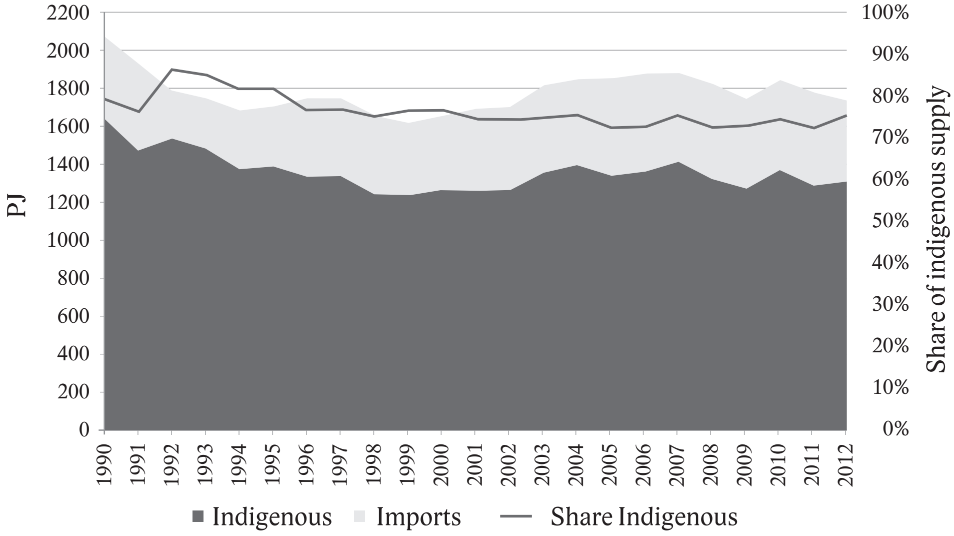
Source: MPO, 2014

Fig. 2: Development of primary energy consumption in the Czech Republic from 1990 to 2012 by energy carrier (incl. electricity imports)



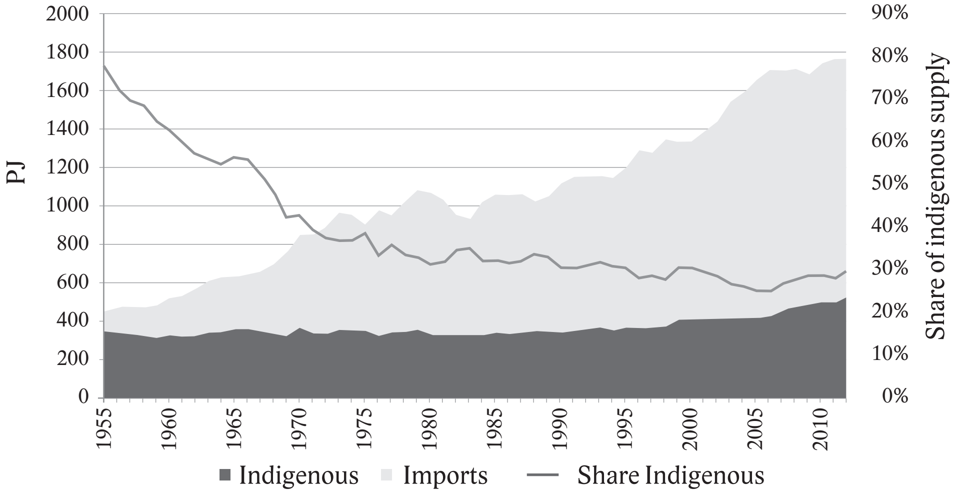
Source: Gesamtenergiebilanz Statistik Austria

Fig. 3: Development of primary energy demand in Austria from 1955 to 2012 by energy carrier (incl. electricity imports)



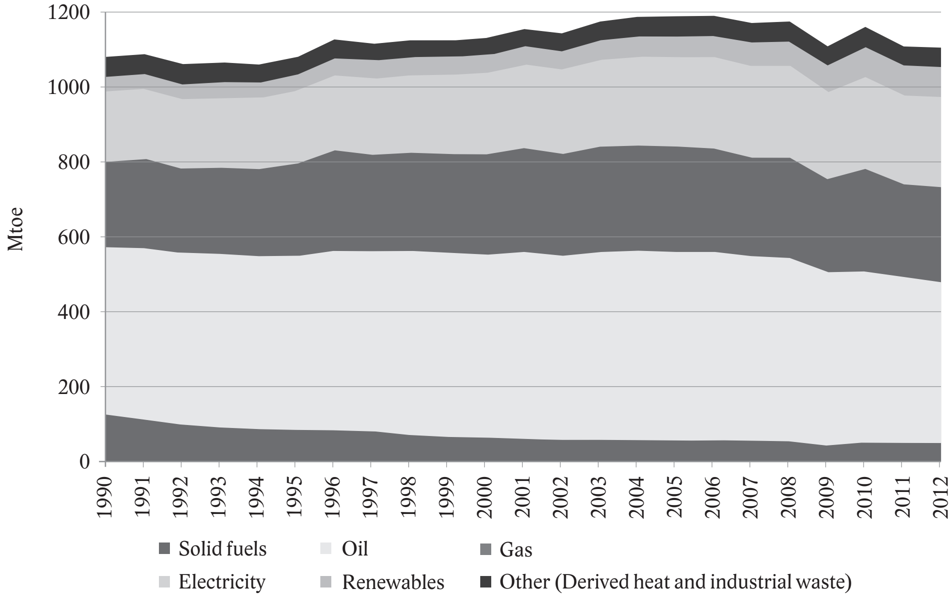
Source: MPO, 2014

Fig. 4: Development of indigenous primary energy supply and imports in the Czech Republic from 1990 to 2012



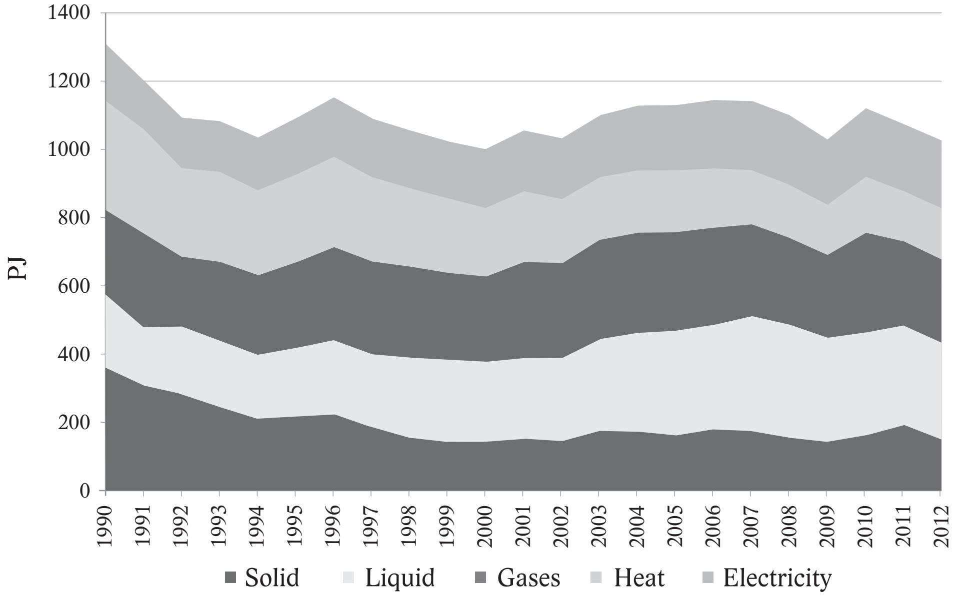
Source: Gesamtenergiebilanz Statistik Austria

Fig. 5: Development of indigenous primary energy supply and imports in Austria from 1955 to 2012 (including exports)



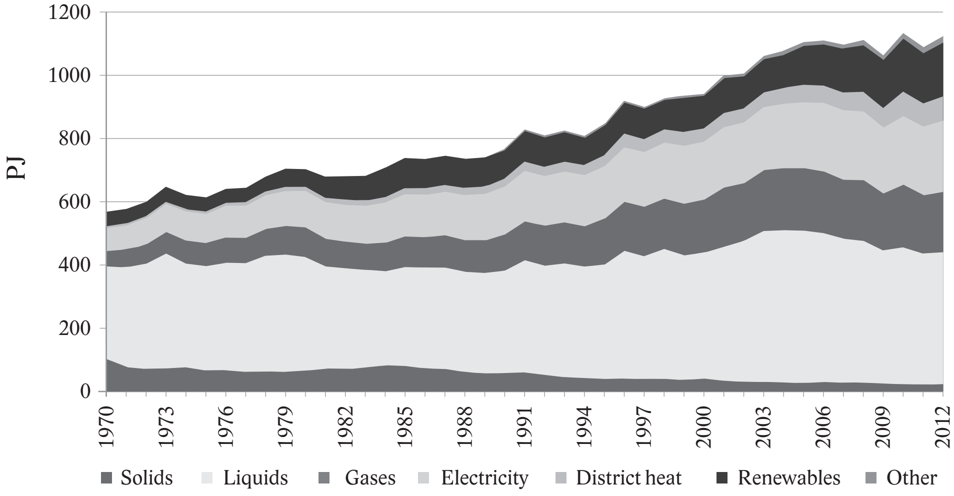
Source: EUROSTAT

Fig. 6: Development of final energy consumption in the EU-28 from 1990 to 2012 by energy carrier



Source: CENIA, 2014

Fig. 7: Development of final energy consumption in the Czech Republic from 1990 to 2012 by energy carrier



Source: Gesamtenergiebilanz Statistik Austria

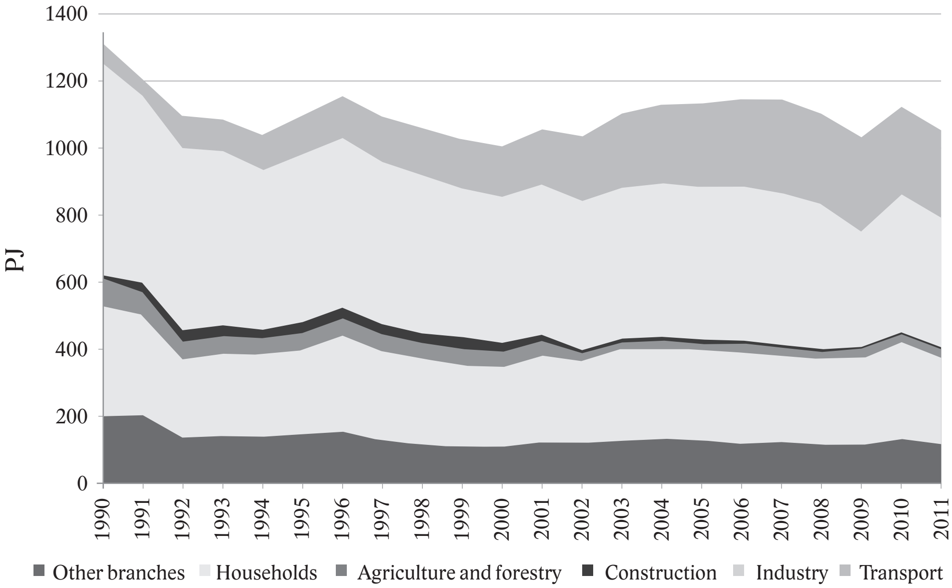
Fig. 8: Development of final energy consumption in Austria from 1970 to 2012 by energy carrier

1.2.3 Development of final energy consumption

Next, we analyse the developments and differences in final energy consumption in the EU-28, the CR and AT. Most impressing is the overall difference. As seen from Fig. 6, 7 and 8, the final energy consumption between 1990 and 2012 stagnated in the EU-28, decreased by about 300 PJ in CR, and increased by about the same amount (300 PJ) in AT. Regarding electricity, there were slight increases in the EU-28 and the CR (about 20%), Fig. 7, and a remarkable increase of about 48% in AT, Fig. 8.

Next, it is of course of interest which sectors contributed to these increases in AT and decreases in the CR.

The development of final energy consumption in the Czech Republic from 1990 to 2012 by sector is depicted in Fig. 9. Most remarkable is the increase in transport, where energy consumption quadrupled (+360%!). In the household sector, there was a moderate consumption decrease (−22%). The strongest drops are observed in industry (−40%) and other branches (−44%).

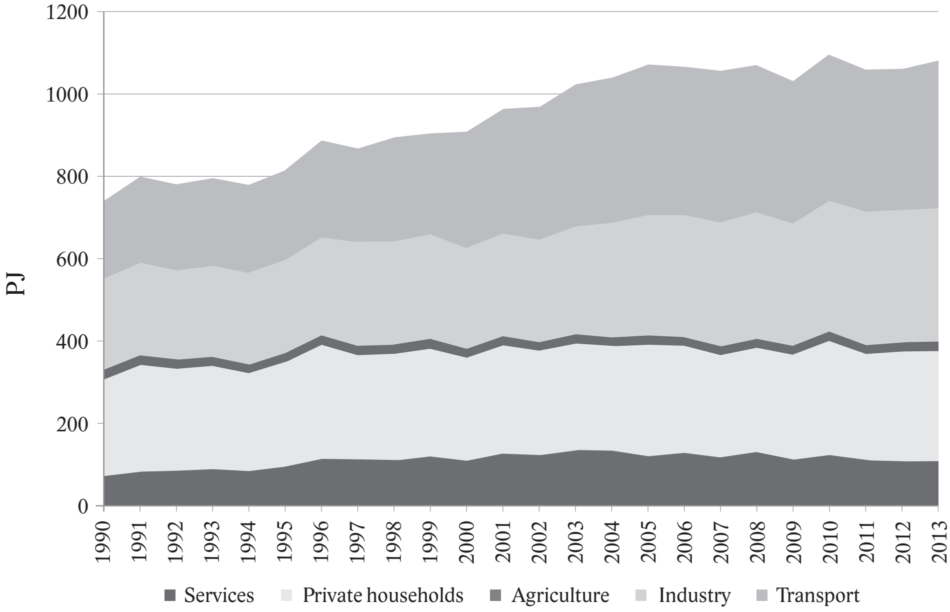


Source: CZSO, 2014

Fig. 9: Development of final energy consumption in the Czech Republic from 1990 to 2011 by sector

Fig. 10 depicts the development of final energy consumption in Austria from 1990 to 2013 by sector. As in the CR, the steepest increase took place in transport, where the energy consumption almost doubled (+90%) from 1990 to 2013. Contrary to the CR, also almost all other sectors (except agriculture) showed considerable growth rates. Next to transport, energy consumption grew by about 50% in industry and in the service sector. Only the growth in the households was moderate (+15%).

A comparison for both the countries setting the values of all the branches equal to 1 in 1990 is provided in Fig. 11 (same scale for both countries to allow a better comparison). Here the completely different patters can be recognised even more clearly. The growth in transport was the steepest in both the countries, yet considerably higher in the Czech Republic.

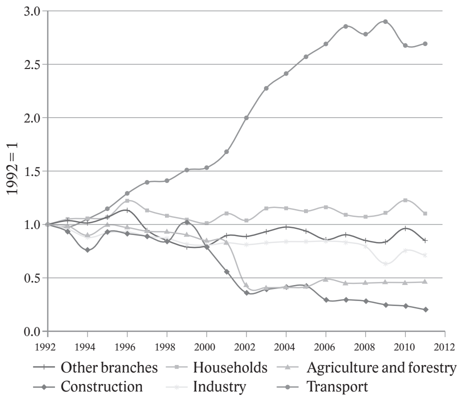


Source: Gesamtenergiebilanz Statistik Austria

Fig. 10: Development of final energy consumption in Austria from 1990 to 2013 by sector

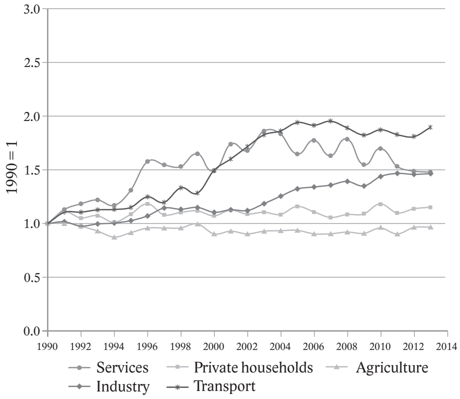
1.3 Comparison of energy indicators: energy intensity and service efficiency

An important indicator for the energy efficiency of countries is energy intensity, which is the amount of energy consumed per unit of GDP. A comparison of the energy intensities in the EU-28 countries is provided in Fig. 12. The average of all the countries is 143 toe/EUR million. It shows that Austria has exactly this value and is ranked in the 5th place. The CR is ranked 25th with about 355 toe/EUR million.



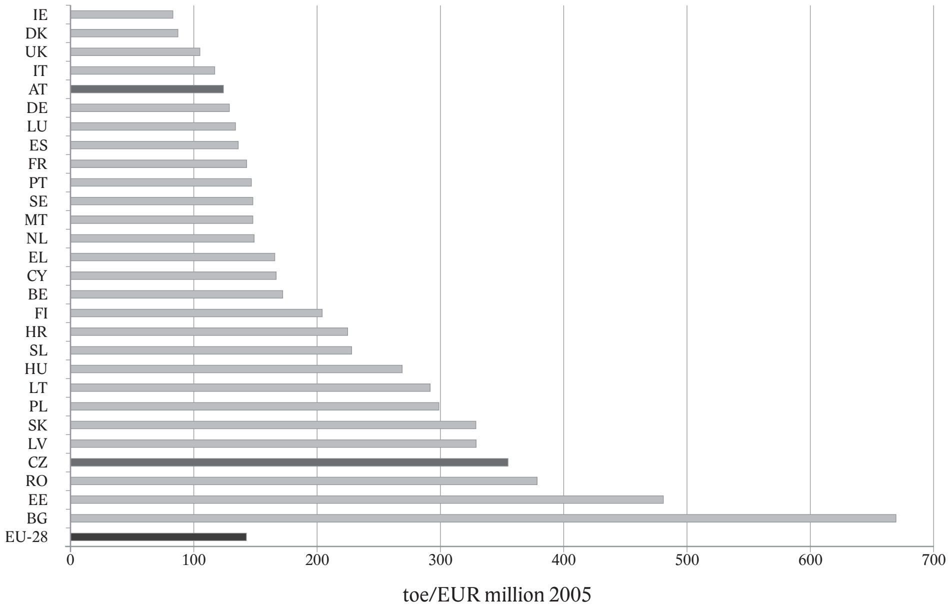
Source: CZSO, 2014

*Fig. 11a: Final energy consumption in the **Czech Republic** 1992 to 2011 by sector, 1992 = 1*



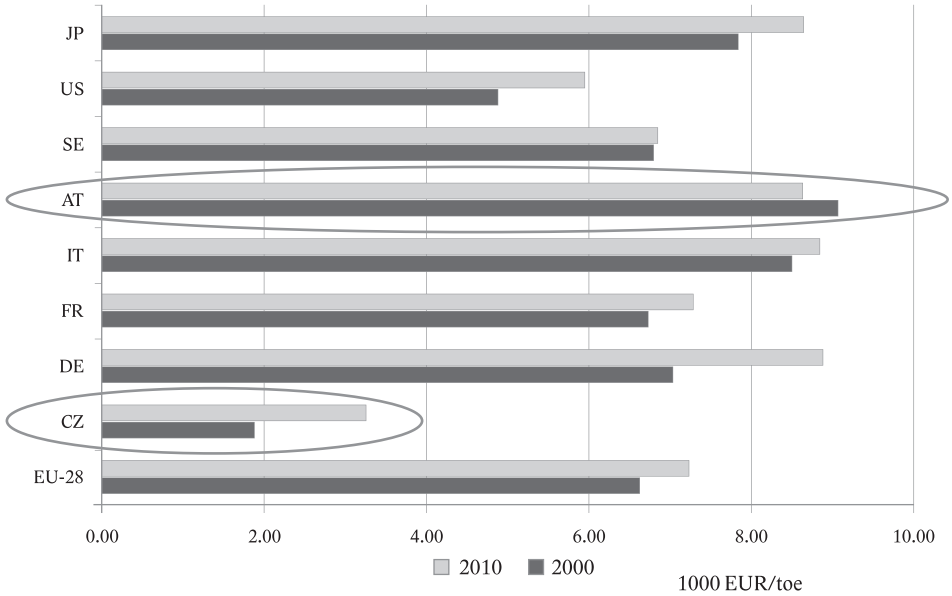
Source: Gesamtenergiebilanz Statistik Austria

*Fig. 11b: Final energy consumption in **Austria** 1990 to 2013 by sector, 1990 = 1*



Source: EC, 2012

Fig. 12: Energy intensity of different EU countries in 2011



Source: EUROSTAT 2013; IEA, 2013

Fig. 13: Service intensity in 1000 EUR/toe in selected countries

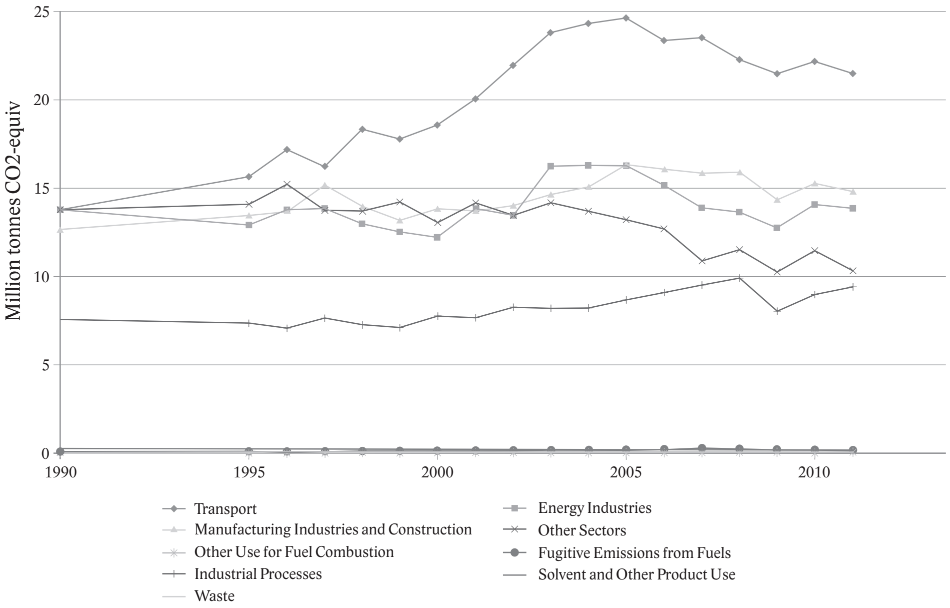
In addition, a comparison of service efficiency – the inverse of energy intensity – provides quite a good ranking for AT at a first glance. Yet the trend is problematic; see Fig. 13. While in the year 2000, AT ranked first among the compared countries with 9100 EUR/toe, AT dropped behind Germany, Italy and Japan in 2010 with 8630 EUR/toe. Moreover, in this comparison AT was the only country whose performance became worse.

On the other hand, the CR almost doubled its performance from 1900 EUR/toe to 3700 EUR/toe.

1.4 Comparison of environmental indicators

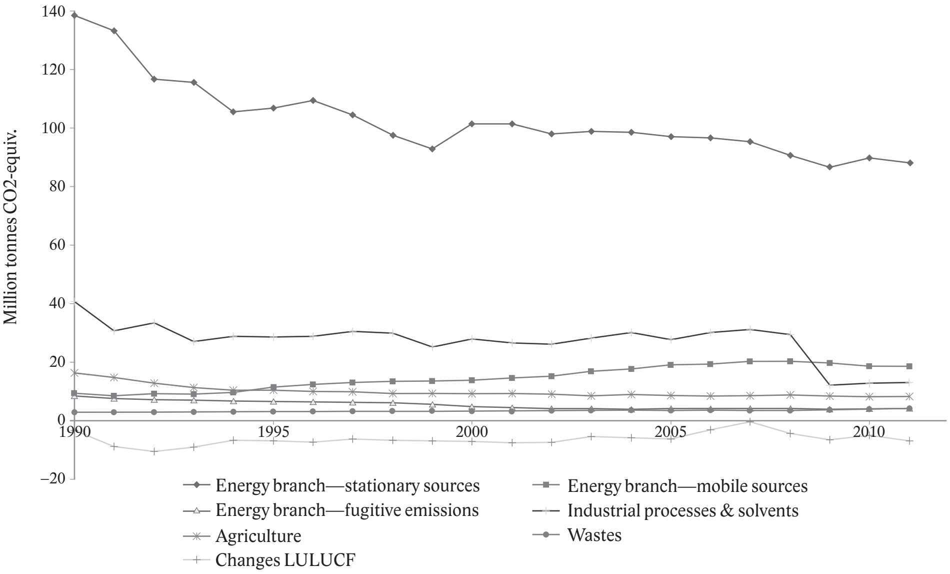
Aside from the energy indicators, most important in the international context is to look at the development of GHG emissions. A comparison between the CR and AT is provided in the following. The development of total greenhouse gas emissions in Austria by sector from 1990 to 2011 is shown in Fig. 14. By far the steepest increases took place in transport while all the other sectors stagnated by and large.

The development of total greenhouse gas emissions in the Czech Republic by sector from 1990 to 2011 is shown in Fig. 15. Stationary processes on the energy branch as well as industrial processes had clearly decreasing emissions; the steepest increase also took place in transport.



Source: UBA, 2013

Fig. 14: Development of total greenhouse gas emissions in Austria by sector from 1990 to 2011



Source: http://issar.cenia.cz/issar/page.php?id=1509

Fig. 15: Development of total greenhouse gas emissions in the Czech Republic by sector from 1990 to 2011

A comparison of total greenhouse gas emissions in the Czech Republic and Austria from 1990 to 2012 is provided in Fig. 16. While there is a remarkable decrease in the CR, no significant changes can be seen in Austria. In comparison to the average of the EU-28 countries, the trend in AT was worse while in the CR it was much better than the EU-28; see Fig. 17.

Finally, a comparison of greenhouse gas emissions per capita in the EU-28, the Czech Republic and Austria from 1990 to 2012 is shown in Fig. 18. The CR is still above the EU-28 average per capita; the Austrian position has changed. While AT was better than the EU-28 in the 1990s, it has been worse since about 2003.

Next, we compare the greenhouse gas emission indicators for primary energy. We look at the relationships between tonnes of CO_2-eq./toe. As Fig. 19 shows, AT performs very well in an international context. Only Sweden performs better. The CR has the highest emissions in this comparison. Yet, it is the only Eastern European country considered.

The trend is positive for both the countries. Austria reduced its emissions from 2.13 tonnes of CO_2-eq./toe in the year 2000 to 1.93 in 2010. The CR reduced its emissions from 3.6 tonnes of CO_2-eq./toe in the year 2000 to 3.1 in 2010.

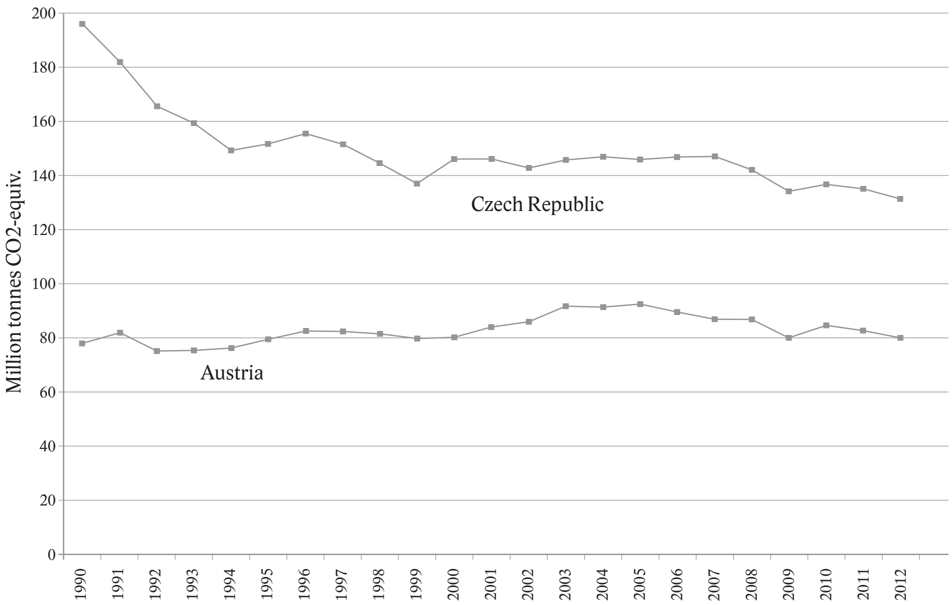
1.5 Conclusions

The development of the structures of primary and final energy supply in the EU-28, the CR and AT in recent decades were quite different. The major difference was that the trend was rather decreasing in the CR and quite stable in the EU-28, while in AT energy consumption has been increasing in all the categories investigated. An interesting specific aspect is that energy consumption in transport showed the steepest increases in both the countries.

Regarding a comparison of service efficiency (EUR GDP/energy unit), the assessment for the CR and AT is also quite different. On the one hand, AT started in 1990 from a top ranking with 9100 EUR/toe. But the trend is problematic. In 2010, AT dropped to 8630 EUR/toe. On the other hand, the CR started from a rather bad position but almost doubled its performance from 1900 EUR/toe to 3700 EUR/toe in 2010.

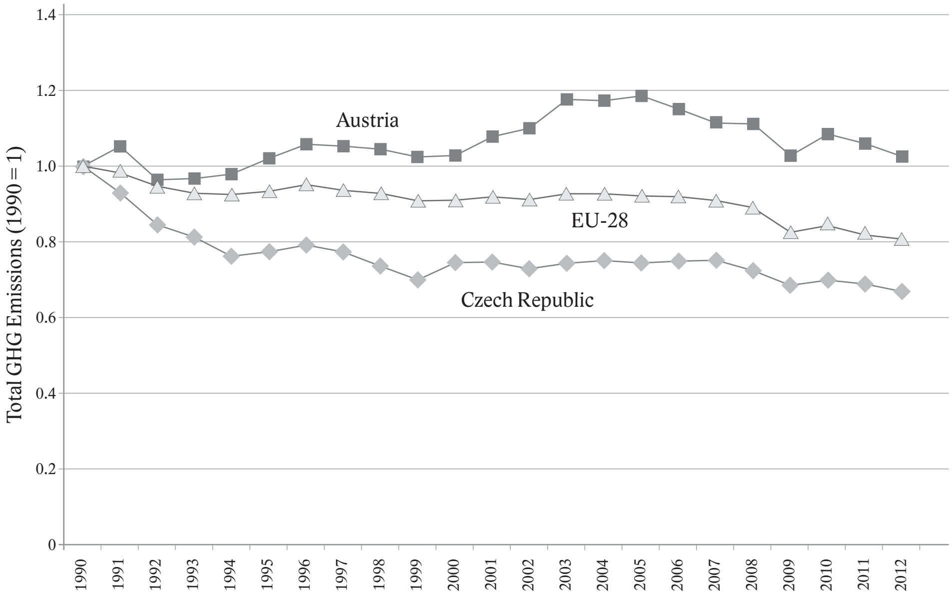
Looking at the development in the environmental performance indicators, the trend is positive for both the countries. Austria reduced its GHG emissions from 2.13 tonnes of CO_2-eq./toe in the year 2000 to 1.93 in 2010. The CR reduced its emissions from 3.6 tonnes of CO_2-eq./toe in the year 2000 to 3.1 in 2010.

Eventually, the major conclusion is that both the countries still have a potential for further improvements in their energy and environmental performance.



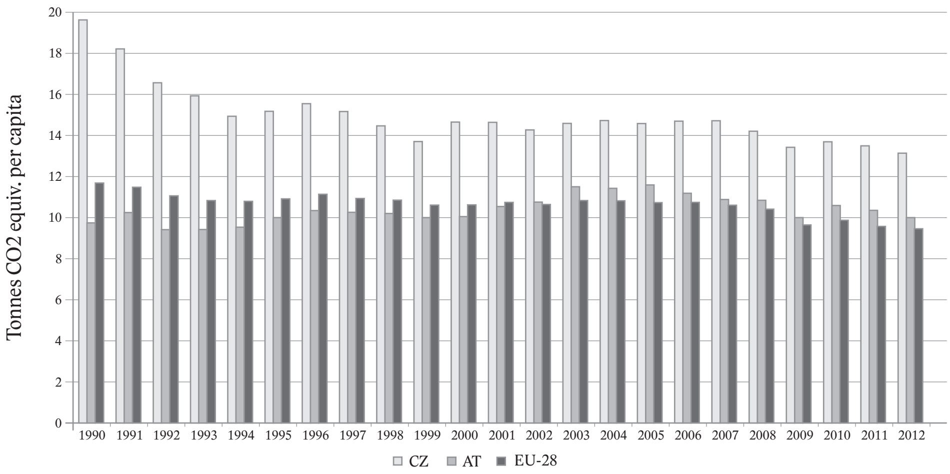
Source: CENIA, 2014; Statistik Austria, 2014

Fig. 16: Comparison of total greenhouse gas emissions in the Czech Republic and Austria from 1990 to 2012



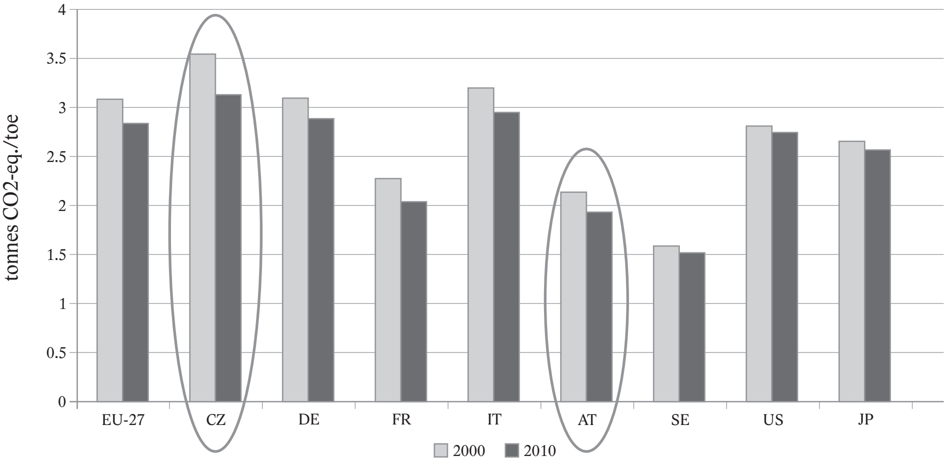
Source: CENIA, 2014; Statistik Austria, 2014; EC, 2014

Fig. 17: Comparison of total greenhouse gas emissions in the EU-28, the Czech Republic and Austria from 1990 to 2012; 1990 = 1



Source: CENIA, 2014; Statistik Austria, 2014; EC, 2014

Fig. 18: Comparison of greenhouse gas emissions per capita in the EU-28, the Czech Republic and Austria from 1990 to 2012



Source: EUROSTAT 2013

Fig. 19: Specific GHG-Emissions in tonnes of CO_2-eq./toe in selected countries

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2

Trends in Renewable Electricity and Corresponding Support Costs in the EU-28 with a Special Focus on the Czech Republic and Austria

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Abstract

Renewable energy sources (RES) are considered to be a promising option for mitigating global warming. To fully harvest these potential benefits, the EU has set ambitious targets to increase the share of RES in energy use. Generation of electricity from renewable energy sources (RES-E) plays a very specific role in this context.

The core objective of this chapter is to analyse recent developments in deployment of renewables in the EU-28 with a special focus on the CR and AT. Moreover, the costs of the currently existing promotion schemes for RES utilisation in the Czech Republic and in Austria will be investigated.

The major results are as follows. Due to higher potentials, especially from large hydro power, conditions for the use of RES-E are much more favourable in AT than in the CR. In the last 20 years, the share of RES-E in the total final demand was always between 60% and 65%. However, the CR has at least caught up with the trend. In 2012, four times more RES-E were produced than in 2000.

Regarding the costs of support, the surcharge in cent/kWh RES-E generated in AT is by far the lowest while it is much higher in the Czech Republic as well as in Germany. The costs of support per kWh RES-E generated skyrocketed in the Czech Republic after 2010; they increased in Germany and remained rather constant in Austria.

Key words: renewable electricity, costs of support, promotion schemes, Austria, Czech Republic

2.1 Introduction

Renewable energy sources (RES) are considered to be a promising option for mitigating global warming. To fully harvest these potential benefits, the EU has set ambitious targets to increase the share of RES in energy use. Generation of electricity from renewable energy sources (RES-E) plays a very specific role in this context.

Already in 2001, Directive 2001/77/EC (EC, 2001) of the European Parliament and of the Council *"on the promotion of electricity from renewable energy sources in the internal electricity market"* was implemented. The objective of this Directive was to enhance deployment of renewables in the electricity sector, establishing an indicative RES-E target of 22.1% at the EU(27) level by 2010.

In recent years, due to generous support schemes in a number of countries, electricity generation from renewables has been growing at a remarkable rate, as illustrated in Fig. 4 and 5 for EU-28 countries between 1990 and 2013. The growth of "new" renewables excluding hydropower is even more impressive over the same period: it grew from less than 1% to about 13%, mainly from wind and biomass (Fig. 5).

The rapid growth of renewable energy generation is mostly attributed to support schemes[1] such as feed-in tariffs and tradable green certificates encouraged by EU policies. These generous subsidies are expected to continue in one form or another in the coming years, resulting in continued growth of renewable energy generation. Germany plays a significant role in this context due to the large size of its economy and the political decision to phase out its nuclear fleet by 2022, mostly to be replaced by renewable energy generation. The impact of the German "Energiewende", or turnaround, plus similar developments in other EU countries is likely to fundamentally change the electricity supply system in Europe. Already, the impact of large amounts of renewable energy generated is being felt on the spot market prices at the German electricity exchange, EEX, as explained in detail in Chapter 6 of this book.

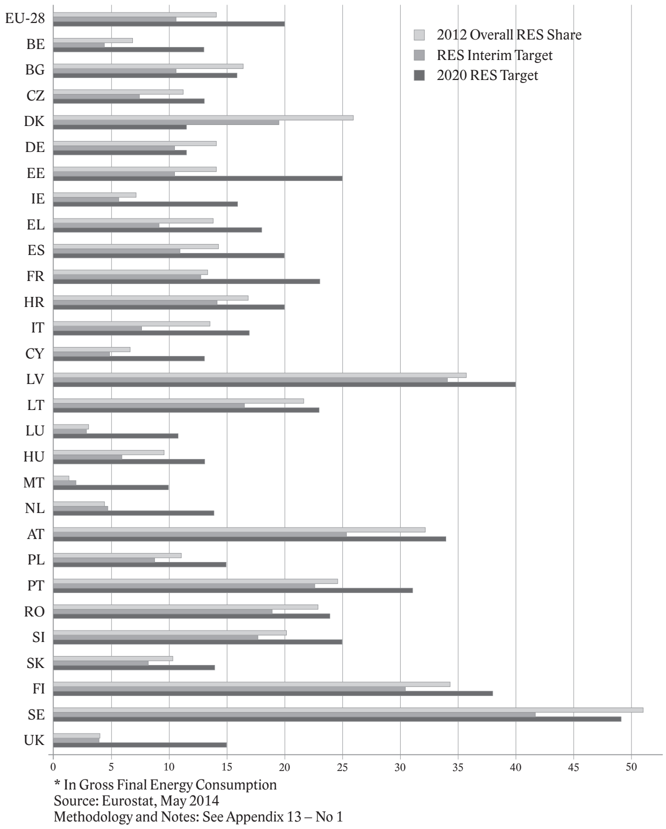
The core objective of this paper is to analyse the current opportunities and promotion schemes for further deployment of renewables in the EU-28 with a special focus on the CR and AT. The currently existing promotion schemes for RES utilisation in the Czech Republic and in Austria will be analysed.

2.2 Development of the use of primary renewable energy sources in the European Union, the Czech Republic and Austria

The first comparison focuses on the shares of RES. Fig. 1 depicts the shares of RES in the total primary energy in EU countries (Source: EUROSTAT, 2013).

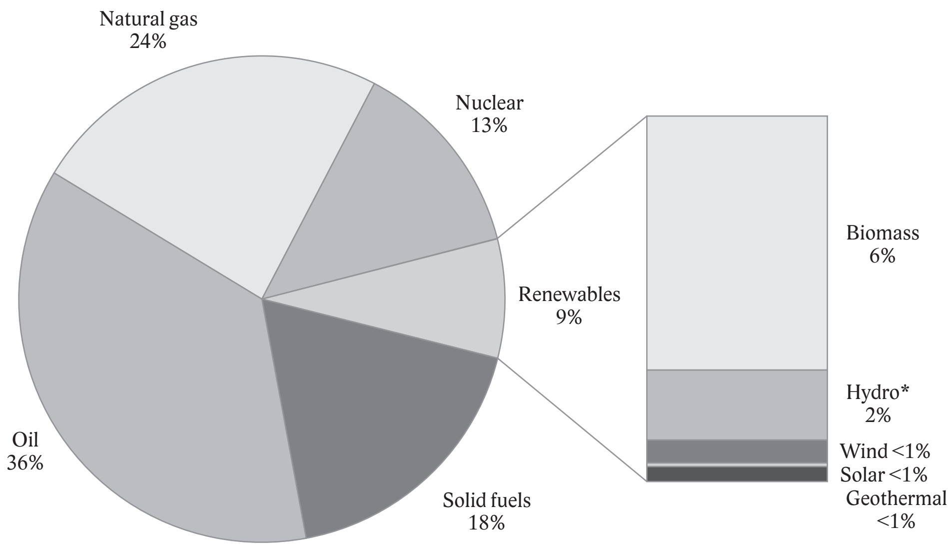
RES contributed in total by 9%. In general, the production of renewable energy in the EU-28 is dominated by biomass.

[1] *For further details on the support schemes, refer to Haas et al., 2011a, Jacobsson et al., 2009.*



Source: EU, 2014

Fig. 1: Shares of RES in total primary energy interim goals and RES 2020 targets in EU countries in 2012



Source: EU Pocket book, 2014

Fig. 2: Primary renewable energy sources in the EU-28 in 2012 in comparison to all other energy sources

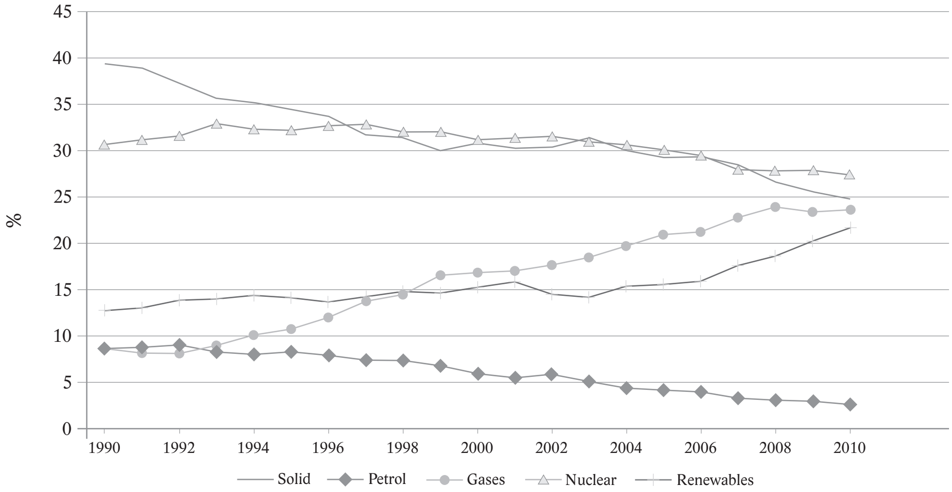
2.3 EU-28: Development of the use of renewable energy sources in electricity generation

In recent years, due to generous support schemes in a number of countries, electricity generation from renewables has been growing at a remarkable rate, as illustrated in Fig. 3 for EU-28 countries between 1990 and 2013. The growth of "new" renewables excluding hydropower is even more impressive over the same period: it grew from less than 1% to about 13%, mainly from wind and biomass (Fig. 5).

The renewable component of electricity generation in the EU-28 grew continually from 12 to 22% between 1990 and 2013, as illustrated in Fig 4. Even more impressive is the growth in electricity generation from natural gas from 9% to 24% over the same period, while the share of coal and petroleum has decreased. Nuclear electricity reached its peak of about 33% in the mid-1990s, dropping slightly to 28% by 2010, a trend that is expected to continue with the German nuclear phase-out.

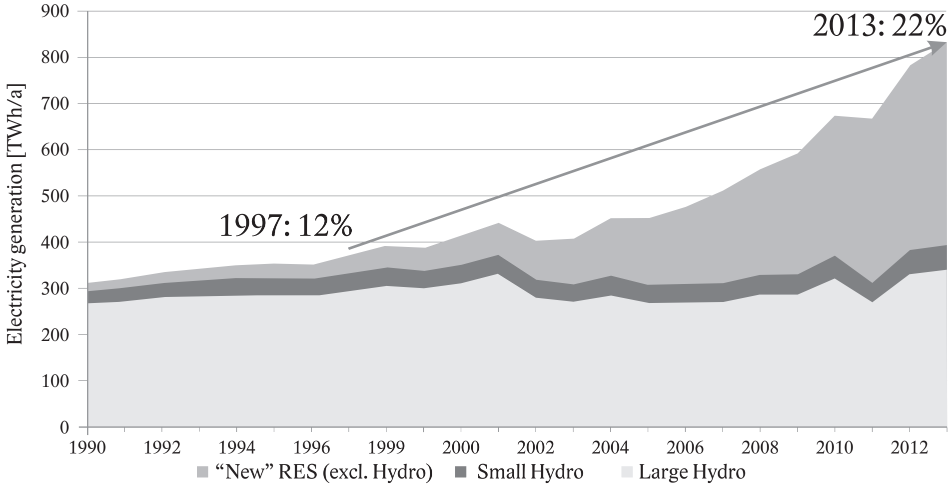
The rapid growth in renewable energy generation is mostly attributed to schemes[2] such as feed-in tariffs and tradable green certificates encouraged by EU policies. These generous subsidies are expected to continue in one form or another in the coming years, resulting in continued growth of renewable energy generation. Various estimates, e.g., Resch et al. (2012), suggest that contribution of renewables as a

[2] *For further details on the support schemes, refer to Haas et al., 2011a; Jacobsson et al., 2009.*



Source: EU, 2012

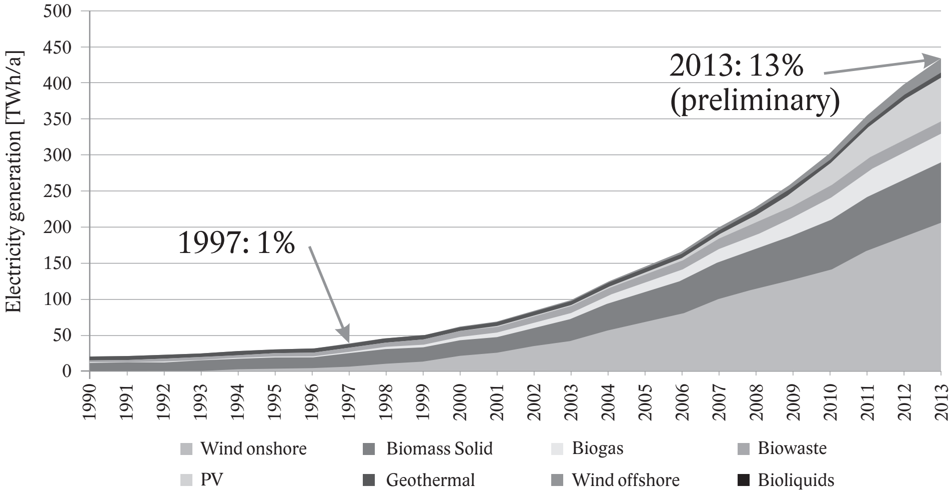
Fig. 3: Development of fuel shares of electricity generation in the EU-28 from 1990 to 2010



Source: EUROSTAT; EU, 2014

Fig. 4: Historical development of electricity generation from all renewables including hydropower in the EU-28 between 1990 and 2013, in TWh

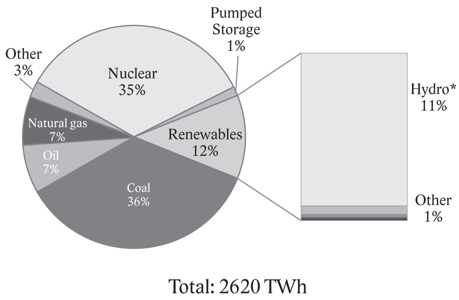
percentage of total electricity generation within the EU will rise from 21% in 2010 to 34–36% by 2020. Beyond 2020, the policy framework is less certain but a strong renewable energy component for the period up to 2050 is among the central features of the current EU policy debate.



Source: EUROSTAT; EU, 2014

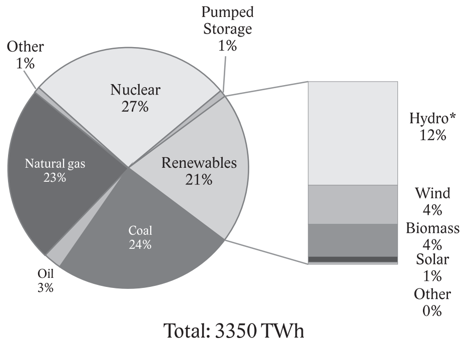
Fig. 5: Development of electricity from "new" renewables (excluding hydropower) in the EU-28 between 1990–2013, in TWh

The composition of the renewable electricity mix between 1990 and 2013 changed remarkably with hydro power dominating the picture in 1990 (Fig. 6.a), while wind, biomass and solar became noticeable by 2011 (Fig. 6.b).



Source: EU, 2014

Fig. 6a: Electricity generation in the EU-27 by fuel in 1990

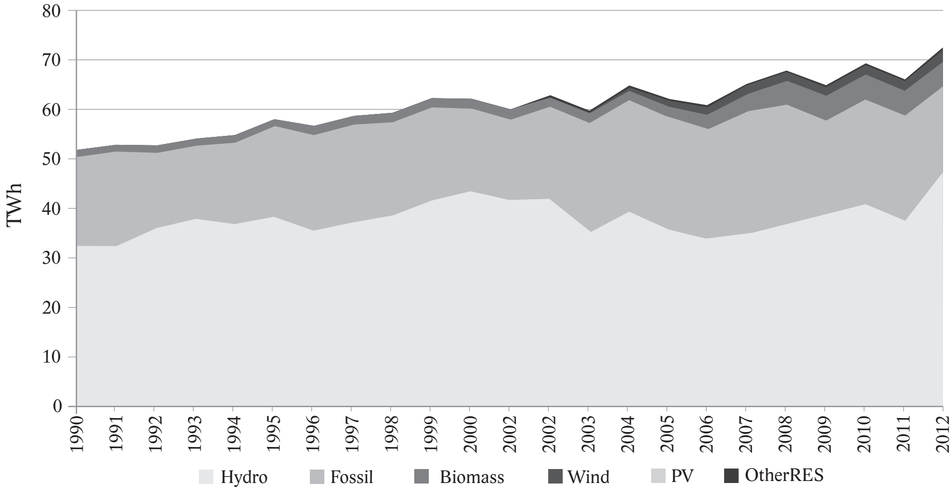


Source: EU, 2014

Fig. 6b: Electricity generation in the EU-27 by fuel in 2011

2.4
Austria: Development of the use of renewable energy sources in electricity generation

The structure of the development of total electricity generation broken down by energy source is shown in Fig. 7. As seen over the last decade, biomass and wind have shown the highest growth rates.



Source: E-Control

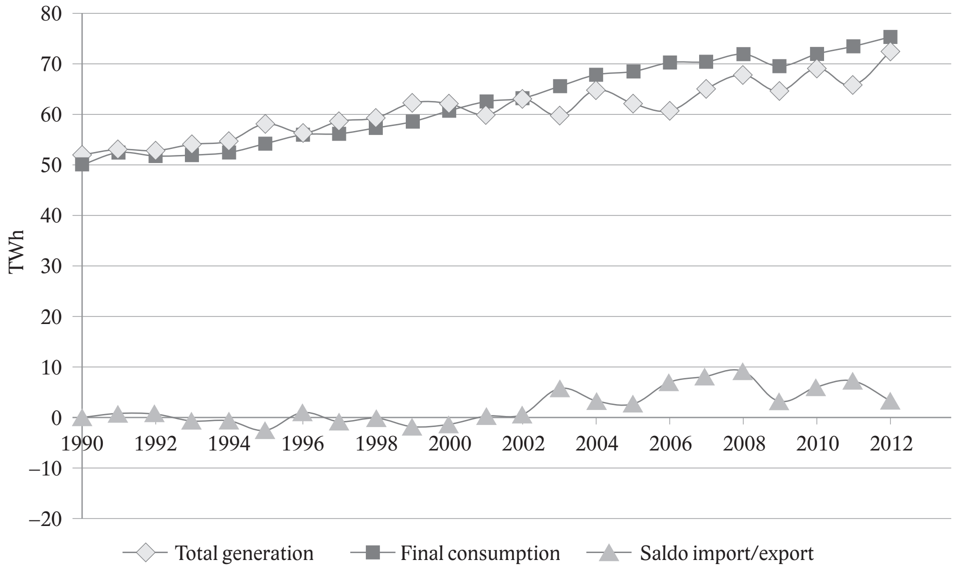
Fig. 7: Total electricity generation by fuel in Austria, 1990

The development of electricity generation, consumption and input/output balance in Austria 1990–2012 is shown in Fig. 8. While until 2002 AT was a net export country, the trend reversed afterwards. Since 2003, AT has been a net import country.

2.4.1
Current penetration of electricity from RES in Austria

The total electricity generation by fuel from "new" RES in Austria from 1990 to 2012 is shown in Fig. 9. As seen over the last decade, mainly the use of solid biomass, biogas and wind has shown the highest growth rates in renewable electricity generation.

Electricity generation from solid biomass and biowaste almost doubled in the period from 1993 to 2004 (from 984 GWh to 1,886 GWh) and once more from 2004 to 2012. A major share of the biomass electricity is attributed to industrial waste, especially in the paper industry. Being in contrast to the European definition, the biomass plants based on industrial waste are not considered "new renewables".



Source: E-Control

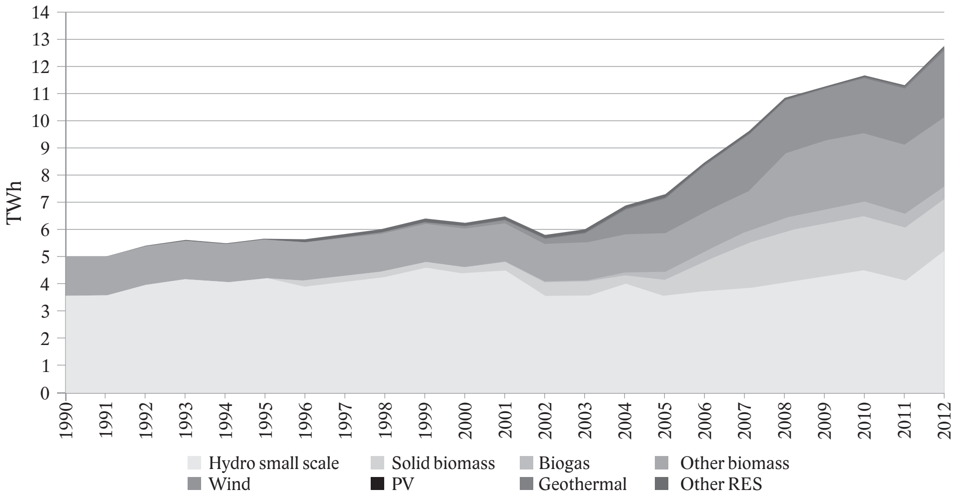
Fig. 8: Development of electricity generation, consumption and input/output balance in Austria 1990–2012

Only those RES-E technologies where the use started basically from scratch, such as PV and wind energy, could reach significantly higher growth rates. In the case of wind energy, a very strong growth could be observed in the last two years as an effect of the established feed-in tariffs.

Fig. 10 depicts the development of electricity consumption, electricity generation from renewables and the percentage of RES-E in total electricity consumption. However, the percentage of RES generation has decreased continuously since 2004.

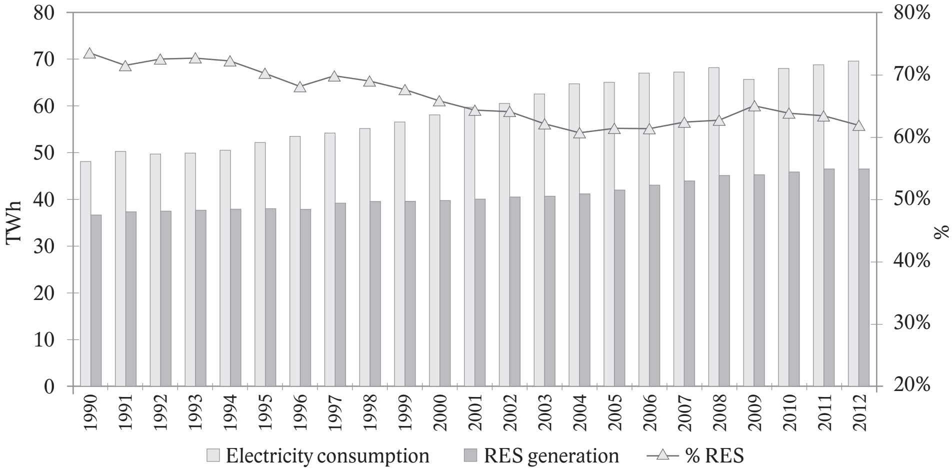
2.4.2
Support schemes for RES-E in Austria

The development of feed-in tariffs in Austria in comparison to the market price from 2003 to 2013 is depicted in Fig. 11. Most remarkable is the much steeper decrease for PV after 2011 than before. Regarding wind power there was a slight increase after 2011, leading to making wind power more attractive. With respect to small hydropower, it is of interest that the FIT in some years was smaller than the market price, e.g., 2006, 2008 and 2011. This led to the fact that small hydro power plant operators started to market their electricity in the spot market and not via the FIT-system. The FIT for biogas was the highest first in 2008 with another peak in 2013.



Source: E-Control

Fig. 9: Total electricity generation by fuel from "new" RES in Austria 1990–2012

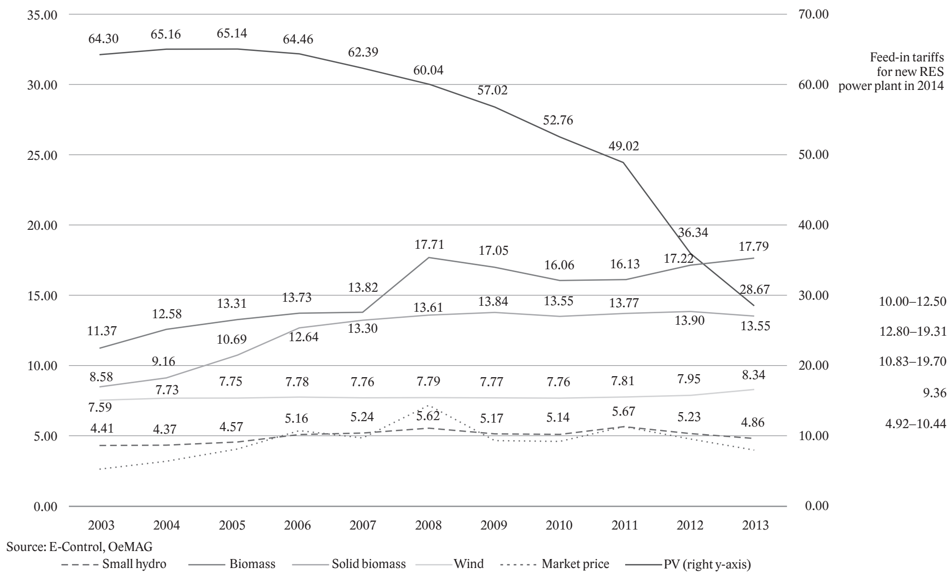


Source: E-Control

Fig. 10: Historical development of total RES generation, electricity consumption and the share of RES in Austria 1990–2012

2.5
Development of the use of renewable energy sources in electricity generation in the Czech Republic

The development of the use of renewable energy sources in electricity generation in the Czech Republic is documented in this chapter.



Source: E-Control, 2014

Fig. 11: Development of feed-in tariffs in Austria in comparison to the market price 2003 to 2013

First, the development of total electricity generation by fuel is shown in Fig. 12. The generation from nuclear plants doubled from 1990 to 2012, while production from coal remained stable. In total, power generation increased by one third.

The development of electricity generation, consumption and input/output balance in the Czech Republic in the period of 1990–2012 is shown in Fig. 13. In comparison to the remarkable growth in generation, consumption almost stagnated. Hence, there was enough electricity available for exports.

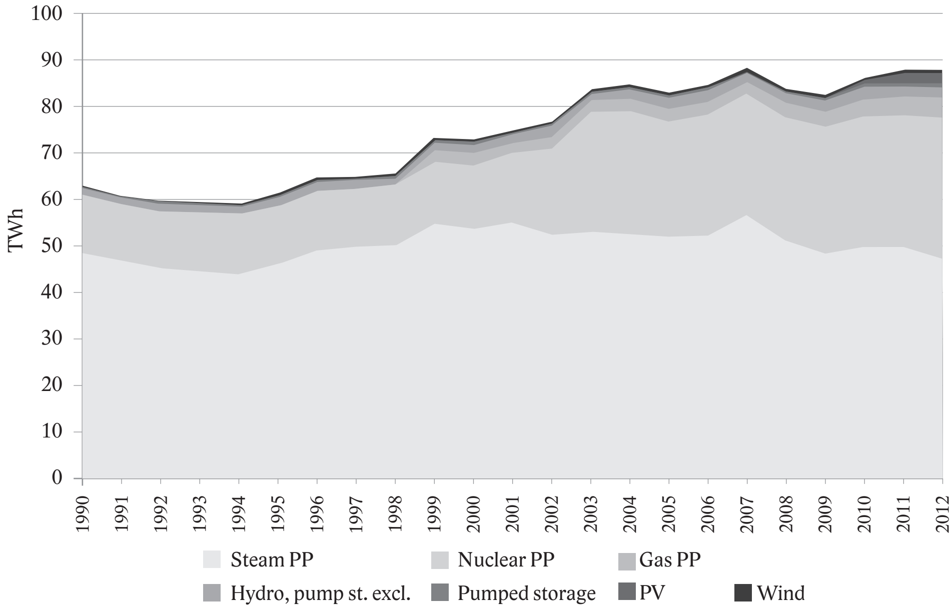
2.5.1 Electricity generation from RES in the Czech Republic

Next, the development of electricity generation from RES in the Czech Republic is analysed.

Total electricity generation by fuel from "new" RES (excl. large hydropower) in the CR from 2000 to 2012 is shown in Fig. 14. As seen over the last decade, mainly the use of solid biomass, biogas and wind has shown high growth rates in renewable electricity generation. Yet, the absolutely highest increase took place in PV generation.

Fig. 15 depicts power generation from RES and final electricity consumption in the Czech Republic from 2000 to 2012. Fig. 15 also documents the progress in RES-E share in gross domestic consumption of electricity[3].

[3] *Gross domestic consumption of electricity equals gross electricity generation minus balance (export – import).*



Source: MPO

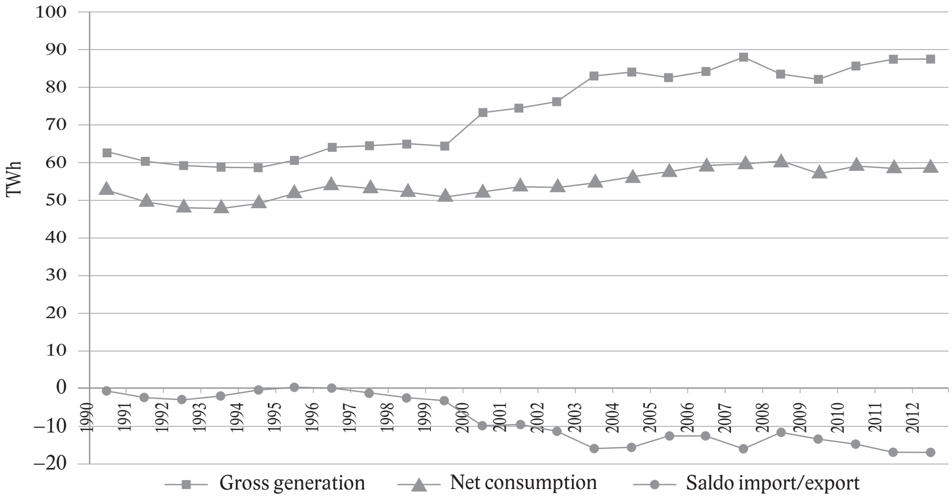
Fig. 12: Total electricity generation by fuel in the Czech Republic 1990–2012

Two major findings from this Figure are as follows. The percentage of RES remained constant at about 5% from 2000 to 2008. Afterwards a steep rise to about 12% in 2012 took place.

2.5.2 Overview of the support scheme for RES-E projects in the Czech Republic

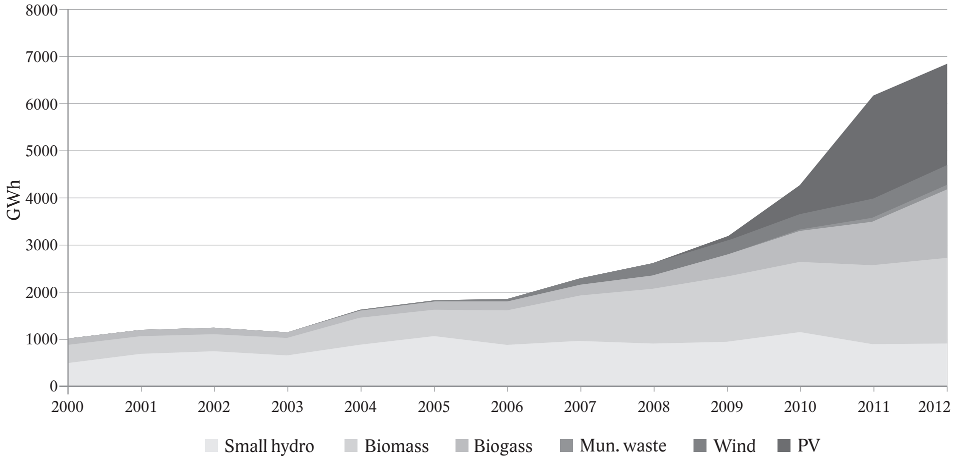
The history of the RES-E support scheme in the Czech Republic can be divided into the following time periods:

- Until the end of 2001: there was no operational support to RES-E projects, operators of RES-E plants had to sell electricity on the power market for the market price (which was much lower than was needed for the great majority of the projects). Only limited resources from the Czech Energy Agency and State Environmental Fund were available, usually in the form of investment subsidies (there was no legal claim for this support). The great majority of the money from the Czech Energy Agency was aimed at renovation of small hydro power plants. The State Environmental Fund supported namely pilot and testing plants (e.g., a few wind power plants, etc.).
- 2002–2005: Operational support to RES-E projects started in the beginning of 2002. Despite the fact that the support was based in principle on the logic



Source: ERO statistics

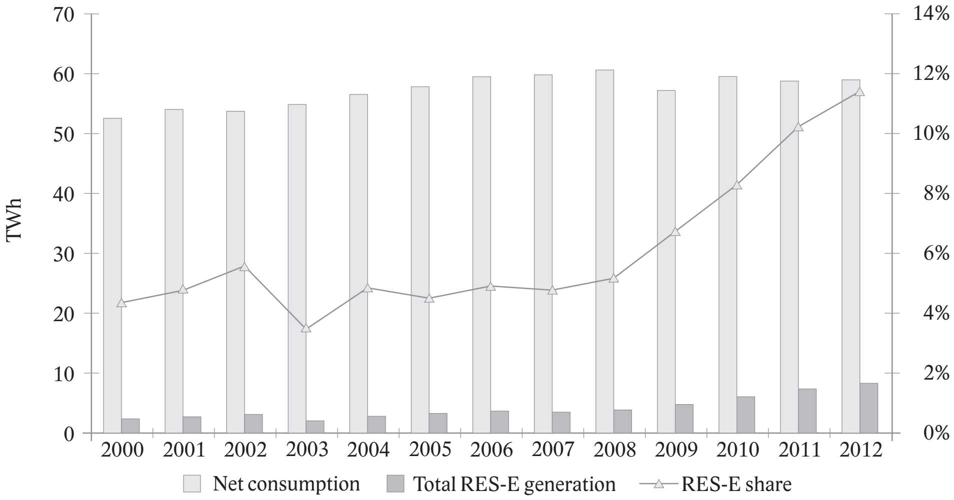
Fig. 13: Development of electricity generation, consumption and input/output balance in the Czech Republic 1990–2012



Source: MPO

Fig. 14: Development of total electricity generation by fuel from "new" RES, Czech Republic 2000–2012

of a feed-in tariff scheme, the Energy Regulatory Office (ERO) could legally guarantee its rates only for one year due to a lack of proper legislation. This fact caused problems with external (banking) financing (banks required much longer guarantee period) and investors were waiting for the establishment of long-term and systematic conditions for RES-E project support.



Source: ERO statistics

Fig. 15: Power generation from RES and final electricity consumption in the Czech Republic

– 2006–2010: Systematic operational support to RES-E projects was introduced by Act no. 180/2005 Coll. The support scheme was based on a rate-of-return approach and investors had the possibility to choose between a feed-in tariff and a green bonus scheme of support (see later). The feed-in tariffs were (and are still) guaranteed for 20 years (30 years for small hydropower). The rate-of-return approach worked with rational categorisation of feed-in tariff and green bonus rates according to the RES type and the technology used (and possibly also according to the installed capacity and other parameters). One of the important ideas within the support scheme was to create favourable conditions for RES-E investors through a guarantee of rate of return and risk reduction. Establishment of systematic rules for (long-term) RES-E support resulted in fast development in almost all the RES-E categories. Until the middle of 2008, the RES-E support scheme seemed to be leading to a win-win solution (both for the investors and for meeting the Czech Republic's country target in cost-effective ways). After the beginning of 2009, many of the RES-E support scheme pitfalls started to occur – e.g., strong lobbyism during reference project updates, limitation of feed-in tariff rate reduction for new projects leading to inadequately high rates, distortion of biomass prices on the biomass market, different rates of return on equity capital for different kinds of consumers resulting from the WACC approach in discount rate determination, absence of any limits for any RES type, etc. These pitfalls led to an unexpected development of RES utilisation for power generation, a boom of PV projects, and an enormous increase of the costs of the support scheme potentially resulting in unacceptable growth of electricity prices for final consumers. All the costs of the RES-E support scheme were fully transferred to the final electricity consumers proportionally to their electricity consumption (through a special RES-E fee).

- 2011–2012: As a result of the PV boom[4] (and enormous increase in the RES-E support costs), the Parliament introduced several changes to the support scheme – namely aimed at stopping the PV boom and also limiting the impact of the electricity price increase on the customers. From 2011 onward, it was not possible to build PV power plants on land and only PV plants on facades and roofs could obtain a permission for grid connection[5]. The average installed capacity of PV plants was reduced to 30 kW only. Legislative changes also introduced a controversial retroactive tax imposed on the monthly gross revenues of PV plants (26%) with installed capacity over 30 kW. This tax was imposed on PV plants with an operation start in 2010 and lasted for 3 years (2011–2013). After that, it was reduced to 10% and is imposed for the remaining part of the 20-year support period. Legislative changes also affected indirect RES-E support through income tax holidays (first 6 years) – tax holidays were no more available since the beginning of 2011.
- 2013–2014: The support scheme was changed significantly by Act no. 165/2012 Coll., which completely substituted the previous Act no. 180/2005 Coll. Despite the fact that support via feed-in tariffs and green bonuses remained, the new Act completely changed their logic. Act no. 180/2005 Coll. was based on a guarantee of rate of return (6.3% in the sense of weighted average costs of capital – WACC). The new Act no. 165/2012 Coll. introduced, among other things, only a guarantee of payback time equal to 15 years. This has led, of course, to a significant reduction in the feed-in tariff and green bonus rates. However, RES-E plants with an operation start prior to the end of 2012 have remained under the umbrella of Act no. 180/2005 Coll. and its support scheme logic. In 2013 and 2014, the Parliament introduced other legislative changes which resulted, in fact, in a complete stop to the operational support for new RES-E projects – support is no more available for PV, biogas and biomass power plants since the beginning of 2014 and, since the beginning of 2015, for the remaining types of RES-E plants excluding small hydropower.
- 2015–??: The state policy on support to RES-E plants is unclear (as of early 2015). The Government stated that energy savings and RES utilisation for heat

[4] Thanks to the limitation of the feed-in tariff rate reduction for new plants from year to year by only 5%, a rapid decrease in PV technology costs resulted in the fact that the feed-in tariff rates were higher that their adequate (fair) value for about 30–40% (0.48 EUR/kWh instead of 0.29 EUR/kWh). Investors realised extremely high rates of return on low-risk investment. It led to an extremely high interest in investing in PV. Thanks to the political crisis in the Czech Republic in 2009–2010, the Parliament was not able to react and to introduce necessary changes to the RES-E support scheme legislation.

[5] The PV boom was stopped by a decision of distribution and transmission companies in February 2010 not to issue any new permissions for PV plant connection to the grid. There were (almost) no new PV plants in 2011 and 2012 – only PV power plants with permission prior to the beginning of 2010 were completed.

production have a higher priority. Probably only investment support from EU funds (where there is no legal claim for support) will be available.

As mentioned above, systematic support to RES-E projects started in 2006 pursuant to Act no. 180/2005 Coll. The main features of the support scheme were:

- guarantee of rate of return (6.3%),
- possibility to choose between feed-in tariffs and green bonuses (excl. co-firing of coal and biomass, where only green bonuses were available) and to switch between these two options every year;
- feed-in tariffs and green bonuses were differentiated according to RES type, technology used (biomass), type of fuel (biomass and biogas), installed capacity, etc.;
- rates of feed-in tariffs for each category were derived from reference projects, which represented well-prepared (typical) projects in suitable locations (assuming typical prices of technology and other inputs);
- green bonuses were defined as the difference between given feed-in tariffs and expected electricity market prices (assuming technical parameters of electricity delivery from a given RES-E power plant – e.g., reliability of delivery) and their rates also reflected the higher risk compared to the feed-in tariffs;
- feed-in tariffs were guaranteed for 20 years (30 years for small hydropower), feed-in tariffs for already running RES-E plants were annually updated for inflation (between 2 and 4% according to the producer price index);
- limitation of FIT rate reduction – decrease in FIT rates from year to year (for new power plants) was limited by 5% at the most;
- obligatory purchase of electricity (in the feed-in tariff option) by distribution and transmission companies.

2.6
Costs of promoting RES-E: A comparison between the Czech Republic, Austria and Germany

In the following chapter, the costs of promotion of RES between the CR and AT are compared. Because Germany is currently the most important European country with respect to development of RES-E, it is also included in the following analysis.

A comparison between power generation from RES in the Czech Republic, Austria and Germany is provided in Fig. 16. It can be clearly seen that Austria started at the highest level, but in total terms Germany surpassed Austria. The CR increased RES-E generation moderately, starting from a very low level.

A comparison of the percentage of power generation from RES in the Czech Republic, Austria and Germany in 2000–2012 is shown in Fig. 17.

Fig. 18 depicts a comparison of the development of power generation from RES and the final electricity consumption in the Czech Republic, Austria and Germany in 2000–2013 with 2000 = 1.

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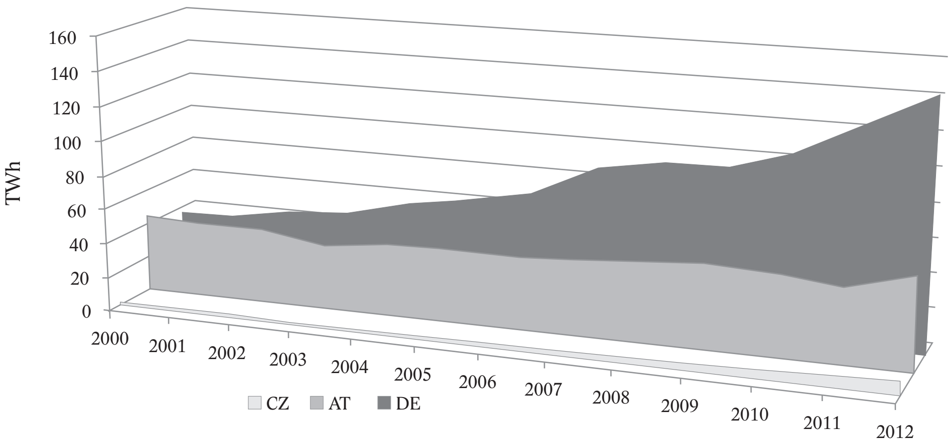
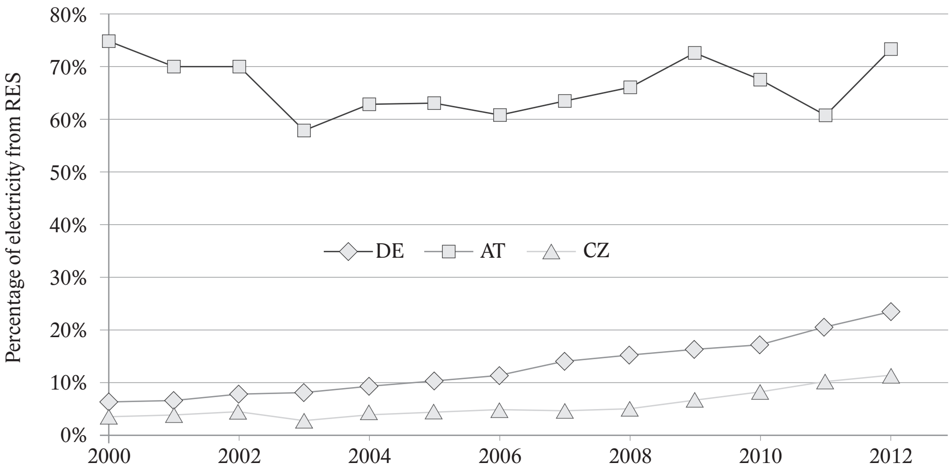


Source: EU, 2014

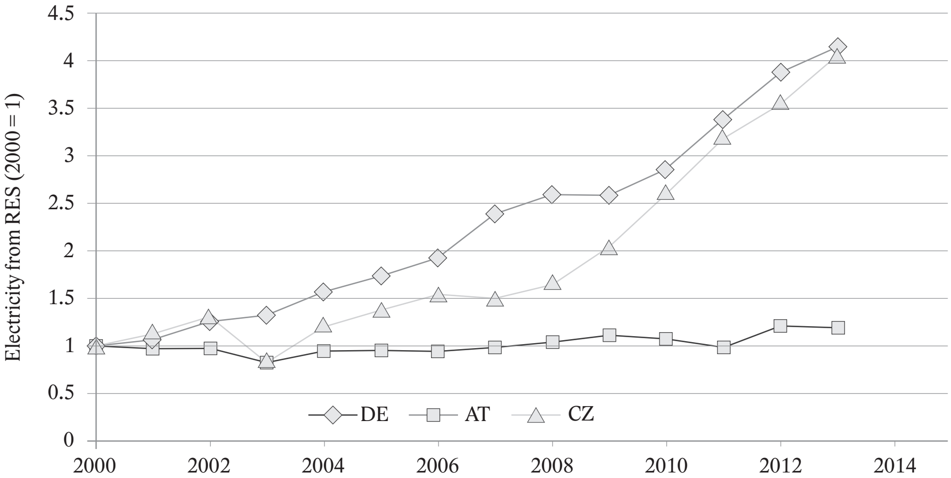
Fig. 16: Comparison of power generation from RES in the Czech Republic, Austria and Germany



Source: EU, 2014

Fig. 17: Comparison of percentage of power generation from RES in the Czech Republic, Austria and Germany, 2000–2012

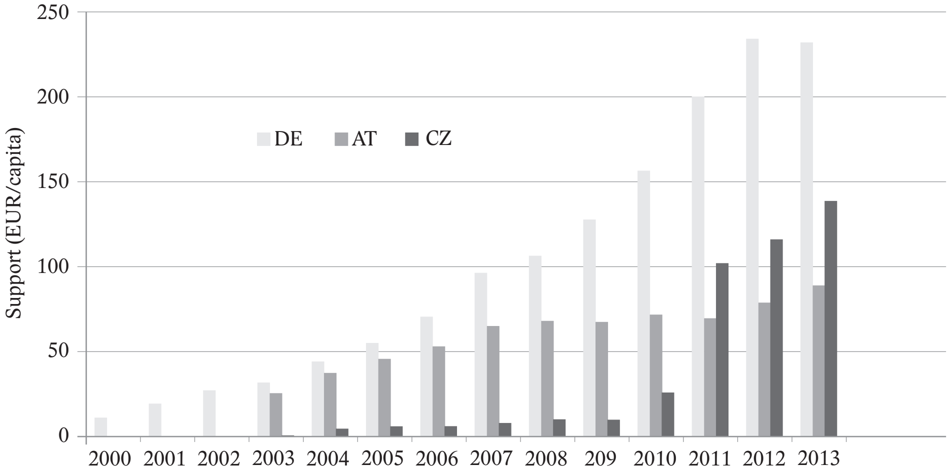
Regarding the costs of support, a comparison of the development of the surcharge in cents/kWh of RES-E generated shows that the support in AT is by far the lowest, while it is much higher in the Czech Republic as well as in Germany. Support to RES per capita in the Czech Republic, Austria and Germany is shown in Fig. 19. Fig. 20 depicts a comparison of the development of the surcharge in cents/kWh of final electricity consumption for support to RES in the Czech Republic, Austria and Germany. A specific pronounced picture is the costs of support per kWh of RES-E



Source: EU, 2014

Fig. 18: Comparison of development of power generation from RES and final electricity consumption in the Czech Republic, Austria and Germany, 2000–2013; 2000 = 1

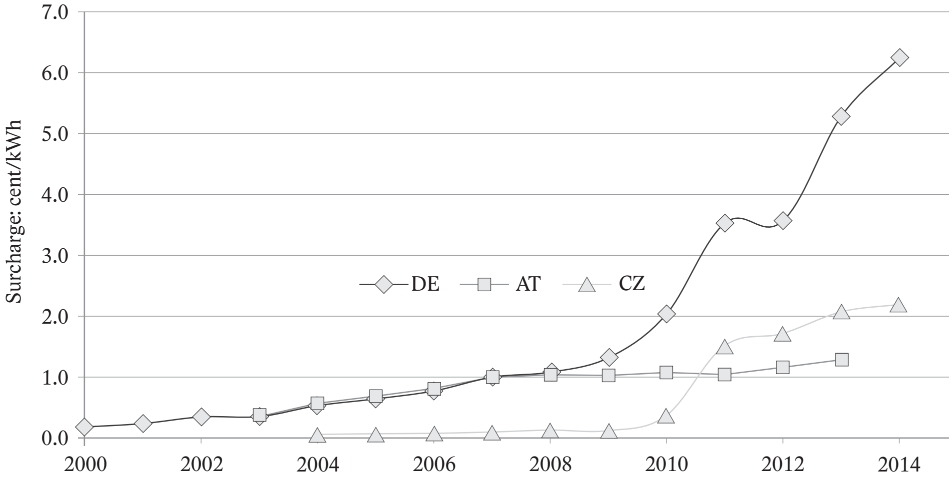
generated, which skyrocketed after 2010 in the Czech Republic, increased in Germany and remained at the level of the previous years in Austria.



Source: EU, 2014; Statistik Austria, ERO

Fig. 19: Support to RES per capita in the Czech Republic, Austria and Germany

The most dramatic picture regarding differences in costs of support per kWh of “new” RES-E generated in the three countries compared is shown in Fig. 21.



Source: own calculation

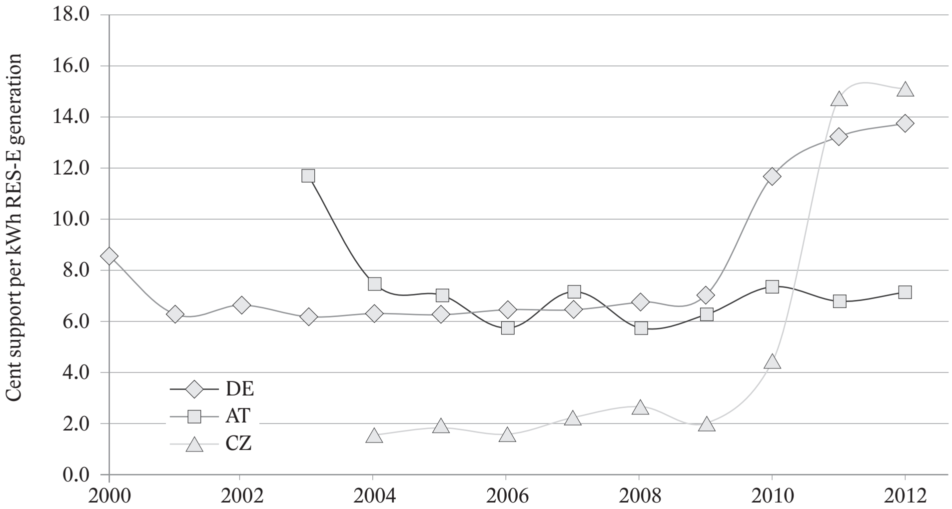
Fig. 20: Comparison of the development of the surcharge in cents/kWh of final consumption for support to RES in the Czech Republic, Austria and Germany, 2000–2014

The costs of support skyrocketed after 2010 in Czech Republic after 2010, increased in Germany and remained at the level of the previous years in Austria.

2.7 Conclusions

The major general conclusions of this chapter are as follows. Due to higher potentials, especially from large hydro power, the conditions for the use of RES-E are much more favourable in AT than in the CR. In the last 20 years, the share of RES-E in the total final demand was always between 60% and 65%. However, the CR has at least caught up with the trend. In 2012, four times more RES-E were produced than in 2000. In CR, the increase was from 4% in 2000 to about 12% in 2012. Annual fluctuations in the availability of hydro power were the major reasons for the year-to-year variations.

Regarding the costs of support, a comparison of the development of the surcharge in cents/kWh of RES-E generated shows that support in AT is by far the lowest, while it is much higher in the Czech Republic as well as in Germany. A specific pronounced picture is the costs of support per kWh of RES-E generated, which skyrocketed in Czech Republic after 2010, increased in Germany and remained at the level of the previous years in Austria.



Source: own calculation

Fig. 21: Comparison of the costs of support in cents/kWh of "new" RES-E generated in the Czech Republic, Austria and Germany, 2000–2012

2.7.1 Specific Czech conclusions

The support scheme for RES-E projects in the Czech Republic was basically defined in a transparent, consistent and economically effective way – see the description of individual periods from 2002 to 2014. The support scheme defined by Act no. 180/2005 Coll. (and valid for new RES-E plants between 2006 and 2012) was targeted at minimisation of investors' risks on the one hand and at a creation of adequate economic motivation for the investors on the other hand. Investors in RES-E projects have assured feed-in tariffs for the whole technical lifetime of the power plants, including annual adjustment for inflation. The support scheme does not differentiate among investors based on their size and capital power. Thanks to the logic of the support scheme (derivation of feed-in tariffs based on regulated rate of return and the WACC logic), small and medium-sized companies (with worse access to capital) could have problems with possible negative CF at the beginning of projects and lower rates of return.

Even faster development of RES-E projects than was seen between 2006 and 2012 was slowed down by different kinds of barriers, especially the complicated process of obtaining building permits and zoning decisions, lack of suitable locations and, in some cases, small support from regional councils or municipalities (sometimes even resulting in rejecting some types of projects, e.g., wind power projects). Here, the central government and ministries could play a better role, especially in spreading information, simplification of official procedures, etc.

Contrary to the support to RES-E projects, there was no systematic support to RES utilisation for heat production pursuant to Act no. 180/2005 Coll. Operational support to RES utilisation for heat production was only introduced under Act no. 165/2012 Coll. and its rate is CZK 50/GJ (approx. EUR 1.8/GJ).

A boom of PV and a fast growth of other RES-E projects (especially biogas plants) has resulted in an enormous increase in the RES-E support cost: e.g., in 2014 these costs exceeded CZK 40 billion (approx. 1.5 billion euros). Taking into account the 20-year support guarantee (under Act no. 180/2005 Coll.), the total RES-E support (excluding support to cogeneration and utilisation of secondary energy sources) is expected to exceed CZK 800 billion (in the 20 years), which creates an enormous pressure on the national economy.

The RES-E support scheme was changed significantly between 2013 and 2015. Since 2013, new RES-E plants have the right to only a 15-year payback period, which means, in fact, a significant reduction in the feed-in tariffs and, of course, the rates of return. Successive legislative changes have even stopped the operational RES-E support for new RES-E plants since 2014 and 2015 respectively. Currently only small hydro power plans are eligible for operational support.

2.7.2 Specific Austrian conclusions

The Austrian support scheme for RES-E is targeted to minimise overall specific support costs. From 2003, when favourable FITs were introduced, there was an important growth in the capacity of wind, biomass and biogas sources. In the period from 2007 to 2011, after new legislation passed by the Parliament, less favourable and partly insecure investment conditions implicated a stagnation of RES-E development, but in recent years, after an increase in the support levels and/or a reduction in the costs, a strong market uptake of wind and solar PV has been achieved.

For the future, it is important to strive for efficient support policies that take into account customers' full WTP and that favour market integration of renewable producers.

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3

Biomass Potential – Biofuels in the Czech Republic

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Abstract

Biomass plays an important and growing role in meeting of RES targets both at the EU level and in the Czech Republic. Any reasonable RES policy needs identification of the long-term (sustainable) biomass potential. As sources of easily available waste and residual biomass are quickly depleted, intentionally planted biomass plays an increasingly important role. A geographic information system working with information about the soil and climate conditions in each (agricultural) land plot and biomass yield curves (for each kind of crop) can significantly increase the quality of biomass potential estimates. The paper discusses the present state of biomass utilisation in the EU and the Czech Republic, expected strategies of future biomass utilisation, and basics of a methodology for biomass potential estimation using a GIS approach and high-resolution spatial data. Application of the methodology is demonstrated on an estimate of the biomass potential of agricultural land as a function of land allocated for energy crops (example for the Czech Republic).

Key words: biomass potential, energy crop, GIS

3.1 Introduction

Renewable energy sources (RES) play an important and growing role in the EU energy mix. The EU goals until 2020 (defined within the EU Climate and Energy Package of 2009, which includes Directive 2009/28/EC) expect a share of RES in final energy consumption equal to 20%. Directive 2009/28/EC defines the RES goals for individual EU member states. This Directive also establishes the National Renewable Energy Action Plans (NREAPs) as obligatory instruments for national RES policy definition. NREAPs define the national strategy for reaching national RES targets by the year 2020 (their structure is defined by EU Commission Decision 2009/548/EC). The Czech Republic's national RES goal until 2020 is 13.5%. The RES goals until 2020 consist of RES utilisation for electricity generation, heat production and also for transportation.

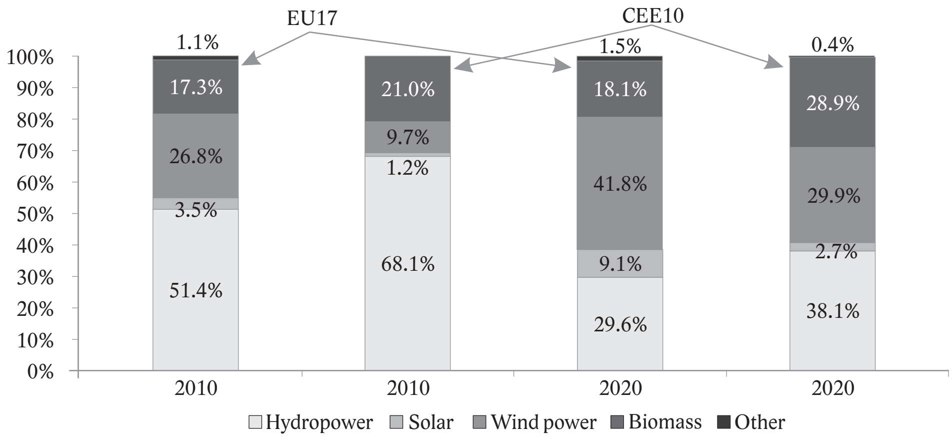
Biomass is currently the most important RES in both the EU and the Czech Republic. The role of biomass in the Czech Republic is underlined with the fact that the Czech Republic has relatively worse conditions for wind, PV and hydro power. Biomass currently plays the most important role in the RES portfolio and its importance is even expected to grow.

The total production of renewable energy in the EU-28 reached 7423 PJ in 2012. Renewable energies contributed to primary energy sources consumed by approx. 22.3%. Renewable energies were growing during the last decade (2002–12) with an annual increase by approx. 6% (and by 80% in absolute terms during this decade).

NREAPs assume that power generation based on biomass will go up from 114 TWh to 232 TWh. Similarly, NREAPs expect an increase in biomass utilisation for heating and cooling from 61.7 mtoe to 89.9 mtoe.

According to the NREAPs, biomass currently plays a decisive role in RES contribution to the final energy consumption for heating and cooling (approx. 90% in 2010). NREAPs assume further development of biomass utilisation, which would mean an increase in biomass utilisation in absolute terms by about 46% in 2020 (only for heating and cooling). Another growth of biomass utilisation is expected for liquid biofuel production andpower generation.

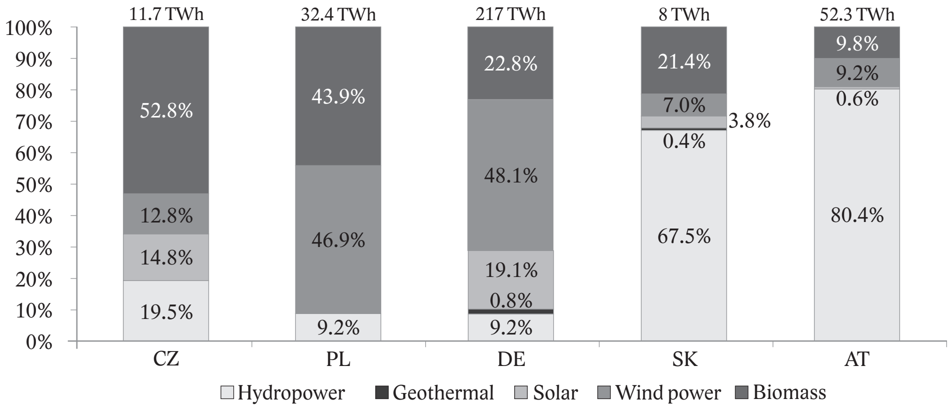
Each individual EU member state has a unique situation in RES utilisation which results from its climate conditions, land availability, density of population, distance from the sea, tradition of RES utilisation, etc. Differences in RES utilisation – including biomass – are documented in Fig. 1 and Fig. 2, presenting the structure of power generation based on RES in 2010 and 2020. Fig. 1 presents the EU-27 member states (without Croatia) divided into two groups: the EU-17 (which basically means "older" member states in Western, Northern and Southern Europe) and the CEE-10 (which represents "new" member states in Central and Eastern Europe).



Source: NREAPs

Fig. 1: Structure of power generation in 2010 and in 2020 (expected) in EU-17 and CEE-10

Fig. 2 shows an insight into deeper detail on expected RES power generation in 2020 for five Central European countries: Germany, Austria, the Czech Republic, Poland and Slovakia. Despite the fact that these (neighbour) countries have basically similar climate conditions, they have very different conditions for RES utilisation, including biomass. This documents that RES utilisation and RES potentials should be seen from the perspectives of individual countries taking into account their unique conditions. Similar differences can be found in biomass utilisation for heating and cooling.



Source: NREAPs

Fig. 2: Expected power generation in 2020 from RES for five Central European countries

Biomass is a rather heterogeneous category: biomass in fact consists of different biomass types having different origins, limitations for utilisation, heating values and, last but not least, also costs of obtaining – see later. Any assumptions on future biomass utilisation are based on so-called "biomass potential in the short and long run". When looking at the different sources of data[6], one can see a huge spread of biomass potential estimations. These studies estimate the biomass potential (for heat and power, liquid biofuels are excluded) between approx. 100 and 285 PJ. This difference results from adoption of different approaches and methodologies for biomass potential calculation and also from different understanding of the nature of the biomass potential.

When working with a projection of future RES utilisation development, one should understand the term biomass potential (as an energy source) properly. Biomass potential can be seen from several different perspectives, which results in different

[6] *E.g. Lewandowski et al. (2006), Scholes et al. (1197), Sladký (1996), SRCI CS (1999), Paces et al. (2008), Havlíčková and Suchy (2009)*

understanding of its content and meaning. One can distinguish among the following types of biomass potentials[7]:

- **theoretical potential**: biomass potential here is limited by fundamental constraints (biological, area available, etc.);
- **technical potential** (also called geographic): this definition of the biomass potential takes into account environmental (e.g., biodiversity protection), territorial (e.g., utilisation of land for other purposes such as recreation, food production, etc.), agronomic (e.g., necessity to rotate crops) and land accessibility;
- **economic potential**: this considers only such biomass contribution which is competitive against other conventional fuels and for which there also exists a market or utilisation (e.g., biomass potential from permanent grassland is relatively high, but it is very complicated to use grass as a fuel – it could only be a smaller part of input fuel for biogas stations, significant technical obstacles exist for direct hay burning, etc.);
- **realistic potential**: this considers all other restrictions for the given kind of biomass utilisation; it plays a role especially in the short-term point of view: if there are no technologies prepared for the given kind of biomass utilisation, the biomass contribution is rather theoretical (e.g., biomass cannot be burnt in gas boilers). Also sustainability issues should be taken into account.

The way in which the yields of biomass are derived (respecting given climate and soil conditions in the analysed country or region) is the other source of significant differences. Some authors work with rather aggregated data (e.g., average biomass yields and area assumed) – e.g., Scholes et al. (1999). An approach based on utilisation of high-resolution spatial data (GIS) including valuation of agricultural land can lead to more accurate biomass potential estimation – see, e.g., Vávrová et al. (2014). This approach is based on derivation of biomass potential from climate and soil conditions on each individual land plot assuming utilisation of agricultural land for conventional and energy crops.

3.2
Biomass as an energy source in the Czech Republic

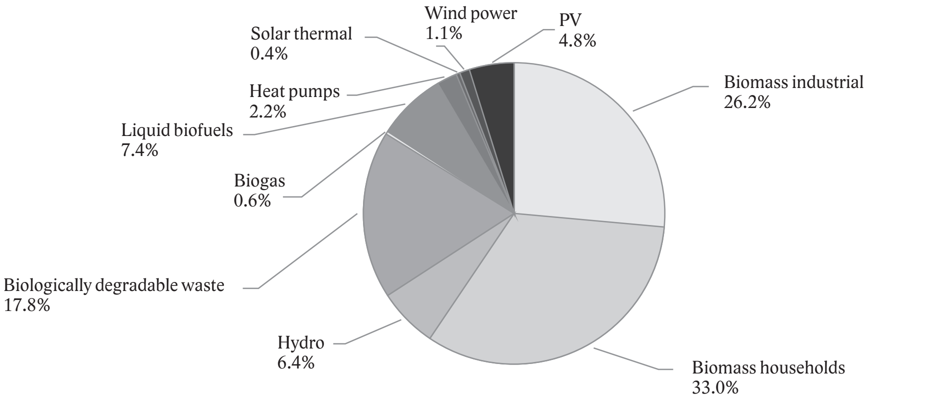
3.2.1
Present state of biomass utilisation for energy purposes and expectation for the future

As mentioned above, biomass plays a significant role in the energy mix of EU member states. The Czech Republic, as the other Central and Eastern European countries, has an even higher share of biomass in the RES portfolio – in both primary energies and final energy consumption. This is caused, in the case of the Czech Republic, namely

[7] Slade et al. (2011). Similar definitions of RES potential categories (here not primarily aimed at biomass only) can also be found in SRCI CS (1999).

by its less favourable conditions for wind and hydro power. Biomass has significantly contributed to the growing share of renewable energies in the portfolio of primary energies and also in power generation – see Fig. 3 and Fig. 4.

RES contribution to the consumption of primary energy sources (PES) in the Czech Republic reached approx. 154 PJ in 2013 (approx. 8.7% of the total PES). Biomass plays by far the most important role in the RES portfolio – solid biomass is 59%, biomass used for biogas production is 15.6%, and liquid biofuels accounts for 7.4% – see Fig. 3.



Source: MPO, 2014

Fig. 3: Contribution of RES categories to the primary energy source consumption in the Czech Republic in 2013

The total biomass consumption in the Czech Republic for energy purposes is approx. 7.7 million tonnes (2013). Table 1 provides a more detailed look at the biomass utilisation for energy purposes.

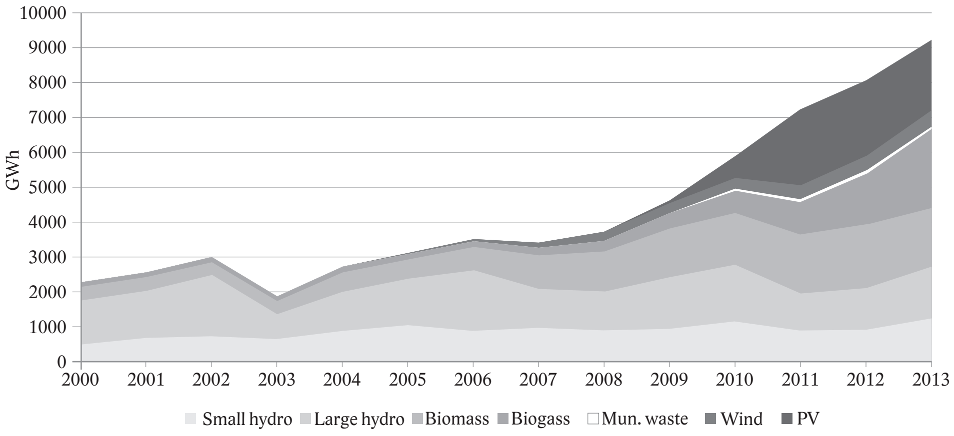
A great majority of biomass used for energy purposes is currently coming from waste and residual biomass – paper production (pulp extracts) and the wood-processing industry. Biomass used by households (either purchased firewood biomass or so-called self-collection of wood biomass in forests) makes up about 50% of the total biomass consumption for energy purposes.

Biomass currently also plays a significant role in power generation – see Fig. 4. Burning of solid biomass contributes to RES power generation by 22.6% and other biogas plants contribute by another 18.1% (biogas power plants showed the fastest relative growth in the period 2010–2013).

The Czech Energy Policy (2014 update) assumes further growth of RES consumption – up to 300 PJ in the target year 2040. Biomass is expected to play the dominant role in the future RES development – see Fig. 5.

Biomass type	**Electricity** (mil tonnes)	**Heat** (mil tonnes)	**Total** (mil tonnes)
Wood waste	0.868	1.252	2.120
Firewood	0.000	0.052	0.052
Plant materials	0.097	0.061	0.158
Briquettes and pellets	0.096	0.075	0.171
Pulp extracts	0.334	0.996	1.330
Households			3.897
Biomass (energy) export			0.750
Biomass (energy) total			**8.478**

Tab. 1: Structure of biomass consumption for energy purposes in the Czech Republic, 2013 (Source: MPO, 2013)

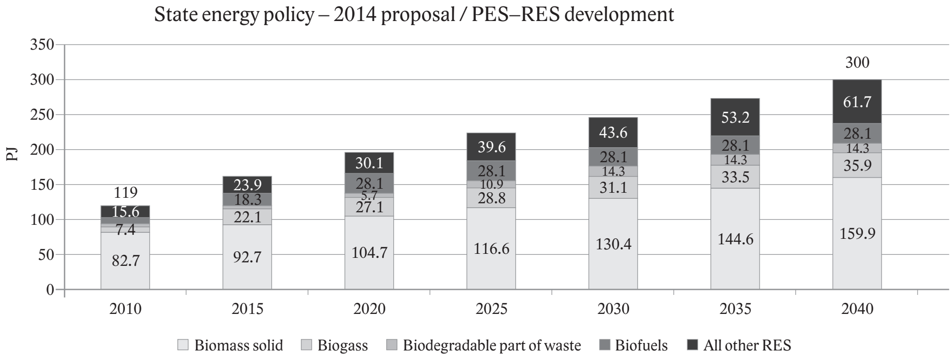


Source: MPO, 2014

Fig. 4: Development of power generation based on RES in the Czech Republic

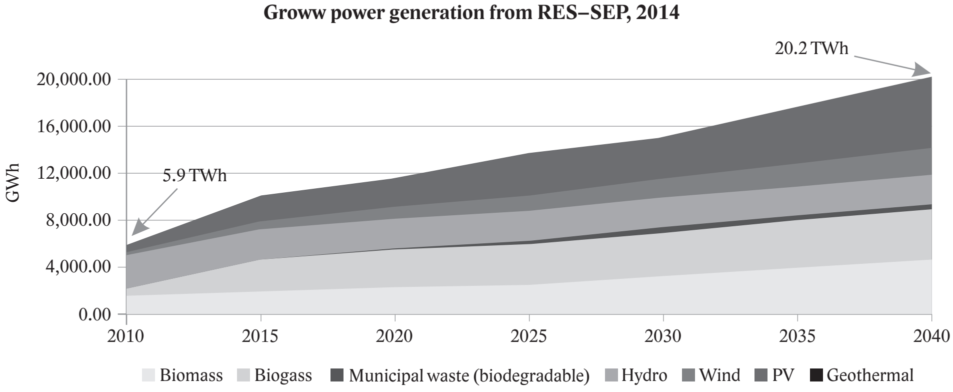
Biomass is also expected to play (in the horizon of the Czech State Energy Policy) a significant role in power generation. Biomass utilisation for power generation, even when assuming fast development of PV beyond 2020, will contribute to total RES power generation by 44% in 2040, which means an increase from 2.1 TWh in 2010 to 8.9 TWh in 2040.

Sources of relatively cheap and easily accessible (and utilizable) biomass are being rapidly depleted in the Czech Republic. Future development of biomass utilisation should thus be based on intentionally planted biomass on agricultural land (for



Source: State Energy Policy, 2014 update

Fig. 5: Expected development of RES contribution to primary energy consumption in the Czech Republic



Source: Czech Energy Policy, 2014

Fig. 6: Expected development of power generation from RES

energy purposes) and reasonable utilisation of waste biomass from forestry (assuming preference of wood for material utilisation and limited and already utilised allocation for energy purposes – which is individual space heating in the Czech Republic).

The Czech National Action Plan for Biomass identifies the potential allocation of agricultural land for energy purposes at up to 1.1 million hectares (maintaining the country's "food security") beyond 2020.

3.2.2 Biomass categories

Biomass as an energy source consists of many different subcategories:

Biomass type	2010 [ha]	longer-run potential [ha]
Maize (biogas, biomethane)	22,052	160,000
Wheat (bioethanol)	22,474	24,000
Rapeseed (FAME)	96,841	200,000
Sugar beet (bioethanol)	11,237	126,000
SRC plantations	760	110,000
Permanent grasslands	2,400	370,000
Perennials (reed canary grass, etc)	892	85,000
Other	5,600	45,000
TOTAL	**162,256**	**1,120,000**

Note: The total area of agricultural land was 4.2 million ha in 2012, of which 2.5 million ha was farmed arable land and 1 million ha was permanent grasslands (Source: Czech Statistical Office)

Tab. 2: Present utilisation of arable land for "energy" biomass and possible arable land allocation for energy purposes in the long run (Czech National Action Plan for Biomass, 2012)

- residual material from industry and service sectors (e.g., residuals from paper production industry, wood processing industry, food production – e.g., used cooking oil, etc.);
- residual biomass from conventional agricultural production:
  - for direct burning or solid biofuel production: residual straw,
  - for biogas stations: farm animals' excrements and other biodegradable residuals from agriculture;
- biomass from plantations of perennial (non-wood) plants – in the case of the Czech Republic climate conditions, reed canary grass, miscanthus and schavnat (sorrel dock – hybrid) are currently being assumed – this kind of energy crop has an expected plantation lifetime of up to 10 years;
- biomass from annual crops:
  - for direct burning or for solid biofuel production: e.g., triticale,
  - for biogas stations: maize (maize is currently the preferred type of biomass as the standardised input for biogas stations),
  - for liquid biofuel production: rape seed (for FAME production), corn and sugar beet (for bio ethanol production);
- biomass from short-rotation coppice (SRC) plantations – SRC plantations have a lifetime of up to 25 years;
- grass from permanent grasslands;
- forest residuals;
- firewood.

As already mentioned, future development of biomass utilisation for energy purposes should be based especially on intentionally planted biomass. In the climate conditions of the Czech Republic, the category of intentionally planted biomass for energy purposes consists of:

- **perennial plants:** reed canary grass, schavnat and miscanthus. These plants can be characterised as follows:
  - typical lifetime of plantation: up to 10 years (which means that initial establishment costs are absorbed over a 10-year period and also activities on the field are reduced),
  - reed canary grass and schavnat can be harvested in dry form (schavnat during the summer time, reed canary grass at the end of winter) which is suitable for direct biomass burning (low moisture content between 15–20%),
  - yield curve reaches its maximum one year after plantation establishment,
  - biomass is available in the form of pressed bales;
- **short-rotation coppice plantation**s: in the Czech Republic's conditions, it means domestic clones of poplar and willows. The lifetime period is approx. 25 years, the maximum biomass yield is reached 8–12 years after plantation establishment. The typical rotation period is 3 or 4 years, biomass is harvested with the help of special machinery (e.g., Claas Jaguar machines with special extensions for corn maize harvest). Biomass is in the form of wood chips (of homogenous quality). Harvest is assumed during the winter period, when the moisture content is about 53%. Wood chips can be used directly for burning in wood chip boilers or can be added to coal.
- **annual crops** (non-food): e.g., triticale, which can be used for direct burning in suitable boilers. The major advantage of annual crops is that "farmers' decision what to plant" can be changed from year to year without incurring any sunken costs[8].

3.2.3 Biomass potentials on agricultural land – categories and principles of estimation

As previously discussed, the term "biomass potential" is not an easy term and can be understood from several different points of view. One of the most important points of view is the time factor, which enables us to distinguish:

- biomass potential sustainable in the long run – usually it has the meaning of technical potential – see classification in Chapter 3.1 (i.e., all the constraints for biomass production but technical limitations for biomass utilisation are omitted),

[8] In general, also conventional kinds of crops can be easily used for energy purposes, such as direct burning. Energy utilisation of crops (cereals) that can be utilised for human food production is seen as very controversial by many people (even when they do not suffer from land utilisation for non-food production).

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– additional biomass potential which can increase the long-term (technical) potential in a period of up to one year – this means an increase in biomass availability in the short run at the expense of future biomass potential reduction (to keep balance).

Biomass potential on agricultural land consists of:

– potential of biomass residuals (straw) from conventional production on arable land,
– potential of energy crops (perennials and SRC plantations) on arable land,
– potential of SRC plantations on permanent grasslands (can usually be neglected due to the specific features of permanent grasslands).

Biomass potential on agricultural land is, in principle, the function of land available. Simple approaches based on average biomass yields and the area of land assumed can be used only for very rough estimation. These approaches (due to very high variability of biomass yields in relation to climate and soil conditions on site) can easily lead to an significant under or over (more probable) estimation of biomass potential.

Factors influencing, among others, biomass yields (both conventional agricultural crops and energy crops) depend on:

– climate and soil conditions on a given site (land plot),
– method of allocation of the given type of energy crop to the given land plot (different kinds of energy crops have significant differences in biomass yields under the given climate and soil conditions),
– agrotechnologies used (e.g., fertilisation, selection of most suitable clones for site-specific conditions, way of plantation establishment, technologies used for harvest, etc.).

Straw, as will be presented later, is a very important part of biomass potential in countries with highly developed agriculture. Straw yield is site-specific (reflects allocation of conventional plants to the site, soil and climate conditions of the given site) and its volume is also influenced by the harvest method (i.e., what portion of straw remains on the site). Another factor influencing the availability of straw for energy purposes is its utilisation for farm cattle (which has the priority in utilisation, of course).

One of the ways to improve biomass potential identification is a methodology based on a bottom-up approach (Vávrová et al., 2014). This methodology is based on identification of each individual land plot (through LPIS – Land Parcel Identification System – information system primarily developed for identification of agricultural land utilisation) and allocation of climate and soil conditions to these land plots. The methodology uses results of long-term investigation of soil and climate conditions on individual land plots in the Czech Republic. This has resulted in the so-called Czech agricultural soil valuation. Each uniquely identified "piece of land" is characterised by a five-digit numerical code (which is called BPEJ in the Czech language), where the structure of the code is:

V.XX.YZ

V ... reflects the climate region (10 different climate regions are defined in the Czech Republic based on, e.g., daily average temperatures, annual precipitation, probability of dry periods, etc.),

XX ... indicates the so-called main soil unit (i.e., soil characteristics and quality, approx. 78 different categories are defined),

Y ... indicates a combination of slope and plot orientation (north, south, ...),

Z ... indicates a combination of soil profile and its skeleton.

The combination of the first three digits defines the so-called main soil unit – MSU (not all the combinations have a meaning and approx. 550 MSUs exist for agricultural land in total). The MSU reflects the most important factors influencing (or even defining) the potential of biomass yield (individually for each kind of conventional as well as energy crops). Based on long-term investigation and experience, individual MSU are grouped according to similar expected biomass yields. Finally, so-called yield curves are defined for each individual biomass crop (both conventional and energy crops). Typically 5–7 yield curves are defined: individual MSUs are assigned to each yield curve. If we have information on soil and climate conditions on the analysed site, we can derive the biomass yield for a given kind of crop. Yield curves thus have the meaning of expected biomass yield assuming utilisation of standard agrotechnologies used for establishment and utilisation of plantations (or growth) and can be interpreted as the long-term average biomass yields in the given soil and climate conditions. Yield curves can be expressed either in tonnes of biomass per hectare (in dry matter – see example of yield curves for schavnat on Figure 7) or in GJ of heat content. Different kinds of biomass have different heating values, so the utilisation of GJ for the yield curves gives us the advantage of possibility to directly summarise individual contributions.

The land plot (i.e., an identified piece of land with defined climate and soil conditions, allocation and area) is the key driver of biomass potential identification. One can assign other information to the land plot – e.g., information about the cost of biomass production – individually for each kind of conventional and energy crops. One of the possibilities to express the costs of biomass production (a given crop type on a given kind of soil and climate conditions influencing the biomass yield) is the so-called minimum price of biomass (for the calculation methodology, see Vávrová and Knápek, 2012). The minimum price of the biomass is calculated using reference economic models for each individual energy crop type (and each assumed yield curve). The economic model for the given energy crop type reflects standard agrotechnologies during the whole lifetime of the plantation (or growth) and is based on a simulation of cash flows related to it. The minimum price of the biomass (for the given energy crop type and the given yield curve) is calculated using the net present value (NPV) concept from the binding conditions NPV=0. More detailed information on economic modelling and minimum price of biomass calculation can be found, e.g., in Vávrová and Knápek, 2012.

Straw yields (part of straw which is not ploughed into soil for keeping its quality) are derived from corn yields using MSU valuation of soil (i.e., the given land plot

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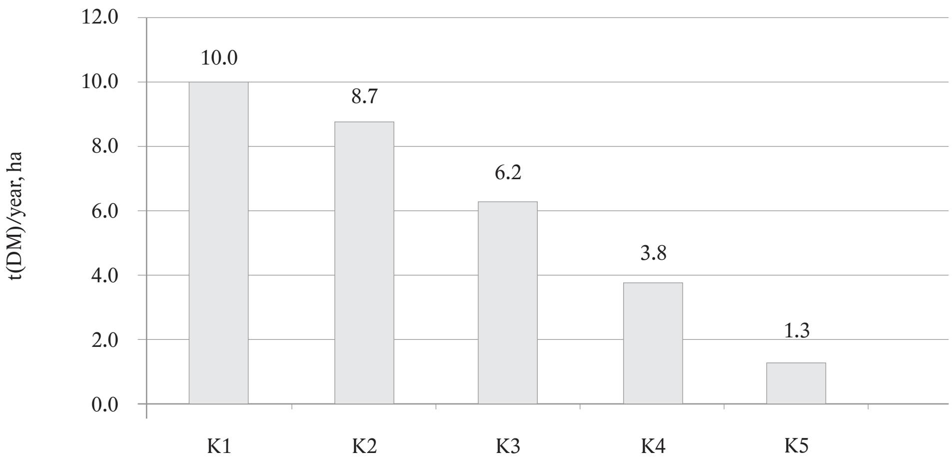

Source: own data

Fig. 7: Example of biomass yield curves for schavnat (sorrel dock)
Note: K1 to K5 means individual yield curves for schavnat

is assigned with the expected corn yield based on its MSU value) and the so-called straw-to-grain coefficient. This coefficient for wheat, for example, is equal to 0.8 – this means that the weight of the straw is 80% of the corn weight assuming 12% moisture of both. The value of this coefficient ranges from 0.7 for barley to 0.8 for rapeseed and wheat, 1.05 for oat to 1.2 for rye and 1.3 for triticale – for details see, e.g., Havlíčková et al. (2010) and Vávrová et al. (2014).

When determining the biomass potential for a given area, region, country (either present or future), it is known how individual kinds of conventional and energy crops are allocated to concrete land plots. Only the area of arable land, acreage of conventional crops (or their expected structure in the future) and allocation of arable land for energy crops (usually in percentage terms) are known. As already mentioned, biomass yield (including straw as the most important part of biomass potential from agricultural land) is significantly dependent on climate and soil conditions in the given land plot and allocation of individual crop types to individual land plots (keeping the total acreage for individual crop types). As it is not known, one should adopt some reasonable assumptions. The methodology discussed in Vávrová et al. (2014) assumes that conventional crops are allocated first (priority of food production). Conventional crops are allocated in the "sequence" of the soil quality requirement – starting with the crop with the highest soil quality requirement, i.e., sugar beet, rye and oat – for details, see Vávrová et al. (2014). The algorithm of crop allocation to individual land plots searches (in the analysed area such as a region, country, etc.) for the best allocation for the given crop type (in the sequence of soil quality requirements) – the highest biomass yield is the criterion for best allocation. The allocation of a given crop type ends when the total expected acreage for it is reached.

Allocation of individual energy crop types to given land plots which remained after the allocation of the conventional crops can be done using the following criteria:

- maximisation of biomass yield in GJ,
- minimisation of biomass costs (using the minimum price approach – see above).

Some other constraints can be included in the allocation algorithm, such as:

- limitation on share of individual energy crop types in the area (to prevent creation of monocultures),
- limitation on biomass types (woody, non-woody).

Increasing allocation of arable land for energy crops leads to a gradual increase of biomass potential for energy purposes. As discussed in Vávrová et al. (2014), biomass potential is not a simple linear function of land allocated for energy purposes.

Estimation of biomass potential for energy purposes using the approach mentioned above needs extensive data, such as:

- information on individual land plots (climate and soil conditions) and exclusion of unsuitable land such as national parks, other environmentally protected areas, gardens, cities and villages, etc.;
- assignment of biomass yields (for each assumed crop type) to conditions of each individual plot (yield curve definition).

Processing of all the above information (one should take into account, e.g., one hectare as the minimum area of agricultural land plots and combinations with MSU and yield curves) requires the creation of a model using a GIS – Geographic Information System and relatively high computing power.

This method leads to the determination of a conservative (bottom) estimate of the biomass potential. One of the reasons for that is the preference of land utilisation for food production. Allocation of higher quality land for energy crops would lead, of course, to a higher biomass potential – but at the expense of lower conventional production.

3.3 Estimate of biomass potential on agricultural land for the Czech Republic

Sustainable biomass potential as a function of arable land allocated for energy crops is presented in Fig. 8. This potential is derived based on the following assumptions:

- priority of conventional agriculture production (food production),
- priority of energy gain from energy crops (economic effectiveness – i.e., costs of biomass production are not taken into account).

The above methodology leads to an estimation of biomass potential which is lower than some of preceding studies, such as Paces et al. (2008), which estimate a biomass potential (in the horizon of 2050) up to 276 PJ. The reason for this significant difference is the application of a different assumption: e.g. Paces et al. (2008) worked with the assumption of average yields on an "average" hectare. The assumption of

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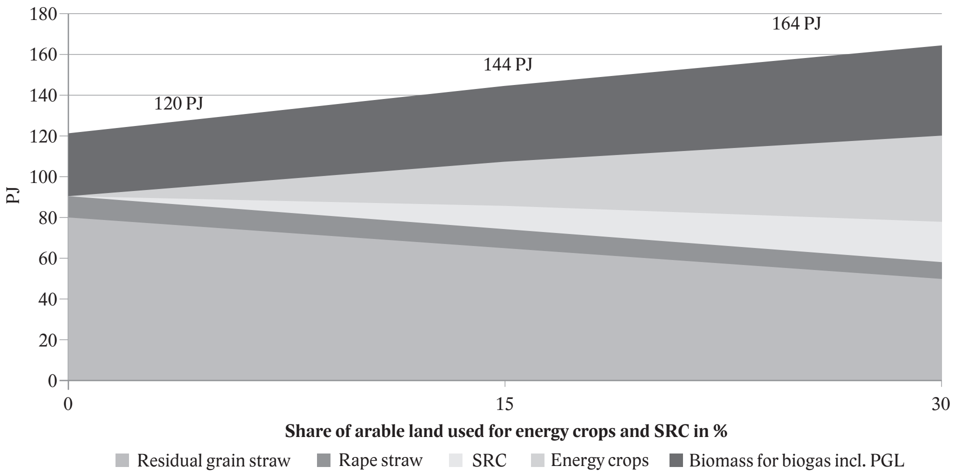

Fig. 8: Sustainable biomass potential in the Czech Republic as a function (percentage) of arable land used for energy crops (own calculation)

preference of conventional agricultural production to energy crops and utilisation of detailed information on soil and climate conditions and their influence on biomass yields lead to significantly lower (but more realistic) estimates of biomass potential.

The above method determines biomass potential as the primary energy source on a "growing site" – no losses from biomass harvest, storage and transportation are taken into account. Biomass is, in principle, biodegradable matter and losses especially during its storage can be significant. Thanks to using a "bottom-up approach", the above methodology enables inclusion of biomass losses in the logistic chain. This is important especially in a task where biomass potential is analysed for a concrete project, e.g., installation of a biomass boiler in a cogeneration plant or construction of a district heating system based on biomass.

3.4 Conclusions

Biomass plays a significant role in the portfolio of energy sources in both the EU and the Czech Republic. Biomass is currently a very important RES and for many countries even the decisive one. The EU and the Czech Republic expect further increases in RES utilisation and biomass is expected to play a very important role.

Any reasonable policy of future RES development should be based on identification of objective (and sustainable) RES potentials, including biomass potential. As biomass is rather a heterogeneous category, it is necessary to identify individual biomass categories and their potential contributions to the total balance of primary energy sources. It is necessary to properly define the meaning of the term biomass potential and distinguish between theoretical and technical (geographic) potentials.

Intentionally planted biomass on agricultural land is expected to play the decisive role in future development of biomass utilisation for energy purposes. Models based on average biomass yields typically lead to an overestimation of biomass potential. Improvement in biomass potential estimates can be reached using GIS models working with information about soil and climate conditions on individual land plots and derivation of biomass yields from these concrete conditions on land plots.

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4

Potentials of Biomass and Biofuels in Austria

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Abstract

The need for alternative energy carriers is rapidly increasing due to the problems related to the use of fossil energy. This paper provides an analysis of biomass-based alternative energy carriers (AEC) which are of interest in Austria now or could be by 2050. The study focuses on the long-term prospects of different types of AEC depending on available land and resources in Austria. Different scenarios have been derived using a modelling approach. The final energy output from biomass-based AEC is highly dependent on the implemented policies and preferences as well as the willingness to use additional arable land for energy purposes. There are huge expectations in the future of second-generation biofuels, which are less dependent on the limited areas of arable land, while the relevance of first-generation biofuels is decreasing over time. However, since first-generation biofuels will continue to be cheaper than second-generation biofuels in the medium term, they will remain on the market at least until 2030.

In the best case, biomass-based AEC will contribute to the energy supply in the transport sector with about 125 PJ in 2050. To realise this, more land use will be needed, about 0.7 million hectares by 2050.

To exploit this potential optimally for society, a broad portfolio of actions, such as a CO_2 based tax system, an ecological monitoring system, and further R&D especially focused on second-generation biofuels and fuel cells, will be required.

4.1 Introduction

Although the energy supply system in Austria is still mainly reliant on fossil energy, the use of alternative energy carriers (AEC) is continuously increasing. This development is supported with different policy measures according to the EU goals related to the reduction of GHG emissions and increasing use of renewable energy in the energy supply system. Currently, the most important AEC used or discussed are electricity from renewable energy sources (RES), biofuels and other biomass-based energy carriers.

In this paper, focus is on biomass-based AEC which could be relevant for the energy supply until 2050. The core objective is to analyse the prospects of different types of biomass-based AEC depending on land and resources available in Austria.

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In detail, we investigate under what circumstances, to what extent and when biomass-based AEC may enter the market. Their potentials are analysed in a dynamic context, whereby technological learning effects are considered. To answer these questions, various scenarios have been created, showing the land use for biomass-based AEC as well as the resulting contribution to the energy supply up to 2050. Three major framework conditions considered in scenarios are:

– possible developments of the energy price level and energy demand;
– technology developments (particularly regarding learning effects);
– energy and environmental policies.

Finally, from these analyses we derive market diffusion of the biomass-based AEC in a dynamic context and identify which AEC have a special relevance in Austria in the medium to long term. In this context, second-generation biofuels are currently expected to offer the largest biofuel quantity potential since the range of raw materials includes all plant components and waste products.

Since biomass-based AEC could be produced from different primary energy sources and with different technologies, we have chosen the most promising chains for Austria regarding resource potentials, costs and the environment. Table 1 provides an overview on AEC and the primary energy sources considered in this paper.

As shown in Table 1, there are different sources which could be used for the production of biomass-based AEC. The most important characteristics of an ideal energy crop are high yield, low inputs, low costs, low composition of contaminants and nutrients and high pest resistance. However, not one crop has all these characteristics and therefore a choice must be made from available crops to select the optimal crop-mix that can be cultivated in Austria (Breure, 2005).

4.2
Biomass-based AEC in Austria: current situation

The total land area in Austria – 8.2 million hectares – can be divided into five groups: arable land (17%), permanent crops (1%), permanent meadows and pastures (22%), forest area (46%) and other land (14%); see Fig. 1.

Different biomass-based energy carriers can be produced using biomass products from various land areas. As illustrated in Fig. 2, the importance of the biomass-based primary energy sources in energy production in Austria has increased rapidly over the last four decades. About 50 PJ were produced from these sources in 1970. The largest part of this energy was based on fuel wood. The significance of biogen fuels has increased dramatically in the last decade. Please note that, since 2004, biogen fuels have been divided into ten categories and separately illustrated, according to the available data from Statistic Austria. In 2010, biomass-based primary energy sources contributed to the energy supply with about 240 PJ.

The development of biomass-based alternative energy carriers in Austria in the period 2000–2010 is depicted in Fig. 3. Here, we can see that the increase in the last decade was brought mainly by pellets, electricity from biomass, bioethanol and

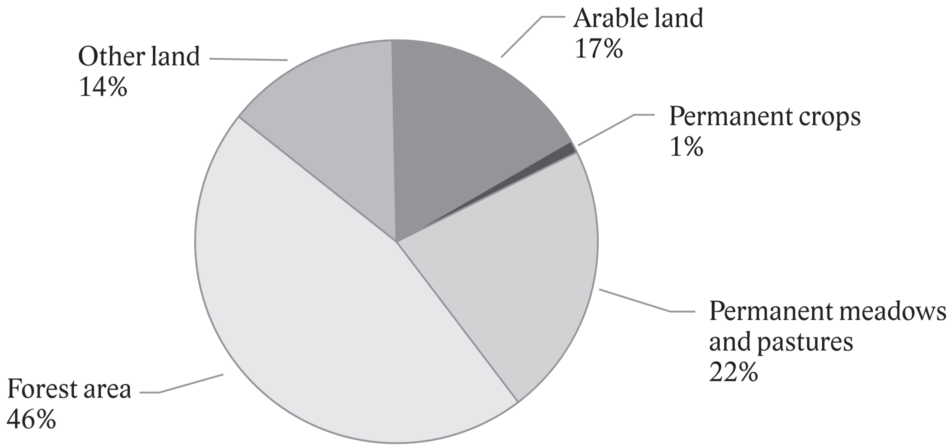
Source	AEC										
	BD-1	BE-1	BG	BD2	BE2	SNG	Elec-tricity	H2	Pel-lets	Wood chips	Fuel wood
Feedstock											
Rapeseed	×										
Sunflower	×										
Soy beans	×										
Wheat		×									
Corn maize		×									
Sugar-beet		×									
Green maize (incl. cover crops)			×								
SRC				×		×	×	×			
Corn stover				×		×	×	×			
Grass			×								
Forest wood										×	
Residue											
Straw		×		×	×	×	×	×			
Forest wood residues				×		×	×	×		×	
Wood industry residues				×	×	×	×	×	×		
Liquid manure			×								
Dry manure			×								
Waste wood							×				
Organic waste (incl. waste fat)	×		×								
Black liquor							×				

Note: BD-1: 1st generation biodiesel; BE-1: 1st generation bioethanol; BG: biogas; BD2: biodiesel 2nd generation; BE2: bioethanol 2nd generation; SNG: synthetic natural gas; H2: hydrogen; SRC: Short rotation coppice

Tab. 1: AEC and primary energy sources considered

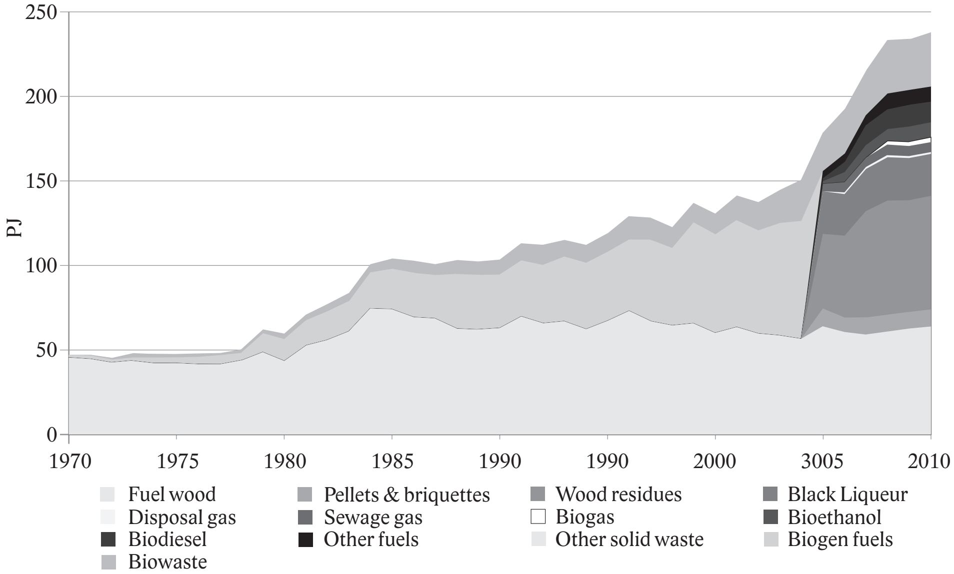
biodiesel. However, the largest energy output from biomass-based AEC is made up of fuel wood and wood chips.

To provide this energy, about 670,000 ha are necessary, see Fig. 4. This figure provides a comparison between total areas available and areas currently used for biomass-based AEC in 2010.



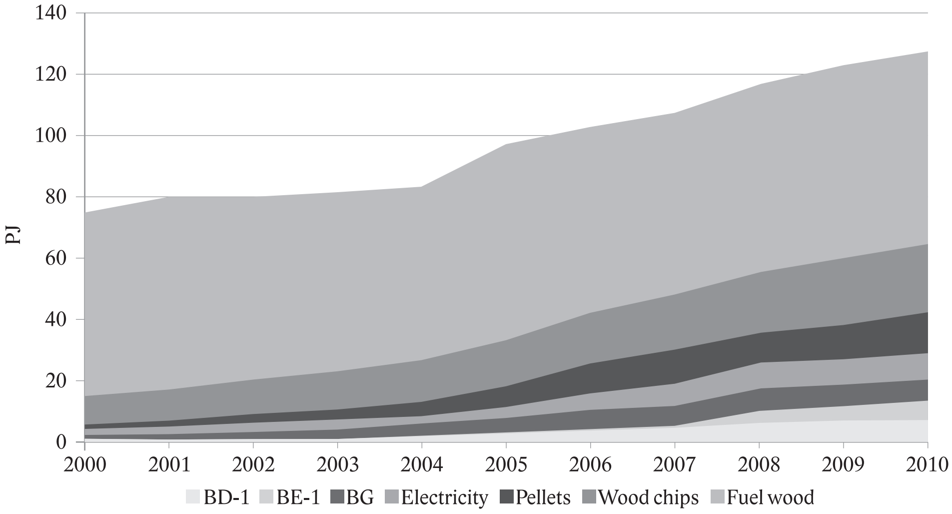
Source: Statistic Austria

Fig. 1: Land area in Austria 2010



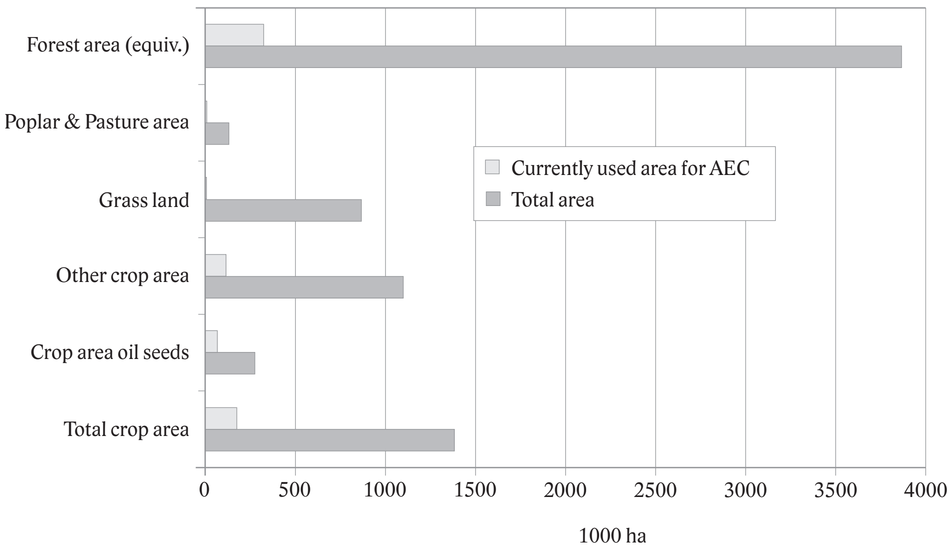
Source: Statistic Austria

Fig. 2: The energy use of biomass-based primary energy sources in Austria in 1970–2010



Source: Statistic Austria and own investigations

Fig. 3: Biomass-based alternative energy carriers in Austria in 2000–2010



Sources: Kranzl/Haas et al., 2008; ARGE Kompost/biogas, 2009; Kalt/Kranzl, 2011

Fig. 4: Total areas and currently used areas for AEC in 2010

4.3 Assumptions for future production of biomass-based AEC in Austria

As described above, the core objective of this paper is to analyse the prospects of different types of biomass-based AEC depending on land and sources available in Austria. To do this, we have derived different scenarios for biomass-based AEC:

1. Policy Scenario with additional use of arable land for energy production and an introduction of a CO_2-based tax system
   - 1.A Policy Scenario with priority for biofuels *(Policy Lead Scenario – PLS)*
   - 1.B Policy Scenario with priority for hydrogen
   - 1.C Policy Scenario without priorities
2. Policy Scenario without additional use of arable land for energy purposes and with a CO_2-based tax system
   - 2.A Policy Scenario with priority for biofuels
   - 2.B Policy Scenario with priority for hydrogen
   - 2.C Policy Scenario without priorities
3. No Policy Scenario: without additional use of arable land, without additionally implemented policies, without priorities – a Business-as-Usual (BAU) scenario

The major assumptions relevant for all the scenarios can be divided into three groups: (i) assumptions related to the land areas; (ii) assumptions related to the use of area-independent resources; and (iii) assumptions related to the development of fossil fuel and feedstock prices. No imports of biofuels or feedstocks are considered in our analysis. We only focus on sources available in Austria.

(i) Assumptions for area-based resources

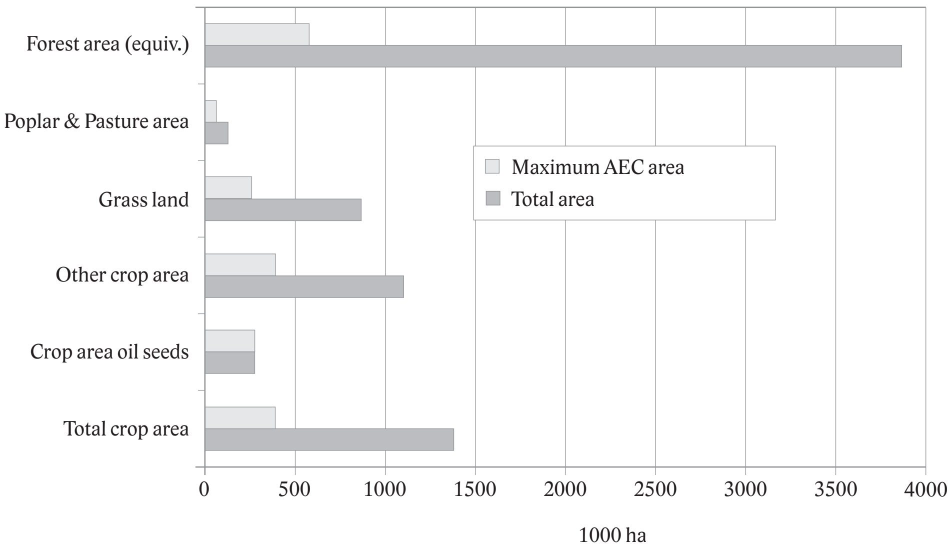
The major assumption regarding the land use is that a maximum of 30% of arable land in 2010, 10% of pasture land, 10% of meadows and 3% of wood and forest wood residues could be used for production of feedstock dedicated for biofuels by 2050.

The conventional biofuels are based on the feedstocks grown on the arable land, which is very limited in Austria, 1.4 mha. However, with the second generation of biofuels, also other land areas such as meadows, pastures and forest areas could be used for biofuel production, so that the total potential for biomass-based alternative energy carriers could be significantly higher.

Fig. 5 presents a comparison of total areas and maximum areas for biomass-based AEC in 2050.

(ii) Assumptions for non-area-based resources

Aside from resources which need land areas for their production (and which are in principle in competition with food or fodder supply or deployment of wind turbines or photovoltaic systems), there are also area-independent ones (such as waste fat, organic



Sources: Kranzl/Haas et al., 2008; ARGE Kompost/biogas, 2009; Kalt/Kranzl, 2011

Fig. 5: Total areas and maximum AEC areas in 2050

waste, wood industry residues, waste wood) which are mainly based on residues and waste.

The major assumption regarding the use of area-independent resources is that an additional 5% of wood industry residues could be used for biofuel production.

Table 2 depicts the maximum potentials for area-independent resources for the year 2010. The potentials are documented in tonnes of feedstock and in PJ of primary energy.

Fig. 6 shows the maximum potentials for area-independent resources in 2050. As can be seen, by far the highest quantities can be expected from wood industry residues (4 million tonnes) and forest wood residues (1.45 million tonnes). In total, these two sources represent an energy potential of about 65 PJ.

For the straw potential, it is important to note that we consider only a potential of 2.3 t/ha for energy purposes. The rest is assumed to be needed for ground recovery and for other non-energy purposes.

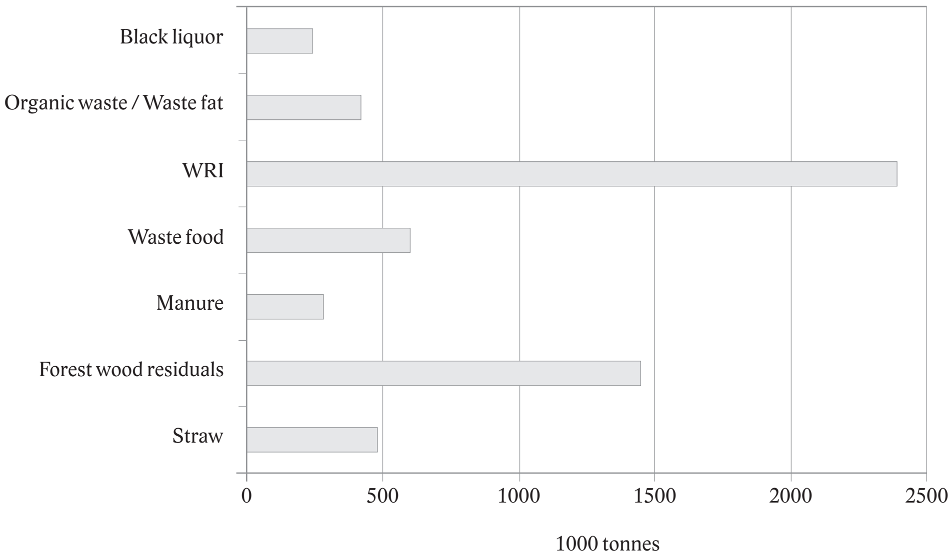
(iii) Assumptions for price developments in the scenario analysis

In order to evaluate the long-term perspectives of biomass-based AEC, the following major influence parameters are considered in the scenarios:

- possible developments of fossil energy prices;
- global developments (particularly regarding technological learning effects);
- environmental and energy policies in Austria and at the EU level, mainly CO_2 taxes.

	Yield	Year: 2010	
	kWh/kg	1000 tonnes	PJ of primary energy
Straw (2.3 t/ha)	4.5	39	0.7
Forest wood residues	4.3	1450	22.4
Manure	8.33	215	6.4
Waste wood	5.30	300	5.7
Wood industry residues	5.00	830	14.9
Organic waste/Waste fat	7.60	230	6.3
Black liquor	3.36	200	2.4

Tab. 2: Survey on maximum potentials for area-independent resources (Sources: Kaltschmitt, 2004; EEA, 2006; Kranzl/Haas 2008; Panoutsou, 2009)



Data sources: Kaltschmitt, 2004; EEA, 2006; Kranzl/Haas 2008; Panoutsou, 2009

Fig. 6: Maximum potentials for area-independent resources in 2050

The major economic assumptions for the scenario analysis are as follows:

- All monetary figures are as of 2010; that is to say all costs and prices are converted to 2010 values;
- Increases in fossil fuel prices are based on expected price developments as documented by the International Energy Agency (WEO, 2009; WEO, 2011) and

own analyses for feedstock and wood prices. For all our scenarios, we use price increases for fossil fuels of 3% per year by 2050, 2% per year for feedstocks (oil seeds, cereals) and 1% per year for wood-based resources;

– In the Policy Scenarios, a CO_2 based tax is applied starting from 2013;
– The development of costs of alternative fuels is based on international learning rates for the corresponding investments.

4.4 Modelling scenarios

The costs and quantities of the defined categories of AEC are modelled in a dynamic framework. The model used is based on economic decision criteria and impacts of policies. In principle, the additional sources will be used if it is favourable due to economic criteria or policy conditions (e.g., quotas). Vice versa, fewer resources (e.g., areas) will be used if a specific AEC becomes less favourable than another. That is to say, additional feedstock sources and land areas are used for additional production of various AEC if these are cost-effective (incl. all taxes, subsidies) or if quotas exist. Note that all the modelling activities begin after 2015 because the capacities to be built before are by and large already known today.

Technological learning with respect to investment costs as well as changes in feedstock production and conversion into AEC are considered and modelled. A basic modelling framework is provided below.

(i) Maximum additional usable areas

For every area category considered, the maximum additional feedstock area per year ($A_{FS\_\mathrm{ADD}\_t}$) is calculated as depending on the maximum possible feedstock area (A_{FS_MAX}) and the area already used (A_{FS}) as:

$$A_{FS\_\mathrm{ADD}\_t} = \varphi(A_{FS\_\mathrm{MAX}\_t} - A_{FS\_t-1}) \qquad (1)$$

φ ... maximum percentage to be added or reduced per year.

(ii) Basic conditions for additional areas used

Additional feedstock areas are used for AEC under the following conditions:

$$A_{FS\_t} = A_{FS\_t-1} + A_{FS\_\mathrm{ADD}\_t} | C_{AECt}(C_{FSt})[1+\tau_{AEC}] < p_{FFt}[1+\tau_{FF}] \qquad (2)$$

C_{AEC} ... total production costs of an AEC [€/kWh]
C_{FS} ... costs of feedstock [€/kWh]
τ_{AEC} ... tax on AEC [€/kWh]
τ_{FF} ... tax on fossil fuels [€/kWh]
p_{FF} ... price of fossil fuels (excl. tax) [€/kWh]

To the contrary, the area of feedstock is reduced if

$$A_{FS\_t} = A_{FS\_t-1}(1-\varphi)|C_{AEC_{\mathrm{VAR}t}}(C_{FSt})[1+\tau_{AEC}] > p_{FFt}[1+\tau_{FF}] \tag{3}$$

or the specific area for growing special feedstocks will be reduced in any case if another way of producing biofuels in the same area using feedstock j is cheaper than the variable costs of using feedstock i:

$$A_{FS\_t} = A_{FS\_t-1}(1-\varphi)|C_{AECt}(C_{FSt\_i})[1+\tau_{AEC}] < C_{AEC_{\mathrm{VAR}t}}(C_{FS\_j})[1+\tau_{AEC}] \tag{4}$$

$C_{AEC_{\mathrm{VAR}}}$ ... variable production costs of an AEC [€/kWh]

(iii) Assigning feedstock areas to AEC categories

Feedstocks as well as feedstock areas may be used for different energy carriers. For example, some crop areas are suitable for oilseeds, wheat and corn stover, which can be used for first-generation biodiesel (BD-1), first-generation bioethanol (BE-1) and second-generation bioethanol (BE-2), respectively. In this case, the feedstocks and/or the feedstock areas are dedicated to the biofuel category which leads to the cheapest production costs per kWh of biofuel:

$$C_{AEC_t}(C_{FS_t}) = \mathrm{Min}(C_{AEC_{tFS_{j\_t}}}; j = 1\ldots m) \tag{5}$$

m ... number of possible biofuel categories.

(iv) Maximum potential of area-independent feedstocks

The maximum potential of area-independent feedstocks $\mathrm{Q_{FS\_max\_BF}}$ is modelled as follows:

$$Q_{FS_{\mathrm{max}_{\mathrm{BF_t}}}} = Q_{FS_{\mathrm{max}_t}}(1-\delta) \tag{6}$$

δ ... share of area-independent feedstock used for other applications.

(v) Policies modelled

We model the quota introduction as:

$$A_{FS\_t} = A_{FS\_t-1} + A_{FS\_\mathrm{ADD}\_t}|q_{t-1_{\mathrm{Act}}} < q_{t0} \tag{7}$$

$$A_{FS\_t} = A_{FS\_t-1}|q_{t-1_{\mathrm{Act}}} \geq q_{t0} \tag{8}$$

q_{t0} ... Quota to be fulfilled at t
$q_{t-1_{\mathrm{Act}}}$ ... Actual quota fulfilled at $t-1$

4.5
Scenarios for biomass-based AEC in Austria up to 2050

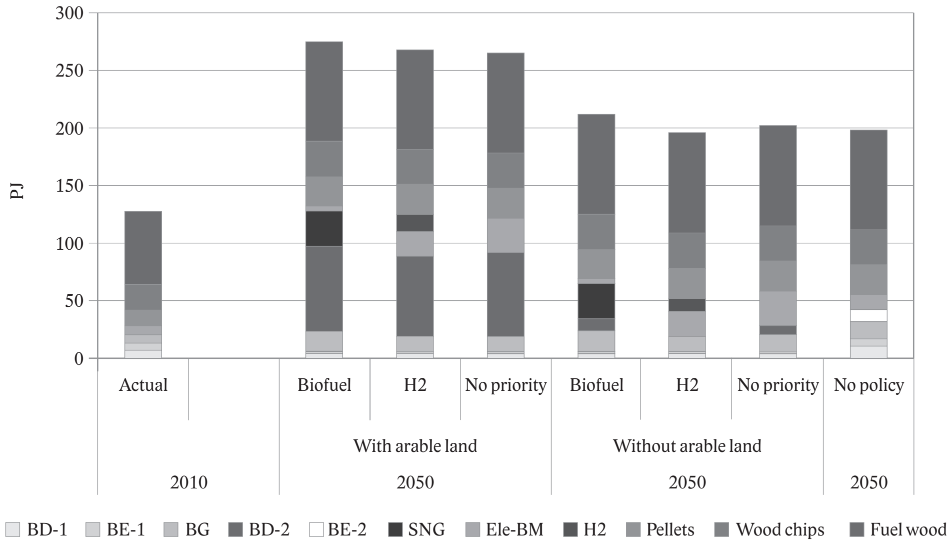
In order to provide a sound assessment of the future prospects of biomass-based alternative energy carriers, we have derived scenarios up to 2050 to show under what circumstances, to what extent and when specific alternative energy carriers could become competitive in Austria.

The energy outputs in 2050 for all the analysed scenarios in comparison to 2010 are provided in Fig. 7. The major perceptions of this figure are as follows:

(i) Scenarios without the use of additional arable land show overall outputs which are about 60 PJ lower than in the case of the additional arable land use.

(ii) Scenarios with biofuel priority have slightly better performance regarding overall energy output than those with no priority or with priority for hydrogen. This is mostly due to better energy conversion efficiency of second-generation biofuels in comparison to the other biomass-based AEC.

(iii) In the scenarios with no priority, electricity shows a higher contribution to energy output mainly due to the lower costs and more mature technology.



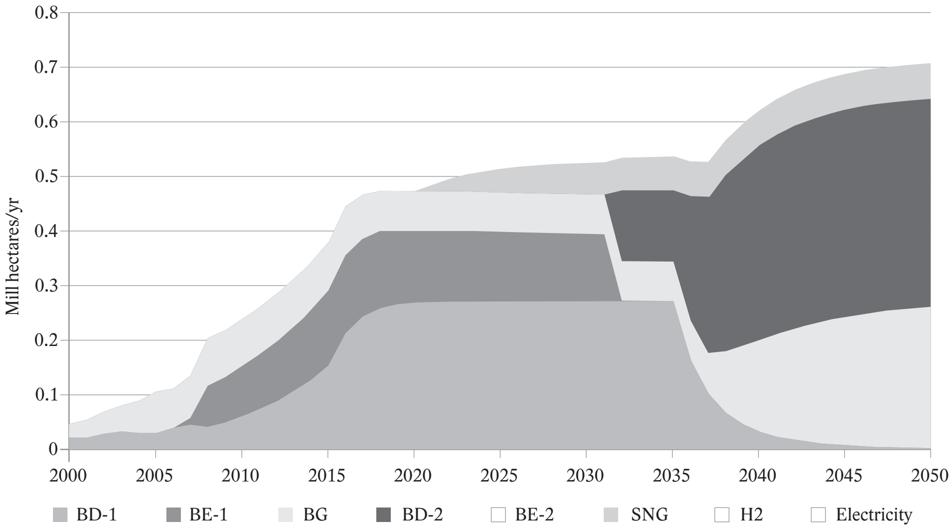
Source: own calculation

Fig. 7: Energy outputs of different scenarios in 2050 from biomass-based AEC in comparison to 2010

Since this chapter takes a special interest in biomass-based AEC that can be used in the transport sector, first and second-generation biofuels and electricity and hydrogen from biomass are discussed in detail below using the Policy Lead Scenario (PLS).

The following figures depict the effects of this scenario on land areas, resource use and energy output. In this scenario, the increasing production of AEC based on domestically produced feedstocks will occupy additional land areas. However, mainly crop area-independent sources will be used for second-generation biofuels.

The total land area used for biomass-based AEC is increasing over time. A very high increase can be noticed in the period 2000–2015. This increase is caused by production of first-generation biofuels. After 2020, about 0.05 million hectares per year will be used for SNG (synthetic natural gas). Substitution of second-generation biofuels for the first generation will begin in about 2030. With growing economic attractiveness of second-generation biofuels, the arable land area is increasingly used for production of whole plants such as corn stover. Consequently, first-generation biodiesel and bioethanol are being phased out. Moreover, an increase in biogas produced from grass can be noticed starting in about 2037. By 2050, first-generation bioethanol and biodiesel will be completely replaced with biogas second-generation biodiesel and SNG. More than 0.7 million ha will be used for these AEC in 2050.



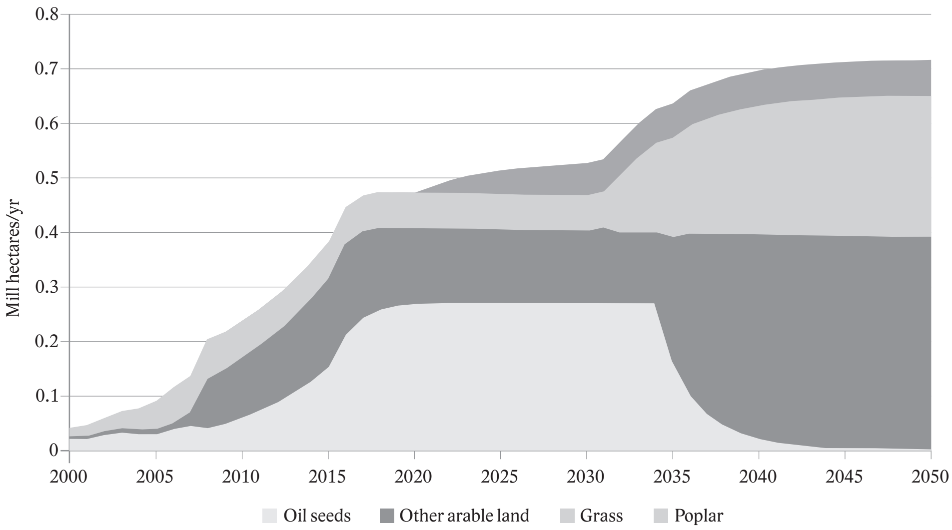
Source: own calculation

Fig. 8: Total area for AEC by AEC category (excl. forest) 2010–2050, PLS

Due to the increasing production of second-generation biofuels starting from 2020, significant poplar areas will be used for feedstock production. The total land area for production of the analysed AEC is divided into four categories: poplar, grass, oil seeds and other arable land; see Fig. 9. Contrary to the dramatically decreasing importance of oil seed areas, grass areas will be increasingly important after 2035.

Finally, Fig. 10 depicts energy from the analysed biomass-based AEC by type of feedstock. The most impressing fact in this figure is that the amount of corn stover used for second-generation biofuels increases considerably after 2035.

The corresponding quantity of feedstocks used for the production of AEC is shown in tonnes per year by type of feedstock in Fig. 11.



Source: own calculation

Fig. 9: Areas for biofuels by area type, 2000–2050, in the PLS (excl. forest area)

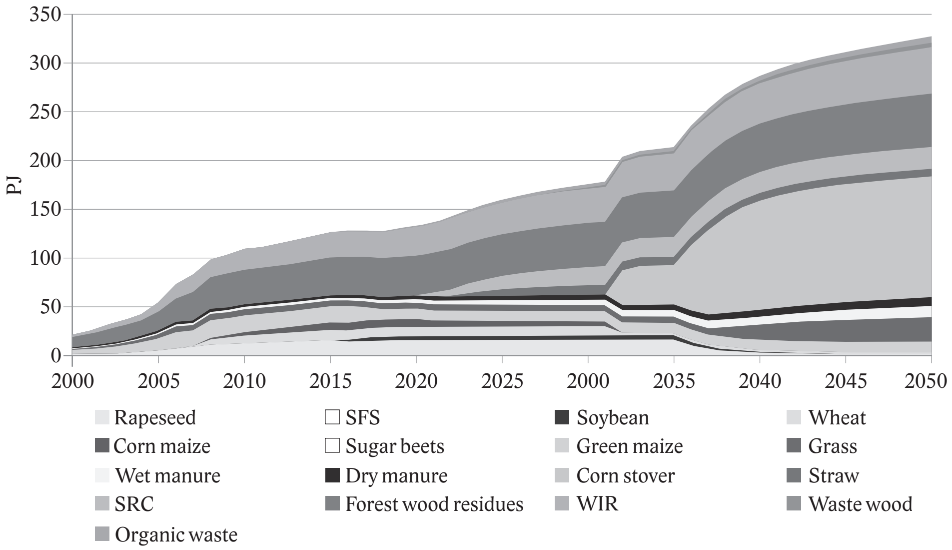
4.6 Conclusions

The use of biomass-based AEC is continuously increasing, mostly due to the growing need for renewable energy-based fuels in the transport sector. In the future, higher amounts of energy from biomass-based AEC can be expected in all the scenarios analysed; however, the magnitude of this contribution is mostly dependent on policy conditions and preferences.

The highest contribution to the energy supply in the transport sector – considering only first and second-generation biofuels, electricity and hydrogen from biomass – could be reached in the Policy Lead Scenario with a preference for biofuel production. About 15 million tonnes of feedstock are needed for the energy output in this scenario – approximately 125 PJ in 2050. In the long-term, the most important feedstock will be corn stover, which is suitable for second-generation biofuels. Consequently, greater areas of land will be needed for feedstock production. By 2050, more than 0.7 million hectares will be dedicated to feedstock production for biomass-based AEC.

The most important AEC in the future are biogas, second-generation biodiesel and SNG. In a favourable case, second-generation biofuels will enter the market between 2020 and 2030, reaching their full potentials only after 2030. The major advantage of second-generation biofuels is that they can also be produced from sources such as lignocellulose-based wood residues, waste wood or short-rotation coppice, which are not dependent on food production-sensitive crop areas.

Although first-generation biofuels are cost-effective under the current tax policies, they will be phased out in the long term. This will happen mostly due to limited land



Source: own calculation

Fig. 10: Energy from AEC from non-conventional biomass sources by type of feedstock, 2000–2050

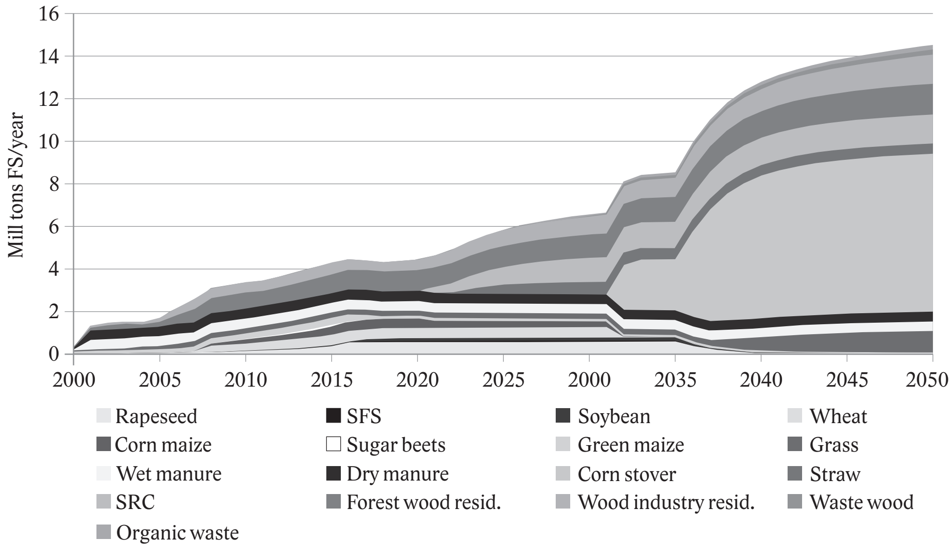
available, as well as their modest environmental performance. However, since the first-generation biofuels will be cheaper than the second generation in the medium term, they will remain on the market at least until 2030.

In this context, land-use change is an important issue for the world as a whole. However, in Austria it will be negligible.

To exploit the maximum potential of biomass-based AEC in Austria up to 2050 in an optimal way for society, a broad portfolio of actions, such as a CO_2 based tax system, an ecological monitoring system, and a focussed R&D programme for second-generation biofuels and fuel cells, will be needed.

Acknowledgement

This paper provides a summary of the work performed in the research project "ALTETRÄ – Perspectives for alternative energy carriers in Austria up to 2050" conducted for the Austrian Research Promotion Agency (FFG).



Source: own calculation

Fig. 11: Tonnes of feedstock used for the production of AEC by type, 2010–2050

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5

Competitiveness of Intentionally Planted Biomass for Energy Purposes

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Abstract

Decision-making on investments in power, cogeneration or heating plants using biomass needs estimates of future biomass prices. A so-called minimum price, which is based on the economic analysis of a project aimed at intentionally planted biomass, can be used for setting the bottom limit of a future biomass price. When calculating the bottom biomass price estimate, one also has to respect alternative options for agricultural land utilisation for conventional crops. The upper limit for the biomass price from the demand side point of view should be based on an economic evaluation of substitution of conventional fuels with biomass. The paper presents methodological approaches for modelling of biomass prices from these different points of view as well as results of model calculations for the conditions of the Czech Republic.

Key words: biomass competitiveness, biomass price, intentionally planted biomass

5.1 Introduction

Biomass is playing an increasingly important role in both the EU and the Czech Republic; see Chapter 3 for details. Increasing biomass utilisation results primarily in utilisation of relatively easily available and cheap waste and residual (solid) biomass from forestry and the wood-processing industry (such as saw dust, wood chips, solid wood waste, etc.). An increasing trend is also observed in utilisation of residual and waste biomass from agriculture and the food industry (e.g., residual straw). However, at least partial substitution of fossil fuels (to meet EU and Czech Republic targets for development of renewable energy sources) requires enormous amounts of biomass. In the Czech Republic, for instance, the total brown coal extraction in 2013 was 40.3 million tonnes (and hard coal approx. 8.6 million tonnes), the equivalent of approx. 511 PJ (181 PJ for hard coal).

Sources of residual biomass suitable for energy purposes (usually for direct combustion or as input for biogas stations) are, to a significant extent, already depleted. The biomass development goals (and RES goals as a whole since biomass is taken as the decisive RES source at least in the perspective of the next two or three decades) thus cannot be met without massive introduction of intentionally planted biomass on agricultural land. Intentionally planted biomass on agricultural land can also play another important role in diversification of activities in rural areas (reduction of dependency on fluctuating agricultural commodity markets). Growing biomass utilization for energy purposes also enables utilisation of agricultural land that is not necessary for food production.

The National Action Plan for Biomass until 2020 assumes that potentially up to 1 million hectares (ha) of agricultural land is available for non-food production (energy biomass) in the Czech Republic.

Type of biomass	Current area (ha)	Proposed area (ha)	Use of biomass
Maize	22,052	150,000	biomethane, biogass
Wheat	22,474	24,000	ethanol
Rape seed	96,841	200,000	FAME
Sugar beet	11,237	126,000	ethanol
SRC	760	120,000	direct combustion
Permanent grasslands	2,400	370,000	biomethane, biogas, solid biofuels
Perennials	892	85,000	direct combustion, solid biofuels
Other	5,600	45,000	direct combustion
Total	**162,257**	**1 120,000**	

Source: National Action Plan for Biomass until 2020

Fig. 1: Agricultural land currently used for energy purposes and proposed areas in the middle run

The expected fast development of biomass use for energy purposes requires, among others, an effective and long-term strategy of support to intentionally planted biomass and removal of barriers that are slowing down such development.

Such effective support needs to respect the economic effectiveness of biomass production on agricultural land, including storage, processing if needed, and other parts of the logistic chain from the biomass producer to the final consumer. The key input for assessment of economic effectiveness of biomass production and use is the costs of production of different types of biomass, e.g., wood chips from short rotation coppices (SRC), baled biomass, etc.

Investors in power stations, cogeneration stations or heating plants develop their business plans taking into account the long lifetime of these facilities – the typical time horizon included in the decision-making process is at least 20 years; in the case of cogeneration plants with a higher installed capacity, it could be even significantly longer. Investors need information on (future) biomass prices to make rational decisions on their investments.

The price of biomass is defined, as in the case of other traded commodities, based on an equilibrium between the supply and the demand for this commodity. Unfortunately, the majority of biomass currently used is waste or residual biomass (which is typically used close to its source of origin) and there is no common market for biomass which could generate proper price signals about the possible future market price of biomass. Only a very small portion of biomass currently used comes from the fields as intentionally planted biomass. This can be documented on the following figures for the Czech Republic for 2013: power generation based on intentionally planted biomass: 333 GWh (out of a total of 1647 GWh from biomass).

Future biomass prices will reflect a new market equilibrium, which will be influenced by many factors, such as:

- economic effectiveness of biomass production on agricultural land;
- value of support to biomass production on agricultural land;
- support scheme for RES utilisation for power generation and heat production (including targets for liquid biofuels);
- prices of conventional fuels (such as coal and natural gas); and
- restrictions imposed on conventional fuel utilisation (such as environmental taxes, emission allowances, etc.).

5.2 Modelling of future biomass prices

5.2.1 The general approach

Modelling of future biomass prices is usually based on economic models reflecting typical processes related to planting of a given type of biomass. Authors of these models usually take care of the supply side and they do not include other factors influencing decision-making of biomass producers and consumers (Fazio et al., 2009; Valentine et al., 2008; Soldatos et al., 2004; Hilst et al., 2008).

When assuming no other significant barriers to biomass planting on agricultural land, the bottom price of intentionally planted biomass can be derived based on the assumption of (economically) rational behaviour of farmers. One can assume that primary motivation of any entrepreneurial entity is the obtaining and maximisation of the rate of return on the capital invested (Brealey and Myers, 2002).

A farmer (or business company) operating on agricultural land basically chooses between four standard options:

- conventional agricultural production (aimed at food production);
- production of inputs for liquid biofuel production (e.g., rapeseed);
- production of inputs for biogas stations (e.g., maize); or
- production of solid biomass (for direct combustion in biomass boilers or as input for solid biofuel production).

It is obvious that agricultural land is the only limiting factor here – if one hectare is used for energy biomass production, it cannot be used for conventional production and vice versa. The farmer will thus compare all the alternative options for agricultural land utilisation – here, we can simplify the decision-making situation only to a decision between energy biomass production and conventional production. If, e.g., prices of conventional commodities (such as barley, wheat, etc.) and agricultural subsidies enable high profits, farmers will ask a price for planted energy biomass which will assure at least the same profit as conventional production. When analysing the supply side of energy biomass and the behaviour of farmers, one has to concentrate not only on the economic analysis of energy biomass planting projects but also has to include in the analysis alternative options for biomass utilisation.

The bottom price c_{nab} of energy biomass intentionally planted on agricultural land is thus defined according to the formula:

$$c_{\text{nab}} = \max(c_{\text{min}}; c_{\text{alt}}) \tag{1}$$

where c_{min} ... means the minimum price of planted biomass for energy purposes that assures adequate rate of return for investors [EUR/GJ]; and
c_{alt} ... means the price of planted biomass for energy purposes that assures the same economic benefit as conventional agricultural production [EUR/GJ].

If c_{alt} is bigger than c_{min}, one can hardly expect that farmers (if there are no constraints) would be willing to supply biomass for the price c_{min}. Farmers would require at least the price c_{alt}. And even if we assume that (especially at the beginning of massive biomass planting development on agricultural land) planting of energy biomass is a riskier activity compared to the well-managed and routine planting for conventional production, farmers will require compensations for the higher risk associated with planting of energy biomass. The biomass price would thus be even higher than the price c_{alt}.

If the price c_{min} is higher than c_{alt} (which would mean that the farmer is realising at the given moment a lower economic return than the required one), it is theoretically possible to assume that the farmer may accept a price lower than c_{min} (but higher than c_{alt}). However, this situation seems to be improbable assuming the currently relatively very high economic effectiveness of conventional agricultural production.

Biomass (especially solid biomass) is a direct substitute for conventional fuels – in the Czech Republic particularly for domestic brown coal (and, to some extent, also natural gas). The third possible point of view of the biomass price is consumers' willingness to accept the price of biomass as a substitute for conventional fuels. Consumers will thus accept (at a maximum) such biomass price c_{subs} that will assure the same economic effect from power and/or hear production as is from utilisation of other (conventional) fuels.

Assuming that massive development of intentionally planted biomass on agricultural land will not significantly influence the price c_{nab} (the price c_{alt} is independent of possible decreases in biomass production costs as a result of the learning curve effect), and also assuming that partial substitution of domestic brown coal with biomass will not significantly influence its prices (the natural gas price is fully independent of biomass prices), then the (upper) limit of the biomass price can be estimated from the prices of substituted fuels and other related costs (such as induced investment costs and changes in operating costs on the side of the power/cogeneration/heating plant operator).

5.2.2 Methodology for estimation of bottom price of biomass

The bottom price of biomass, as previously discussed, is defined as the maximum of c_{min} and c_{alt} prices.

The main criterion for evaluation of economic effectiveness is net present value – NPV (see, e.g., Brealey and Myers, 2002). NPV compares initial investment (made at present) with the sum of future economic benefits generated by a project. The NPV criterion takes into account the time value of money (having the meaning of return on alternative possible investments defined by the value of the discount rate – r_n). Based on NPV, an investor makes the investment if the sum of the discounted cash flows generated by the project is higher than (or at least the same as) the initial investment, i.e., if NPV≥0. A zero value of NPV should be interpreted in a way that the investor is realising a rate of return on his analysed investment equal to the discount rate used in formula (2) for discounting cash flows. The investor is thus getting the same rate of return as in the case of alternative (possible) investments. NPV equal to zero represents the lower boundary for project acceptance.

However, the NPV formula can be used in the opposite way, where NPV value is not searched for, but is fixed to zero and the price of biomass becomes the independent variable. For a given discount and given project outputs (e.g., labour costs, seeds, fertilizers) and a given yield curve of biomass, we calculate such a price of biomass that will ensure NPV equal to zero or higher – see (2). The investor then obtains a rate of return equal to the discount.

$$\begin{aligned} \mathrm{NPV} &= \sum_{t=1}^{T_n} CF_t \cdot (1+r_n)^{-t} = \\ &= \sum_{t=1}^{T_n} (q_{\mathrm{min},t} \cdot Q_t + S_t - E_t)(1+r_n)^{-t} = 0 \end{aligned} \tag{2}$$

where t ... respective year of project implementation
CF_t ... cash flow in the year t [EUR]
r_n ... (nominal) discount [–]
T_n ... project lifetime [years]
$q_{\mathrm{min},t}$ ... minimum price of biomass in the year t [EUR/GJ]
Q_t ... production of biomass measured by heat content [GJ]
S_t ... project subsidy in the year t [EUR]
E_t ... project expenditures in the year t [EUR]

The calculation of the minimum price of a given type of biomass (i.e., given energy crop type) requires the setting of a reference model, which reflects typical conditions of a project for the given type of biomass. Such models therefore should reflect typical yield curves of the given energy crop type (i.e., typical yields for different climatic and soil conditions) and should include all processes necessary for a biomass plantation during the whole life cycle of the biomass plantation. Economic models should also reflect relevant market conditions such as prices of labour, costs of land rental, fertilizers, services, etc. For detailed information on developing such models, see, e.g., Vávrová and Knápek (2012).

The estimation of the price c_{alt} is more complicated. This results from the fact that here we compare an energy crop with a plantation lifetime typically (but not necessarily) longer than one year (e.g., the life cycle of short rotation coppice plantations is up to 25 years, that of reed canary grass plantations is up to 10 years, etc.) with conventional agriculture production, which typically has a one-year production cycle. The price c_{alt} is such a price of the given type of biomass which brings the farmers the same "economic effect" as conventional production. The problem is how to define "the same economic effect" for these two very different options. In the case of perennials (e.g., SRC plantations), one can interpret economic effect as the rate of return on the financial resources invested in project preparation and plantation establishment. Such projects can thus be viewed as conventional investment projects.

Conventional production (such as wheat, barley, maize, etc.) typically has a one-year production cycle and there are no "investment" expenditures at the project beginning. Profit (on a one-year basis) is calculated as the difference between revenues from production sale (plus subsidies) and costs of production. Even when this indicator is expressed in percentage terms, it cannot be compared with the percentage of rate of return which is used for the minimum price calculation (see Formula 2).

When comparing projects with different lifetimes, one has to ensure correct project comparability. When, e.g., an SRC plantation (25-year cycle) is compared with conventional production (1-year cycle), one can reach project comparability through assumption of project repetition for conventional production 25 times (to get the same project duration). Assuming this, it is then possible to derive the price c_{alt} based on a general formula expressing the balance of net cash flows generated from the energy crop (with a cycle longer than one year) and net cash flows generated from the conventional crop (with a one-year cycle) – see Formula 3 (per hectare base).

$$\sum_{t=1}^{T_c}(c_{\mathrm{alt},t}\cdot Q_t+S_t-E_t)\cdot(1+r)^{-t}=\sum_{t=1}^{T_c}(R-C)\cdot(1-d_p)\cdot(1+i)^{t-1}\cdot(1+r)^{-t} \tag{3}$$

where
R ... revenues from one hectare used for conventional production [EUR/ha]
T_c ... comparison period [years]
$c_{\mathrm{alt},t}$ ... price c_{alt} in the year t (price is subject to inflation growth) [EUR/GJ]
C ... costs of conventional production [EUR/ha]
i ... average annual inflation [–]
d_p ... income tax [–]

Formula 3 can be simplified (after expression of the parameters E_t and $c_{\mathrm{alt},t}$) as the product of the first-year value and inflation growth – see Formula 4. We thus get a formula for calculating the price c_{alt} in the first year of the comparison period. The price in the following years is then increased with the inflation.

Formula 3 can be simplified (after expression of the parameters E_t and $c_{\mathrm{alt},t}$) as the product of the first-year value and inflation growth – see Formula 4. We thus get a formula for calculating the price c_{alt} in the first year of the comparison period. Price $c_{\mathrm{alt},1}$ (assuming the given rate of inflation i) should ensure the balance between net present value of cash flows generated from energy crop (with lifetime T_c) and net present value of cash flows generated from the conventional one year crop repeated T_c times. The price c_{alt} in the following years is then increased with the inflation.

$$c_{\mathrm{alt},t} = c_{\mathrm{alt},1} \cdot (1+i)^{t-1} \quad (4)$$

If we compare an energy crop with a one-year cycle with conventional production, the comparison would be much easier. Here, we would compare only the amount of net cash generated from both kinds of production (on a one-year base only) – see Formula 5, where the left side expresses cash generation from the energy crop and the right side shows cash generation from the conventional crop.

$$c_{\mathrm{alt}} \cdot Q - E + S = R - C \quad (5)$$

The minimum price $c_{\min}$ differs significantly for individual energy crop types. The minimum price also varies for each energy crop type depending on climatic and soil conditions in a given area (land plot). Site conditions, especially those influencing biomass yields while planting, remain almost the same. It is thus not possible to define one concrete $c_{\min}$ value, but it is necessary to work with a range of typical values.

The calculation of the price c_{alt} is based on economic effects from the production of conventional plants. Economic effectiveness differs by plant type, and of course is also influenced by the site conditions as in the case of energy crops. When deriving the price c_{alt}, concrete land plots are not assumed and the typical (average) economic effectiveness of conventional plant production is assumed.

5.2.3
Methodology for estimation of upper future biomass price

As mentioned above, the upper limit of the biomass price results from customers' willingness to pay a given price for biomass taking into account other options for satisfying their fuel needs (e.g., with conventional fuels). The upper limit of the biomass price is thus defined based on the price of the substituted fuel taking into account all the related costs of biomass utilisation.

Substitution of conventional fuels can be viewed from two different time perspectives – a short-term and a long-term point of view. In the short run, biomass can be used as a conventional fuel substitute only where installed technology enables this. This is, e.g., the case of so-called biomass-coal co-firing, where biomass is added (typically up to 10–15%) to coal. This technology has been widely used in Czech coal-fired power plants with fluid boilers since 2004.

Biomass is also discussed as a substitute for brown coal, still widely used in rural areas for individual space heating.

In many cases, substitution of conventional fuels with biomass requires significant investment in completely new technology (e.g., a biomass boiler and additional equipment). In such cases, it is necessary to also include these cost in the economic analysis.

The approach presented in this paper is based on the assumption than no specific investments are needed for biomass utilisation, and is thus based only on the difference between the fuel costs (which is the typical case for co-firing).

Substitution of brown coal with biomass leads to savings of emission allowances. This economic effect has to be counted as another economic benefit of biomass utilisation. Biomass utilisation (co-firing case) does not significantly influence costs of power and heat production and it is thus not necessary to assume changes in corporate taxes.

The specific price of biomass (based on substitution of coal) can thus be derived using the following formula:

$$C_{\text{subs}} = \frac{CU_{e,\text{GJ}}}{q} + EP_{\text{GJ}} + ZB_{\text{GJ}} - D_{\text{dop}} \quad (6)$$

where

$CU_{e,\text{GJ}}$ ... specific costs of brown coal used in co-firing [EUR/t]

q ... coal heating value [GJ/t]

EP_{GJ} ... economic benefit from emission allowance saving converted to 1 GJ of fuel (biomass) energy content [EUR/GJ]

ZB_{GJ} ... support to biomass utilisation (for power and/or heat production saving converted to 1 GJ of fuel (biomass) energy content [EUR/GJ]

D_{dop} ... additional costs of biomass logistics [EUR/GJ]

The specific effect EP_{GJ} resulting from the emission allowance saving can be derived from the average CO_2 emission from brown coal-fired power plants (Ministry of Industry and Trade Decree no. 425/2004 Coll.) equal to 1.17 t CO_2/MWh_{el}. The average specific heat consumption for power generation is assumed to be 11 MJ/kWh_{el}.

5.2.4 Data sources for biomass price modelling

The following conventional crop types have been used for the analysis: wheat, barley, maize for grain, rye, and rapeseed. Table 1 presents areas of agricultural land used for these crop types within the total area of arable land, equal to 2.488 million hectares in 2011.

Table 2 presents the costs of conventional crop production per hectare. These costs are derived from an analysis made by the research institute ÚZEI[9]. The costs per hectare range from EUR 555 to EUR 944.

[9] *Institute of Agricultural Economics and Information.*

	Area [ha]	% of total arable land
Wheat	863,132	35%
Barley	372,780	15%
Maize for silage	197,579	8%
Maize for grain	109,651	4%
Rye	24,985	1%
Rapeseed	373,386	15%

Tab. 1: Planting areas of crucial conventional crop types, Czech Republic, 2011 (Source: Czech Statistical Office)

Crop type	Costs [EUR/ha]
Wheat (winter)	753
Wheat (spring)	608
Barley (winter)	658
Barley (spring)	673
Maize for grain	949
Maize for silage	884
Rye	563
Rapeseed	948

Tab. 2: Average costs of planting of conventional crops, Czech Republic, 2011 (Foltýn and Zedníčková, 2010), VAT not included, 1 EUR = 27 CZK

Table 3 presents development of prices of conventional commodities in the period 2008–2011. These prices fluctuate significantly from year to year depending on the harvest and the state of the world market.

When calculating economic effectiveness of conventional agricultural production, one has also to add subsidies (i.e., direct payments per hectare of agricultural land within the Common Agricultural Policy support system – so-called SAPS payments). These payments reached EUR 174/ha in 2011.

Table 4 presents average crop yields in the conditions of the Czech Republic – as the averages for the period 2001–2011.

The minimum prices of intentionally planted biomass were derived based on reference economic models reflecting the typical conditions of energy crop production in the conditions of the Czech Republic. The minimum prices were derived assuming a

Price [EUR/t]	2008	2009	2010	2011
Wheat (for food)	189	107	126	187
Barley (for food)	189	111	123	164
Maize (for cattle)	172	104	122	174
Rye	177	98	106	175
Rapeseed	362	263	287	415

Tab. 3: Average prices of individual conventional crop types in EUR/t (Source: Czech Statistical Office), 1 EUR = 27 CZK

Conventional crop type	Average crop yields (t/ha)
Wheat (winter)	5.14
Wheat (spring)	3.61
Barley (winter)	4.35
Barley (spring)	4.11
Rye	4.23
Rapeseed	2.81
Maize for grain	7.20
Maize for silage	34.01

Tab. 4: Average crop yields (2001–2011) in t/hectare (Source: Czech Statistical Office)

nominal discount rate equal to 8.6% and average inflation of 2.5%[10]. The minimum prices of energy crops are demonstrated on an example of the two energy crop types currently assumed for planting in the Czech conditions: reed canary grass (example of non-woody biomass) and SRC plantations (example of woody biomass). As discussed above, biomass yields depend on soil and climatic conditions on individual land plots – typically 4–6 yield curves are assumed. Two most typical yield curves for each energy crop type are taken into account for the minimum price calculation: 4.8 and

[10] *Values of nominal discount rate and expected long term inflation were derived based on figures used for calculation of feed-in tariffs (FIT) for electricity from RES in the Czech Republic. Till 2012 FIT were calculated using rate of return approach (similar to the methodology of minimum price described here) – 6.3% nominal discount rate was used. Approach presented here assumes higher risk associated with the energy crop that is compensated by higher value of nominal discount rate (increase by app. 2%).*

6 t (dry matter)/ha for reed canary grass, and 6.8 and 9.5 t (dry matter)/ha for SRC plantations.

The price of brown coal used for power and heat production (so-called energy brown coal) is estimated in the range of EUR 1.2–1.4/GJ[11]. The price of emission allowances is assumed as EUR 8/t CO_2[12] only. Higher prices of emission allowances would increase the competitiveness of intentionally planted biomass against conventional fuels.

The calculation also worked with the value of the green bonus for co-firing (valid for 2011) equal to EUR 50.7/MWh (for intentionally planted biomass).

5.3
Results of modelling of future biomass prices

Table 5 presents the results of the gross profit calculation for individual conventional crop types. Values of profitability of conventional crops are relatively very high, which significantly impacts on farmers' expectations for prices of energy biomass (to get the same economic results from their entrepreneurial activities).

	Net profit [EUR/ha]	Net profit [%]
Wheat (winter)	308	41%
Wheat (spring)	193	32%
Barley (winter)	186	28%
Barley (spring)	142	21%
Rye	285	51%
Rapeseed	319	34%
Maize for grain	390	41%

Tab. 5: Results of net profit calculation for conventional crops, 1 EUR = 27 CZK

The average weighted net profitability of conventional crops is then EUR 289/ha.

Tables 6 and 7 present the results of the minimum price calculation for the two typical energy crop types – reed canary grass and SRC plantations – and for their two most typical yield curves.

[11] *Estimate made by the authors based on freely available information.*

[12] *Present price (beginning of 2015) of emission allowances is only approx. 7 EUR, which is the result of poor functioning of the European Emission Allowance Trading Scheme and an excess of allowances on the market.*

Biomass yield	$c_{min,1}$ [EUR/GJ]		$c_{alt,1}$ [EUR/GJ] Net profitability [EUR/ha]	
t(dry)/ha.year	SAPS 2010	no SAPS	289	222
6.0	1.5	2.9	5.2	4.4
4.8	1.9	3.6	6.5	5.4

Note: The c_{alt} price is calculated for the two assumptions of net profitability of conventional crops (EUR 289 and 222/ha).

Tab. 6: Results of c_{min} and c_{alt} calculation for reed canary grass

Yield	$c_{min,1}$ [EUR/GJ]		$c_{alt,1}$ [EUR/GJ] Net profitability [EUR/ha]	
t(dry)/ha.year	SAPS 2010	no SAPS	289	222
9.5	3.5	4.4	6.1	5.5
6.8	4.1	5.4	7.7	6.9

Tab. 7: Results of minimum price and c_{alt} calculation for SRC plantations

Currently the high profitability of conventional agricultural production causes high growth of the price c_{alt} compared to the price c_{min}. This is caused by the fact that the discount rate used for the c_{min} calculation (the value of which is derived from the rate of return for RES-E projects used for feed-in tariff calculation) is significantly smaller than the profitability of conventional production (note: the net profits in the Table 5 cannot be directly compared with the discount rate value used for the c_{min} calculation). It is obvious that keeping this high profitability could easily result (in the longer run) in creation of a significant economic barrier to planting of energy biomass on agricultural land (biomass would not be competitive with conventional fuels or would need massive subsidising).

The growth of the price c_{alt} compared to the price c_{min} is higher (in percentage terms) for reed canary grass than for biomass from SRC plantations. This is caused by the different structure of project expenditures. SRC plantations have a much higher share of costs at the beginning of the project (plantation establishment) than reed canary grass, which is, to the contrary, characterised by a higher share of running costs during the plantation existence.

Assuming all the discussed input parameters, the biomass price c_{subs} derived based on substitution of brown coal with energy biomass (co-firing case – Equation 6) is equal to EUR 1.2/GJ only – assuming no subsidy for biomass utilisation for power and heat production. If we also include a subsidy in the form of a green bonus for power generation in the c_{subs} calculation, c_{subs} increases to EUR 5.8/GJ. If the coal price increases, the price c_{subs} is also higher, and vice versa. An increase in emission allowance prices would lead to the same effect.

Range of biomass prices					
	c_{min}	c_{alt}	c_{alt}	c_{subs} – **co-firing**	c_{subs} – **co-firing**
		NF = 289 EUR/ha	**NF = 222 EUR/ha**	**No subsidy**	**Subsidy through green bonus**
	EUR/GJ	**EUR/GJ**	**EUR/GJ**	**EUR/GJ**	**EUR/GJ**
Reed canary grass	1.5–1.9	5.2–6.5	4.4–5.4	1.2	5.8
SRC	3.5–4.1	6.1–7.7	5.5–6.9		

Note: NF means net profitability of conventional crops per hectare.

Tab. 8: Overview of biomass price modelling

The results of the biomass price modelling are presented in Table 8, which indicates that the high profitability of conventional crops significantly (several times) increases the price c_{min}. This would in fact result in either low motivation for farmers to intentionally grow biomass for energy purposes (if customers require biomass for a price close to c_{min}) or low demand for planted biomass (if farmers asked for a biomass price close to c_{alt}). The biomass price derived from the point of view of substitution of conventional fuels (here, brown coal used for power generation) indicates a significant role of support to power generation through green bonuses. If we assume the currently low emission allowance prices, intentionally planted biomass is not competitive without massive support to its utilisation for this purpose.

5.4 Conclusions

When modelling the biomass price, especially as an input for investment decisions (such as building a new power or cogeneration plant), one has to take into account not only economic effectiveness of biomass planting on agricultural land, but also include the opportunity cost point of view. Rationally deciding farmers would also include the economic effectiveness of conventional crops in their decisions whether to plant energy biomass. The decision-maker will thus require at least such a price of biomass that will ensure the same economic effect per hectare of land.

The biomass price is finally the result of a market equilibrium between the supply and demand. Thus, one also has to take into account the demand point of view – what are the prices of biomass substitutes (and also other related costs and revenues). In the Czech Republic, biomass is expected to substitute especially domestic brown coal, which is massively used for power generation and heat production. Many households are still using brown coal for individual space heating (which is causing significant environmental damage).

The paper presents a methodological background for modelling future biomass prices, taking into account alternative options for agricultural land utilisation and also the results of substitution of conventional fuels with biomass.

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6

Recent Changes and Future Challenges on European Electricity Markets

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Abstract

In recent years, remarkable changes in electricity generation have taken place in several European countries, notably in Germany. The major ones are: (i) increasing shares of renewables; (ii) very low CO_2 prices; (iii) nuclear phase-out in some countries; and (iv) cheap coal (at least cheaper than natural gas). In this chapter, the current situation and the future prospects for renewable resources for electricity generation in Europe are analysed.

The core objective of this chapter is to investigate how these new developments will likely affect the prices on European electricity markets. The major effects of these developments on electricity markets will be: (i) a much higher hour-to-hour and day-to-day price volatility; (ii) an increasing relevance of intra-day markets; (iii) higher costs of fossil plants due to higher shares of investment depreciation costs; (iv) increasing relevance of storage facilities and "smart" grids; (v) higher shares for balancing markets; and (vi) increased complexity in balancing supply and demand over time.

Key words: Renewables, electricity markets, price volatility

6.1 Introduction

In recent years, due to generous support schemes in a number of countries, electricity generation from renewables has been growing at a remarkable rate as illustrated in Figure 4, ch. 2 for EU-28 countries between 1990 and 2013. The growth of "new" renewables, excluding hydropower, is even more impressive over the same period from less than 1% to about 9%, mainly from wind and biomass (Figure 5, ch. 2).

The rapid growth of renewables, especially PVs, is expected to become even more pronounced by 2020. In Germany alone, the total installed PV capacity is projected to increase from about 30 GW installed by the end of 2013 to at least 50 GW by

2020. This is roughly half the total fossil and nuclear capacity in Germany in 2011. The continued growth has increased the need to address a number of critical issues, including:

- suggestions for implementation of capacity markets to ensure supply;
- calls to re-examine unsustainable subsidies which encourage more renewable generation to be added to the network while bypassing the normal market incentives that apply to conventional technologies;
- re-examining the long-term impact of renewables on retail tariffs for households and industry; and
- additional costs of grid extension and storage, which are necessary to compensate for the intermittency and unpredictability of renewables.

The core objective of this chapter is to examine the historical growth, the current situation and the future prospects of renewables for electricity generation in Europe. Similar arguments, of course, apply to other regions of the world with ambitious renewable targets. The main objective is to examine the possible effects of further uptake of renewables on prices on European electricity markets including:

- the impact of renewables at specific times of the year when they shift the supply curve of conventional generators on wholesale markets leading to low or even negative prices;
- the impact of variable renewables with zero marginal costs on the costs of fossil-fuelled plants, mainly natural gas, which are needed for reliability reasons; and
- change of spreads between high and low price levels.

The chapter is organised as follows: Section 2 looks at history and lessons learnt from the past and at future prospects of intermittent renewables in the EU-28. Section 3 presents the basics on how prices come about on liberalised electricity markets and the impact of intermittent renewables on wholesale electricity prices. The impact of larger shares of intermittent renewables on the prices on electricity markets is examined in Section 4. Section 5 asks whether new market rules are necessary, followed by the chapter's conclusions.

6.2
Changes on electricity markets after the liberalisation

This section discusses how the liberalisation of the electricity markets in Europe changed the formation of prices on wholesale markets, and – as further described in Section 4 – the impact of rising shares of renewables on spot market electricity prices.

The liberalisation process in Europe started in the UK in the late 1980s and gradually migrated to continental Europe with EU Directive 96/92/EC (EC, 1997)[13]. One of the major features of the liberalised electricity markets was that the pricing regimes changed. On former regulated markets, prices were established by setting a regulated tariff, which was calculated by dividing the total costs of supplying service

[13] *For further details, see Haas et al. (2006).*

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by the number of kWh sold – with some differences between different groups of customers. The major change that took place after the liberalisation was that prices were now expected to reflect the marginal costs of electricity generation (e.g., Stoft, 2002). At the time when liberalisation started, considerable excess capacities existed in Europe. This led to the expectation that prices would (always) reflect the short-term marginal costs (STMC) as illustrated by supply curve in Figure 1. The graph shows a typical merit order supply curve with conventional capacities, including large hydropower. The typical historical pattern of electricity generation on the European electricity markets consisted of conventional fossil, nuclear and hydropower capacities. Since the late 1990s, nuclear contributed the largest share most of the time, followed by fossil and hydropower[14]. Non-hydro renewables were not a significant factor until recent times.

As shown in Figure 1, the intersection of the supply curve with demand determines the market clearing price at the system marginal costs. The curve D_{t1} shows the demand curve at times of low demand, e.g., at night and p_{t1} is the resulting (low) electricity price. D_{t2} shows high demand times, e.g., at noon, and p_{t2} is the resulting (high) electricity price. The difference between p_{t2} and p_{t1} is the so-called *price spread* further described below. It provides useful information, for example, on the economic attractiveness of storage, which will be of high relevance on markets with large shares of renewables. Until recently, the price spread has been of interest mainly with respect to pumped storage. That is to say, during periods when prices are low, water can be pumped into reservoirs; while generating electricity when the opposite is true.

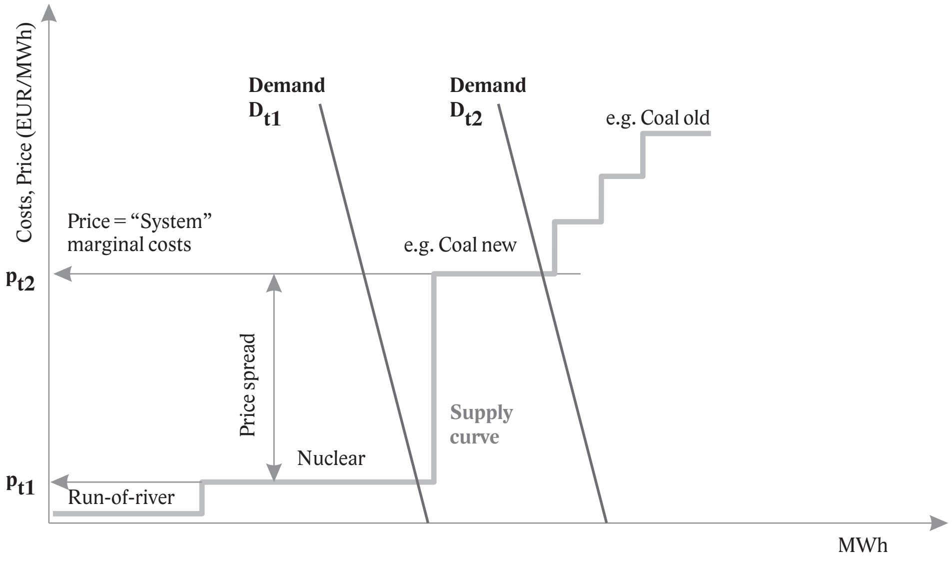


Fig. 1: How prices come about on markets with conventional capacities, including large run-of-river hydropower

[14] *In principle, this pattern can be found on every market, also in the NORDPOOL, where Denmark provides the fossil back-up capacities.*

The price patterns on different European electricity markets are shown in Figure 2 for the period 2000–2014, where price volatility and considerable differences between various sub-markets are observed. Italy tends to experience higher prices and more volatility due to its over-reliance on imported electricity, congested transmission lines, and heavy reliance on expensive natural gas. In the case of the NORDPOOL, which includes Sweden, Norway, Finland, and portions of Denmark, the pattern is different due to heavy reliance on hydropower and lack of strong interconnection with Continental Europe. Despite these differences, a remarkable convergence of prices has taken place even in the case of the isolated Iberian peninsula, which is not yet fully integrated into the European network due to transmission limitations. The reason for high prices in Continental Europe in 2008 was the low hydropower availability while the falling prices since 2008 may be attributed first to the European economic crisis and then to the merit order effect and the increase in variable renewables.

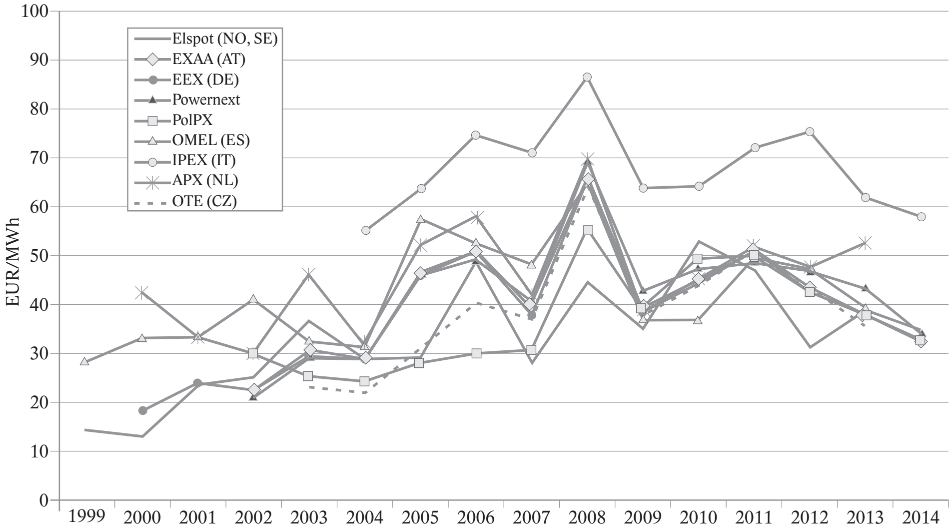


Fig. 2: Development of spot market prices on different European electricity markets, 2000–2014

Figure 3 depicts the historical developments of wholesale electricity market prices at the EEX (Germany), the EXAA (Austria), PolPX (Poland), Powernext (France) and the PXE in Prague (Czech Republic). It can be seen at a glance that the shape and the change in the magnitude are very similar for all these electricity markets. Moreover, it can be seen that wholesale electricity market prices in the CR have gradually approached the German level and are currently virtually the same.

The STMC price regime, illustrated in Figure 1, of course, will not be permanent nor always apply. Once excess generation capacity is exhausted, there will be a shift towards long-term marginal costs (LTMC). Similarly, generators are likely to behave strategically during high demand periods on markets with limited peaking capacity. Moving forward, one can expect deviations from the STMC price regime, as illustrated

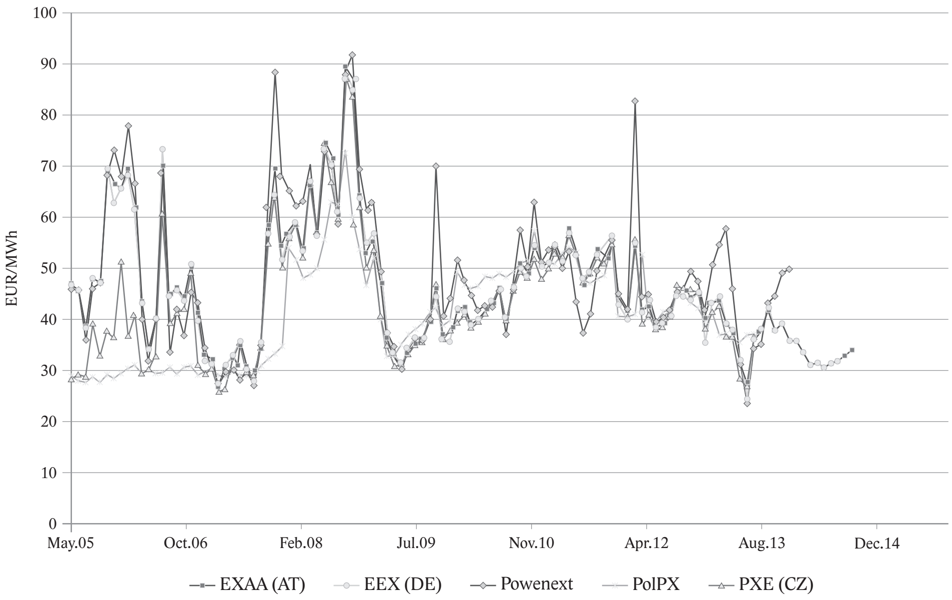


Fig. 3: Development of monthly spot market prices in AT, DE, FR, CZ, PL, 2005–2014

in Figure 4. Moreover, as described below, the introduction of large amounts of renewables with essentially zero marginal costs will further affect the principles behind STMC, a feature described in a number of chapters in this volume.

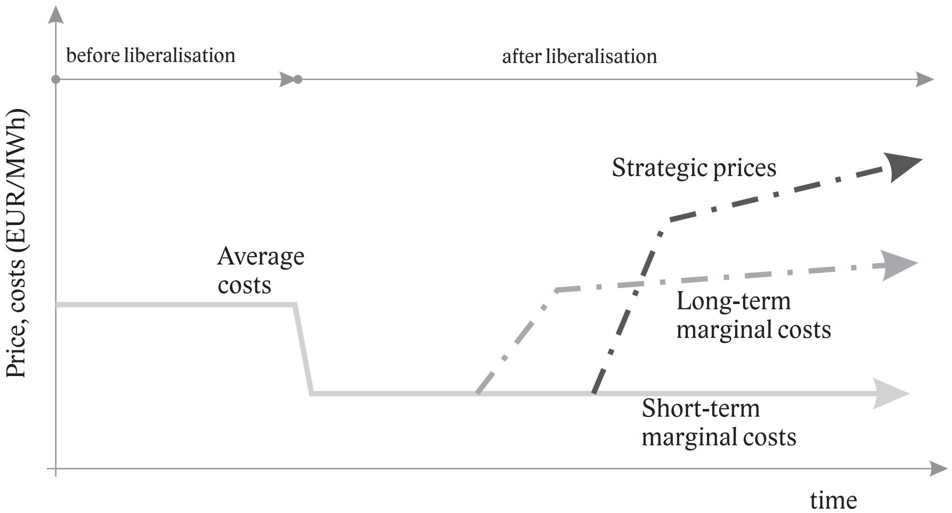


Fig. 4: Changes in electricity pricing before and after liberalisation of electricity markets

6.3
Major impact parameters on electricity market prices

Against the backdrop of rapidly rising renewable generation across the EU, notably in countries like Germany, Denmark, Spain and others, three key questions arise:

- firstly, what is the impact of large amounts of renewable generation feeding the grid especially during low demand periods when renewables shift the supply curve of conventional electricity virtually "out of the market";
- secondly, what is the impact of intermittent renewable generation on the costs at which fossil – especially natural gas – capacities are offered; and
- the impact of CO_2 prices;
- the impact of cheap coal[15]; and
- what is the effect of renewables on the *price spreads*, already defined, over time.

6.3.1
The direct impact of renewable generation on market prices

With a few exceptions, such as hydropower with large reservoirs and geothermal, renewable technologies by their nature tend to be intermittent, not entirely predictable, nor dispatchable. These are familiar characteristics, which have been recognised in networks with large amounts of run-of-river hydropower and wind for some time, for example in Denmark (Lund, 2005) or Spain (Zubi, 2011). Large amounts of wind power generation during low demand periods result in lowering market clearing prices, occasionally leading to negative prices (see also Nicolosi, 2010). However, the wind-driven effects mostly happen during off-peak hours when prices are already low, causing them to become even lower. This phenomenon has led to increasing volumes of intra-day trading, where traders attempt to take advantage of the price differentials on different markets.

The PV generation during mid-day hours not only displaces virtually all hydropower generation but results in lower spot prices during a period when they tend to be high. This is an example of how the rise of renewables will impact spot prices, trading patterns and dispatching of conventional generation. Similar patterns are experienced in other sunny regions such as Italy and Spain, where solar generation has a significant impact on mid-day prices.

The explanation is simple. On a sunny day with ample solar power generation, the supply curve is shifted to the right as schematically shown in Figure 5, which essentially pushes nuclear and fossil-fuelled generation "out of the market".

[15] *Coal prices fell down for several reasons, but one of the most important factors since the end of the last decade is the massive development of shale gas mining, which has resulted (especially in the USA) in a massive substitution of hard coal with shale gas. This has led to an excess of hard coal on world coal markets and a significant decrease in hard coal prices.*

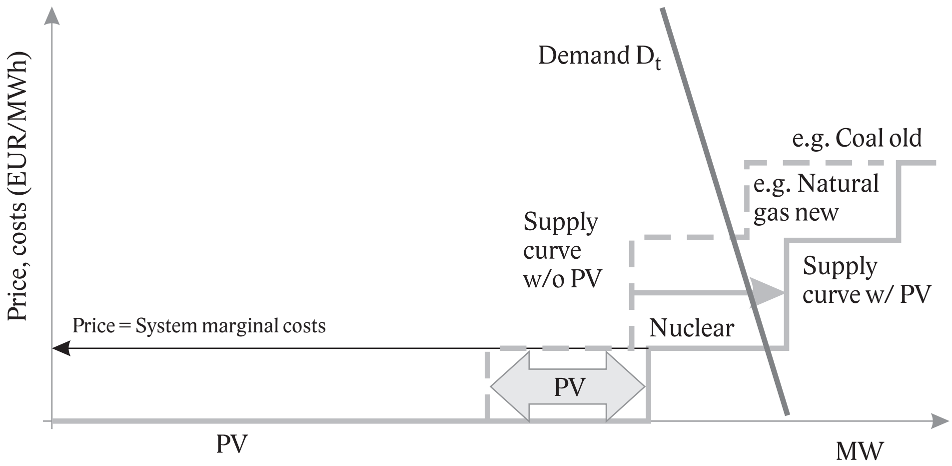


Fig. 5: Merit order supply curve with and without additional PV capacities at peak time of a bright summer day with short-term marginal costs of conventional capacities

6.3.2
The impact of renewable generation on fossil plants[16]

Aside from the above-described effects, intermittent renewables will also influence the costs at which fossil generation – especially natural gas – is offered. The illustration in Figure 6 is based on the short-term marginal costs (STMC) of conventional generation, which may correspond to some 6,000 full-load hours per year[17]. The revenues derived from these hours must cover both the fixed and variable costs, as illustrated in Figure 6. The graph schematically depicts the total and variable (short-term) electricity generation costs of a new combined-cycled gas turbine (CCGT) based on its annual full-load generation hours. As can be seen, the share of fixed costs is considerably higher when the plant operates at full load for a minimal number of hours, say, 1,000 hrs/yr[18] as opposed to a high number of hours, say 6,000 hrs/yr.

Historically, different types of fossil plants were dispatched to meet the load over the course of all hours in a year and it was generally possible to recover the fixed costs when more expensive plants, usually gas-fired peaking units, set the price. In recent years, frequently old and mostly depreciated coal plants have determined the STMC, allowing new peaking units such as CCGTs to recover their fixed costs. In a future where renewables with virtually zero marginal costs set market clearing prices, this may no longer be the case. This problem, sometimes referred to as the "missing money" problem leads to a lack of sufficient investment in peaking capacity and storage, which in fact will be sorely needed to deal with the intermittency of renewables.

[16] *The following analysis draws on Haas et al. (2012).*

[17] *That assumes roughly a 70% capacity factor.*

[18] *Of course, full-load hours vary year by year depending on demand, hydropower and other factors.*

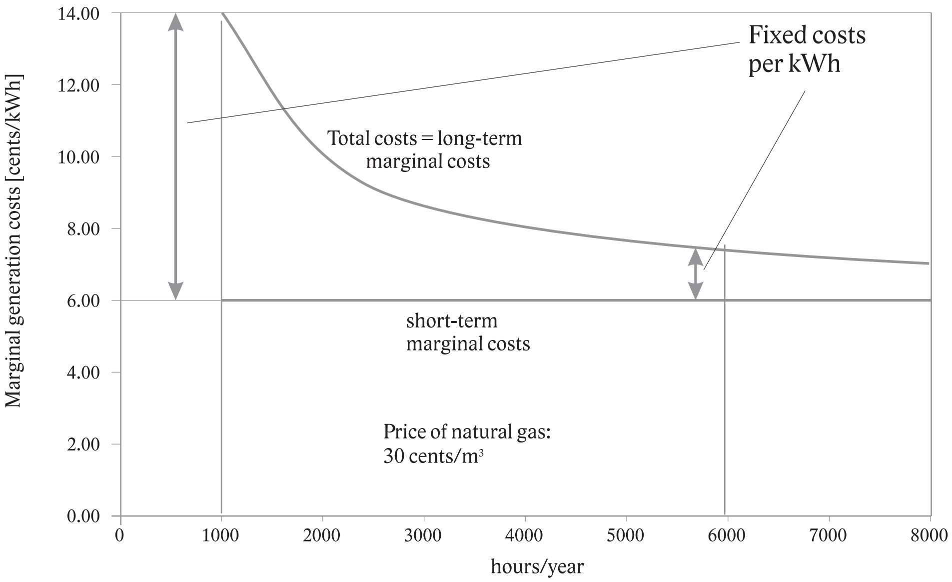


Fig. 6: Short-term (variable) and long-term (total) marginal costs of electricity generation in a CCGT plant depending on yearly full-load hours

As the preceding discussion illustrates, the issue of missing money is likely to become more common and serious as renewables begin to dominate many European markets, as is expected for Germany by 2050. Under such a scenario, only highly flexible CCGT plants can remain viable as described by Auer (2011) or Carraretto (2006). But as the number of hours in which such plants are needed to operate drops, say to 1,000–2,000 hours/year, different pricing strategies, including the implementation of capacity markets, may become more relevant. Regardless of what such schemes may be called, pricing based on long-term marginal costs, which include capacity costs, is likely to become more prevalent than today, as further discussed in Section 5.

How the growth of renewables might impact future pricing strategies of fossil or biomass power plants over time is a subject of speculation. As schematically shown in Figure 7, the merit order supply curve and the high and low demand curves are affected by the availability of renewables, which tend to be intermittent and not entirely predictable. The illustration shows three examples for supply curves: merit order supply curves for STMC vs. LTMC of CCGT plants and a supply curve for strategic bidding, which is shown as a vertical line.

Moreover, quite different demand as well as supply profiles can emerge in practice. Figures 8a and 8b show a completely different pattern of supply and demand curves for examples of positive prices.

Figures 8c and 8d show how the pattern of supply and demand curves can change within one hour on 16 June 2013 in the presence of even negative prices.

Depending on where the supply and demand curves intersect, different prices prevail. The price may be extremely high in the case of strategic bidding – not sustainable

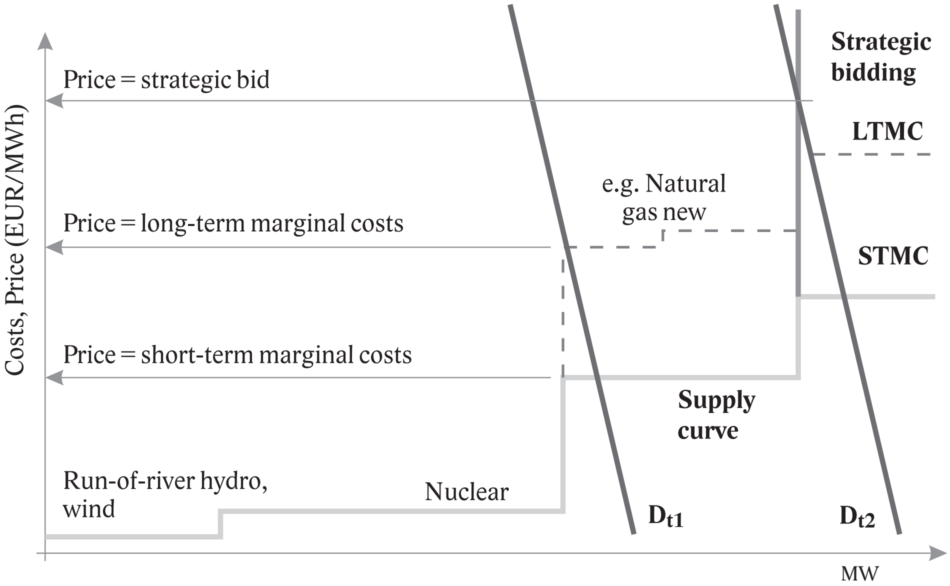
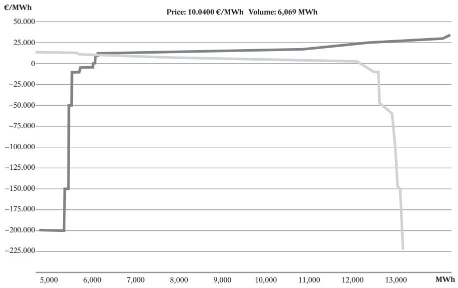
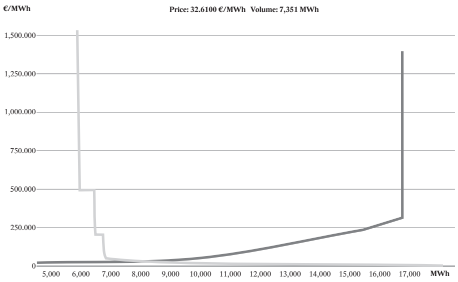


Fig. 7: Merit order supply curve for STMC vs. LTMC of CCGT plants or strategic bidding at times with low intermittent renewables



Source: www.epex.com

Fig. 8a: Pattern of supply and demand curves on 10 August 2014



Source: www.epex.com

Fig. 8b: Pattern of supply and demand curves on 29 October 2014

in the long run – or lower when long-term marginal costs are included, or even lower if short-term marginal costs prevail.

6.3.3 The impact of CO_2 prices

At times where the price is set by coal or natural gas plants, the CO_2 prices impact on wholesale electricity market prices in two dimensions: (i) they influence the absolute level; and (ii) they determine whether coal or natural gas plants are preferred.

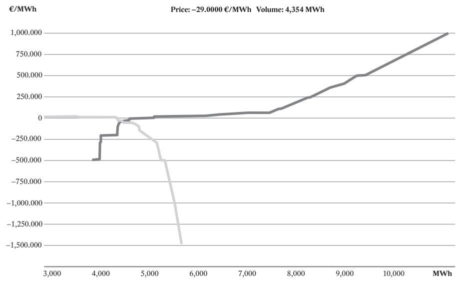


Fig. 8c: Pattern of supply and demand curves on 16 June 2013, 1 pm

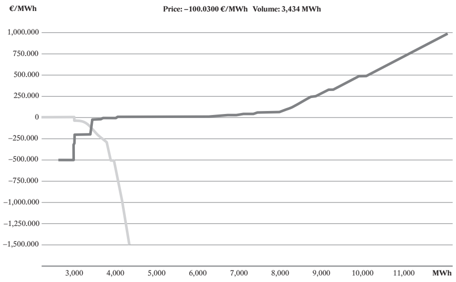


Fig. 8d: Pattern of supply and demand curves on 16 June 2013, 2 pm

As seen from Figure 9, CO_2 prices has dropped in recent years from an all-time high level of about EUR 25/tonne of CO_2 to EUR 5/tonne of CO_2. The major effect was that coal became favourable in the merit order curve compared to natural gas[19].

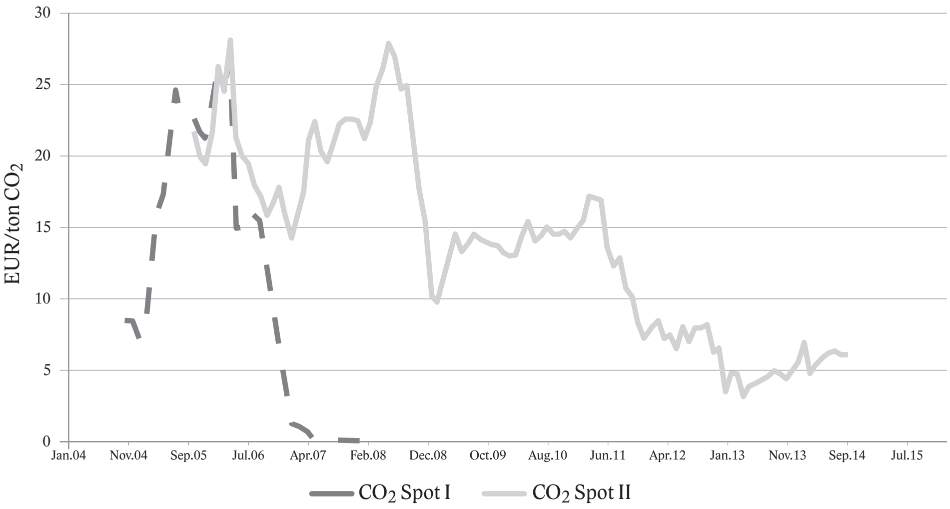


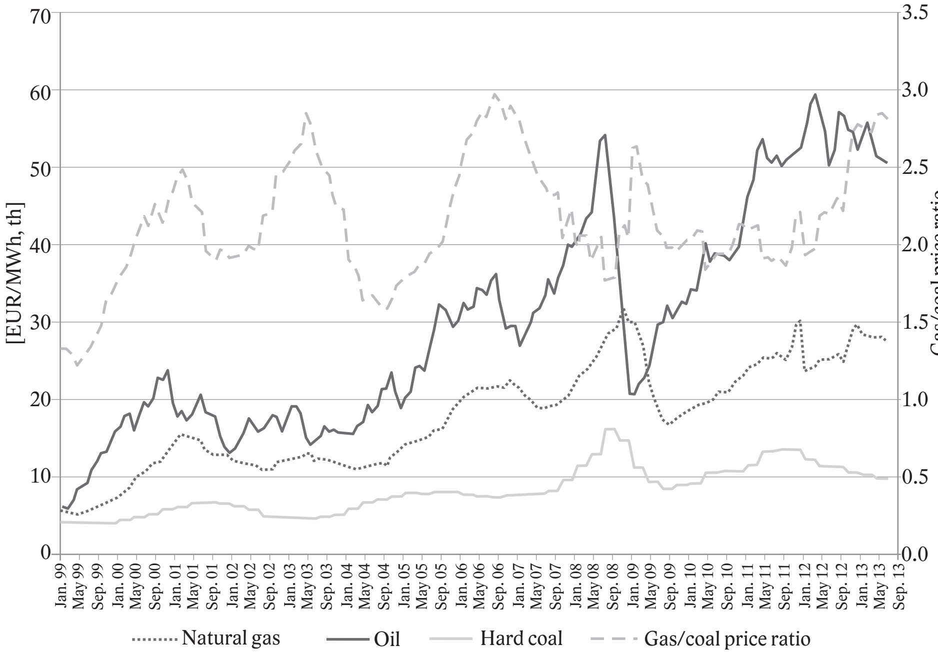
Fig. 9: Development of CO_2 spot market prices (EEX), 2005–2014

6.3.4 The impact of cheap coal prices

Another major interesting issue is to what extent the recent development of fossil fuel prices impact on wholesale electricity market prices. As shown in Figure 10, the coal prices have remained rather stable in recent years compared to natural gas prices. The

[19] *Also thanks to the previously mentioned decline in coal prices.*

price ratio between natural gas and hard coal prices has remained at a level between 2.5 and 3.



Source: www.bafa.com

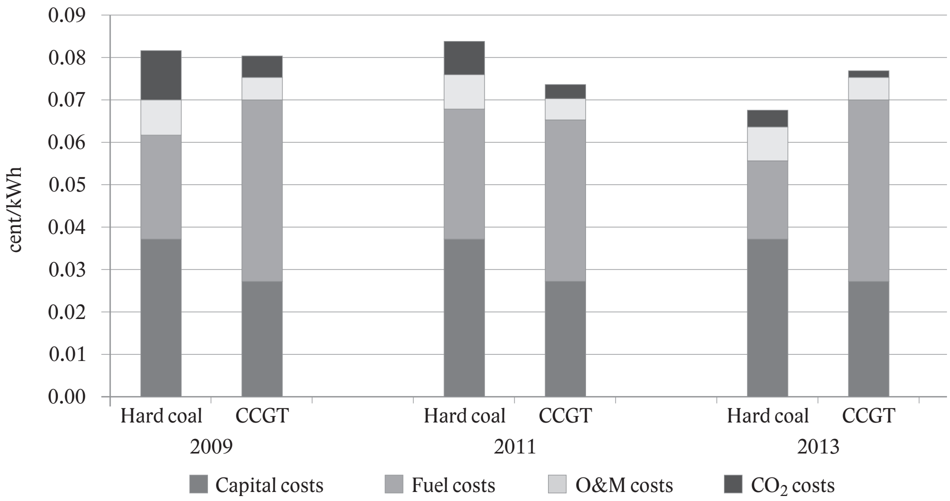
Fig. 10: Development of fossil fuel prices over time, 2000–2013

The major consequences of this development are shown in Figure 11 over time from 2009 to 2013. First, we look at the total generation costs, including investment costs; see Figure 11a. While these costs were almost equal in 2009, there was a clear preference for natural gas plants in 2011. This turned into the opposite in 2013, when there was a clear preference for coal power plants.

This comparison looks even more favourable for coal if only the variable costs are considered; see Figure 11b. Over the whole period 2009–2013, there was never a clear preference for natural gas plants.

6.4 Changes in market patterns

As already discussed, the current electricity spot markets rely mainly on the basic principle that at every point in time, prices are equal to the system marginal costs. This, of course, allows the coexistence of different market segments to take advantage



Source: own calculation

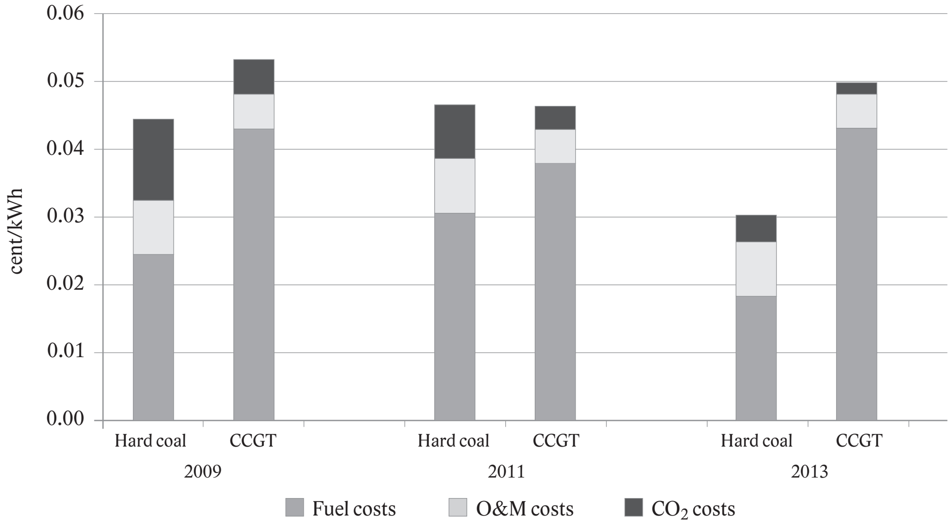
Fig. 11a: Sensitivity of total electricity generation costs over time depending on fuel and CO_2 prices

of arbitrage opportunities, which explains futures and forwards markets, day-ahead, intraday and balancing markets. The question is whether there is a need for fundamental changes in market mechanisms to accommodate large amounts of new renewable generation.

This has raised interest in so-called capacity markets in some circles. The major argument of the advocates of this idea is that in the absence of some sort of fixed "stand-by fee" paid to fossil fuelled plants, the owners/operators will shut them down as they become marginally profitable or not profitable at all[20]. Ironically, these plants will increasingly be needed to maintain system reliability and serve as back-up for intermittent renewables. In some markets, as in Texas, offer cap prices have been raised partially to allow peaking units and those needed for resource adequacy to gain more revenues during periods of supply scarcity and high prices. In this context, if the regulators are willing to accept occasional high spikes in spot prices that are significantly above the STMC – without accusing the stakeholders of abuse of market power – there might be no need for additional capacity markets.

With respect to time-dependent market structures, different new patterns are likely to emerge. Regarding the role of hedging and futures contracts, an argument recently raised is that no hedging is possible on markets with high shares of intermittent renewables and futures markets will break down. Ironically, the very opposite may be true. Hedging and tradable long-term contracts, to a large extent, will assume the role of capacity markets. For example, long-term contracts (LTC) traded years ahead on an annual basis will serve to secure the long-term provision of capacity. If

[20] *Investors may, of course, behave strategically by simply threatening to shut down plants, thus resulting in scarcity and higher prices.*

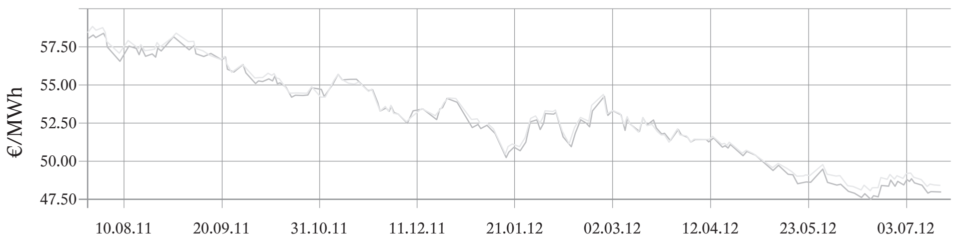


Source: own calculation

Fig. 11b: Sensitivity of variable electricity generation costs over time depending on fuel and CO_2-prices

LTC prices increase, it is a sign that capacity is becoming scarce. This, for example, may provide an incentive to "mothball" old fossil plants rather than shutting them down permanently. If LTC prices are decreasing, the opposite may happen. The closer the delivery date of contracts, the more fine-tuned will be the capacity reservation due to LTC purchasing[21]. The appealing aspect of this solution is that it works as a "voluntary capacity market".

The prices of futures contracts in Germany for the years 2013 and 2014 dropped continuously from August 2011 to July 2012 as shown in Figure 12. This can be seen as a sign that no capacity shortages are currently expected for these years.



Source: EEX (17 July 2012)

Fig. 12: Prices of futures in Germany – price base load year futures for 2013 (red) and 2014 (grey)

[21] *For instance, if good hydropower conditions are observed, less capacity will be hedged than vice versa.*

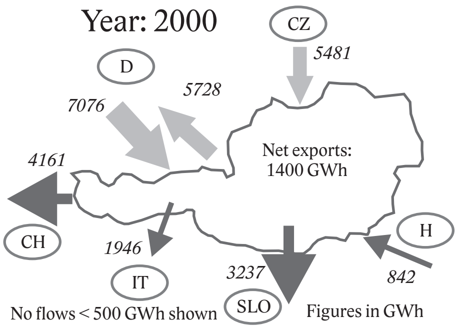
In addition to these conventional futures markets, short-term markets such as intraday and balancing markets are showing a growing relevance. In this context, it is likely that also “long” term markets for these products will emerge. Another effect will be a continuing opening and extension of balancing markets for electricity. The geographical areas for these products will become larger and, hence, more competition will take place. Such competition is likely to happen at the level of decentralised balancing organisations rather than in the current spot markets.

6.5
Changes in physical exchange patterns

Aside from the changes in the financial markets, the physical exchange patterns have also changed significantly.

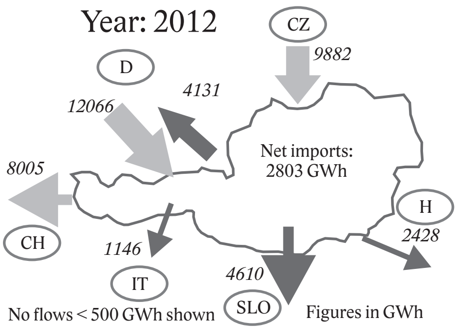
As the following graphs show, there have been considerable changes in the quantities of electricity exchanges between countries. The exchanges between Austria and its neighbour countries are depicted in Figure 13. Most impressing are the increases in imports from Germany (from 7 TWh to 12 TWh) and from the Czech Republic (from 5 TWh to 10 TWh).

In addition, an increase of almost 100% in exports to Switzerland is observed, which traditionally have gone to a very large extent to Italy (because transmission lines from Switzerland to Italy have more capacity than those from Austria to Italy).



Source: www.e-control.at

Fig. 13a: Electricity exchanges between AT and its neighbour countries in 2000 (in GWh)



Source: www.e-control.at

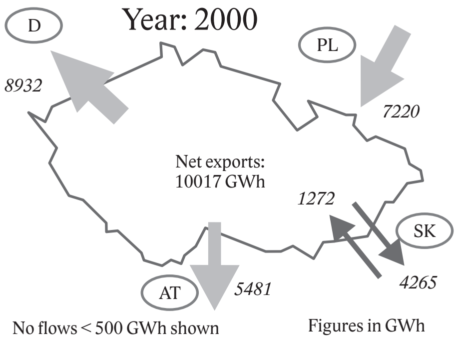
Fig. 13b: Electricity exchanges between AT and its neighbour countries in 2012 (in GWh)

Traditionally, Austria was an electricity exporting country. An amount of 1400 GWh electricity was exported in 2000. Yet, in the meantime the pattern has changed to the opposite. Since 2001, Austria has been a net importer and in 2012, the net imports were already 2803 GWh.

In the following figures, the same comparison is done for the Czech Republic. In general, the CR is a country with huge amounts of net exports. Figure 14a shows the flows in 2000. Major exports were conducted to Germany (8932 GWh) and Austria (5481 GWh). On the other hand, a remarkable quantity of 7220 GWh was imported from Poland.

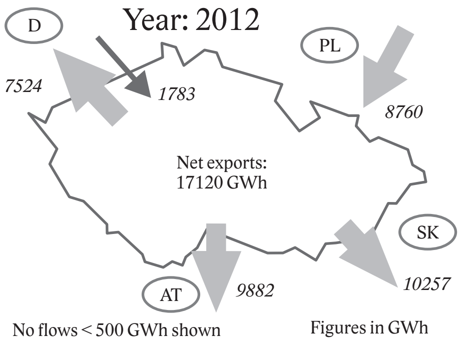
In total, a net export of 10017 GWh to other countries is observed.

From 2000 to 2012, all of these export amounts increased considerably. Exports to Slovakia skyrocketed from 4000 to 10257 GWh. In the context of this paper, it is especially worth noting that exports to Austria increased by about 80% from 5481 to 9880 GWh.



Source: www.ceps.cz

Fig. 14a: Electricity exchanges between the CR and its neighbour countries in 2000 (in GWh)



Source: www.ceps.cz

Fig. 14b: Electricity exchanges between the CR and its neighbour countries in 2012 (in GWh)

From 2000 to 2012, the net exports increased by about 70%. The quantity of export of about 17000 GWh in 2012 exceeds the production of two blocks of Temelín (gross production 15.06 TWh in 2013).

An additional feature of interest is that the net export to Germany decreased remarkably from 2000 to 2012. In 2012, there was even an import of 1780 GWh compared to exports of 7524 GWh, while the net export was about 8900 GWh in 2000.

So, while Austria, a former net electricity exporting country, became a net importer, the Czech Republic strengthened its position as a net exporting country, exporting approx. 21% of its net electricity generation (which was 81.09 TWh in 2012). Especially the exports to Austria increased significantly. From 2000 to 2012, they increased by about 80%.

6.6 Conclusions

The major conclusion of this chapter is that the electricity market and the electricity supply system of the future will look quite different than today while many of the fundamentals will remain. By and large, most of the effects of renewables are already known; what is new is that the variability of their generation will further increase if much higher quantities of wind and PV are fed into the grid, as appears to be the case for the EU.

The effects of these developments on the prices on electricity markets will be:

– much more hour-to-hour and day-to-day price volatility;
– increasing relevance of intra-day markets;
– higher prices of fossil capacities and storage technologies for balancing the intermittent renewable generation;
– growth of balancing markets and intensified competition at the level of decentralised balancing organisations; and
– probably further increase in cross-border electricity exchange.

The major conclusion of our analysis is that capacity markets are a step back towards a planned economy with – all in all – much higher costs for society. The only "negative" aspect of a market without a capacity component will be that – at least in the short run – temporarily higher costs than the short-term marginal costs will occur. However, after some time the market will learn to benefit from these higher costs and also from the very low costs at times when RES are abundant. A reasonable price spread will come about that will provide incentives for different market participants with flexibility options to benefit from these spreads.

Of course, these flexibility options will only be triggered/harvested if sufficiently high price signals from the electricity markets trigger these options, when "the exploration principle on the markets works" (Erdmann, 2012).

In this case, we think that, in addition to pure power generation capacities, other elements like smart grids, technical and economic demand-side management, and short-term storage options will even out a large part of the residual load (the difference between demand and generation from RES). Yet, this will only be done if the market is not distorted by centralised capacity payments.

Hence, in this context, the introduction of centralised capacity payments is a very big danger for ensuring competitive electricity markets in the future. In our view, they would be the death of competition, and head back towards a strictly planned economy. We think that capacity markets are solely a tool which should retain and, as far as possible, freeze the system of "old thinking" based on the old fossil/nuclear system and its advocates to retain their privileges and high salaries. So there is no need for CCP in most European countries especially now. The example of Denmark is a very good role model in this context.

If all our arguments turned out to be wrong, it would still be sufficient to introduce such a model later and to abolish the electricity markets.

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7

Modelling and Forecasting Spot Electricity Prices and Their Volatility

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Abstract

This part of the book deals with the modelling and forecasting of electricity spot prices and their volatility. Presented models are applied to day-ahead forecasts (24 hours), which is the appropriate time horizon for short-term electricity trading. The models try to describe the most important features of the electricity spot price and forecast new values of the electricity spot price using these features. Exogenous variables such as solar, wind and temperature can also be used as an input, where the correlation matrix needs to be computed to know their relevance. The first presented model is a mean-reversion one, which is then improved to a jump-diffusion model. These models are combined in a regime-switching model. The next class is the ARMA model, which uses strong patterns in spot price time series and forecasts a new value as a function of the lagged values.

These ideas are used in forecasting of the volatility of electricity spot prices. Realised measures are also used, which describe more frequent development of the time series.

For the evaluation of the benefit of the forecast, we can compare measured and forecast data (MAE criteria) or compare multiple models and measure the impact of the evaluation model and the benchmark.

Key words: spot electricity price, forecasting model, electricity price volatility

7.1 Introduction

This part focuses on forecasting of electricity spot prices and their volatility. Forecasting of electricity spot prices has been of great importance in recent years, when electricity trading has become very important for both electricity generators and consumers and the number of electricity traders and the amount of electricity traded on the energy exchanges have grown very fast.

The volatility of electricity spot prices is very strong because of the non-storability of electricity and the need for a balance between supply and demand in real time.

In recent years, the volatility has increased significantly because of the rising share of production of electricity from renewable energy sources, which are quite difficult to forecast and the errors in the forecast cause volatility increases. Prediction of spot price volatility can be used for trading as well (there are strategies based on big or small changes in the electricity prices). Volatility estimation based on high-frequency data can improve the understanding of price formulation.

The beginning of electricity price modelling and forecasting can be found in the liberalisation process in the 1990s, which led to the creation of a network of energy exchanges in European countries, the United States and elsewhere. This process generated significant volatility in wholesale electricity prices. The electricity prices were not further set by state authorities and began to be determined by the interaction between supply (generators) and demand (wholesalers, who trade with energy and ultimately sell it to customers). This led to the need for forecasting of electricity prices with maximum precision, because the profit or loss is very often connected with the accuracy of prediction.

Electricity is different from other commodities in its behaviour. The strongest features of electricity are its seasonality, which is most important in daily and weekly cycles, and its mean-reversion, which is quite specific for its quite high rate. Here, we can observe the inverse leverage effect, where positive shocks in the price series result in a larger volatility increase than negative shocks. Another important feature is the existence of high jumps, because of the non-storability of electricity and the need for a balance between supply and demand in real time.

There are numerous approaches to modelling and forecasting electricity prices. First, there are autoregressive time series models, which model the strong autocorrelation in the data and forecast future prices as a function of the weight of previous data samples. These models use the mean-reverting process of Knittel and Roberts (2005) and the jump-diffusion process of Deng (2000), Knittel and Roberts (2005), and Seifert and Homburg (2007). The modelling of the jumps can use the ACD model of Christensen et al. (2012) or high-frequency data to discern jumps in otherwise continuous price paths as proposed by Ullrich (2012).

Next are pure autoregressive models, which include the basic models AR (autoregressive model) and ARMA (autoregressive moving average model). Apart from these basic specifications, a whole range of alternative models is proposed. For example, the AR model with exogenous variables ARX or ARMAX of Misiorek et al. (2006), or the ARIMA model (autoregressions with heteroskedastic) by Contreras et al. (2007).

The second approach to modelling of electricity prices and mainly jumps in electricity prices is to use regime-switching processes with moderate and jump regimes (Weron, 2008; Bierbrauer et al., 2007) or models based on the autoregressive models such as TAR, TARX (Weron and Misiorek, 2008). Here, the probability matrix of the regime staying or changing from moderate to jumpy is used to model jumps. The disadvantage of this model is that it is quite difficult to estimate. More information can be found in Weron (2010).

So far, there has been discussion of ways of estimating electricity spot prices and jumps in electricity prices and the time-varying volatility factor of the continuous sample path variance has been used. However, as the conditional variance evolves over time, volatility forecasting and modelling have to be addressed as well.

This is done by the GARCH-type models, which work with the volatility as a feedback function and specify the conditional distribution of the next period's observation (Eangle and Sheppard, 2005). An extension of this model is the GARCH-SeaDFA (García-Martos et al., 2011).

The connection between forecasting price and volatility can be found in Hickey et al. (2012), where the volatility forecast is used for a more accurate forecast of electricity prices using the ARMAX-GARCH model.

Based on these backgrounds, models for forecasting volatility will be presented, such as the Realised (E)GARCH-type models and the EGARCH.

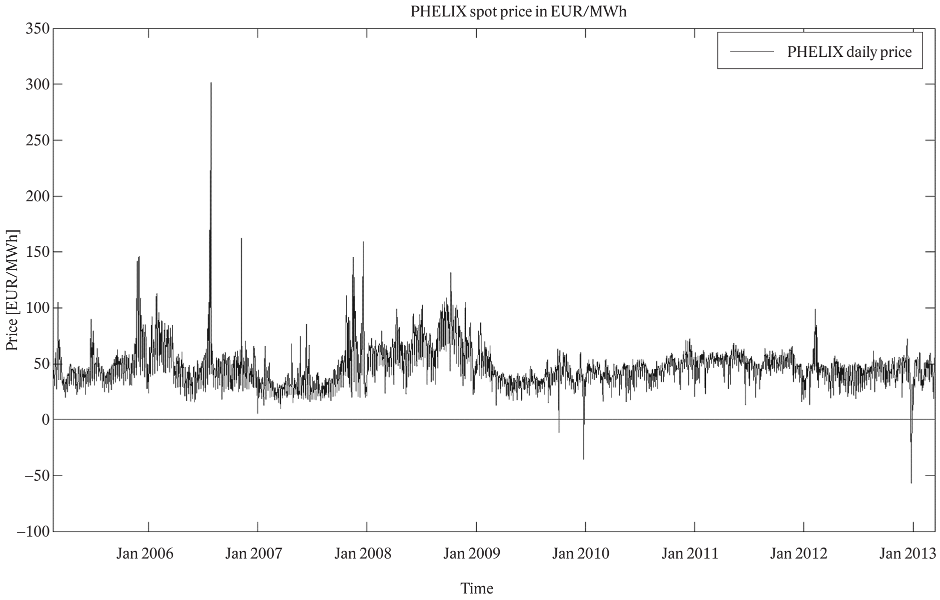
These models extend the GARCH model, which relies exclusively on daily returns for modelling the volatility. This is a shortcoming of this model for periods with volatility jumps to a new level in a short time, because this model is slow and it would take several periods for the conditional variance to 'catch up'. This shortcoming is eliminated by including realised measures in the volatility modelling, presented in the Realised (E)GARCH-type models (Hansen and Huang, 2012), as the realised measures are far more informative about the current level of volatility than the squared results. So the measurement equations tie the realised measure to the latent conditional variance, as we will show further on. These models are the state of the art in volatility forecasting and it has been proven that use of realised measures (in the form of the realised variance and the intraday range) will increase the accuracy of the day-ahead forecasting.

7.2 Data analysis

First, an analysis of the spot electricity prices data used for model estimation and forecasting of new data should be made. For describing the features of the spot electricity prices, we will use market data from the EPEX[22], specifically the Phelix spot index, which is the index for both Germany and Austria. Data are displayed from February 2005 to April 2013 (shown in Figure 1). From Figure 1, we can observe specific features of electricity prices, which are their mean-reverting behaviour and the existence of extreme price jumps. These jumps are quite large, but the duration of the jumps is very short. A jump lasts for several hours, or days at most, and after that period the price returns to its mean value, which is called mean-reverting behaviour. This behaviour can be observed in other commodities too, but the rates of the return are much lower (the changes are slower).

These spot electricity prices data can be described using own descriptive statistics such as mean, median, standard deviation, min and max values, skewness, kurtosis,

[22] *European Power Exchange, established in 2002 and based in Leipzig, Germany. This exchange was formerly known as the EEX. The EPEX operates the power markets in Germany, France, Austria and Switzerland, which accounts for more than one third of the European electricity consumption.*



Source: www.eex.com

Fig. 1: EPEX Phelix spot base index from February 2005 to April 2013

25% and 75% quintile intervals and number of negative values in the data set as shown in Table 1. From the high value of standard deviation, we can see that the prices are very volatile. The prices always fluctuate around their mean value and the behaviour of these fluctuations can be described by the random walk.

Due to the non-storability of electricity, we can observe high maximum and low minimum price values, which are caused by the balancing of the supply and demand in real time, where the price reflects the market behaviour. In case the consumption is lower than the generation, the prices are growing, and vice versa.

The data in Table 1 are divided into columns by the time period in which they are measured. There are defined data measured on weekdays, weekends, in spring, summer, autumn, winter and on German holidays. From the table, we can see that the descriptive statistics differ in each column. This is caused by the patterns and the seasonality, which can be observed in electricity prices and is caused mainly by different consumption in the time intervals. These patterns can be defined as intraday, where the spot price is different in every hour, but the same evolution trend occurs every day. Next is the weekday vs. weekend pattern, where the prices measured on weekdays are higher than the prices measured at the weekend. The last pattern is called seasonality, where the prices are different in each season. All these patterns are displayed in Figures 2 and 3.

	Full sample	Weekday	Weekend	Spring	Summer	Autumn	Winter	Holiday
Observations	2951	2109	842	750	736	728	737	71
Mean	47.34	51.58	36.70	43.17	45.54	52.40	48.36	26.55
Median	45.50	48.92	36.18	41.61	43.54	50.15	47.42	27.87
Std Dev	18.13	18.48	11.79	14.14	19.13	19.70	17.83	18.99
Min	−56.87	−56.87	−35.57	9.93	13.63	−11.59	−56.87	−56.87
Max	301.54	301.54	82.82	104.60	301.54	162.25	158.97	71.37
Skew	2.21	2.56	0.10	0.65	4.86	1.81	0.15	−2.15
Kurt	22.47	25.81	4.97	3.75	55.74	8.19	8.07	10.85
25%	36.51	40.90	28.46	33.52	35.29	41.10	37.49	21.15
75%	54.75	57.79	43.90	51.39	50.94	56.74	57.85	34.98
Negative	4	2	2	0	0	1	3	3

Tab. 1: Summary statistics for the Phelix daily price data from February 2005 to April 2013, EUR/MWh. Source: own calculations

7.2.1 Stochastic and deterministic part estimation

As the features of spot electricity prices can be expressed by both stochastic (unpredictable occurrence of price jumps, high volatility) and deterministic (patterns and trends) descriptions, the original electricity spot price data should be split up into two parts too. These parts will be called deterministic and stochastic.

The deterministic part of the data DP_t expresses at which hour of the day, on which day of the week (if a weekday or weekend), in which season of the year the electricity spot price is measured. Additional information is whether the day is a holiday or not, as it has a significant impact on the value of the electricity spot price. The value of the deterministic part is estimated as follows:

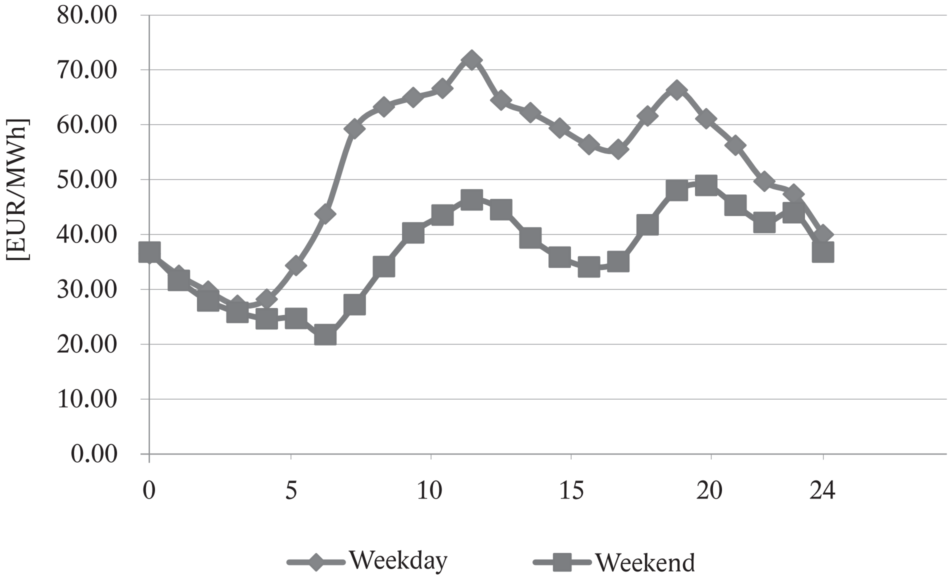
$$DP_t = \alpha_0 + \alpha_1 I_t^{\text{Hour}} + \alpha_2 I_t^{\text{Weekend}} + \alpha_3 I_t^{\text{Holiday}} + \alpha_4 I_t^{\text{Spring}} + \alpha_5 I_t^{\text{Autumn}} + \alpha_6 I_t^{\text{Winter}} \quad (1)$$

where I_t^{Weekend} is the indicator function, which has the value of one in the case that the day t is at the weekend, and zero otherwise. I_t^{Holiday}, I_t^{Spring}, I_t^{Autumn} and I_t^{Winter} have the same definition for holiday, spring, autumn and winter.

After defining the deterministic part, the stochastic part can be defined as the difference between the original spot price and the deterministic part:

$$\varepsilon_t = y_t - DP_t \quad (2)$$

The stochastic part is marked ε_t , because it expresses the error of the expected electricity spot price. In the rest of this chapter, the forecasting of electricity spot



Source: own calculations

Fig. 2: Representation of the intraday and weekday vs. weekend pattern of spot electricity prices

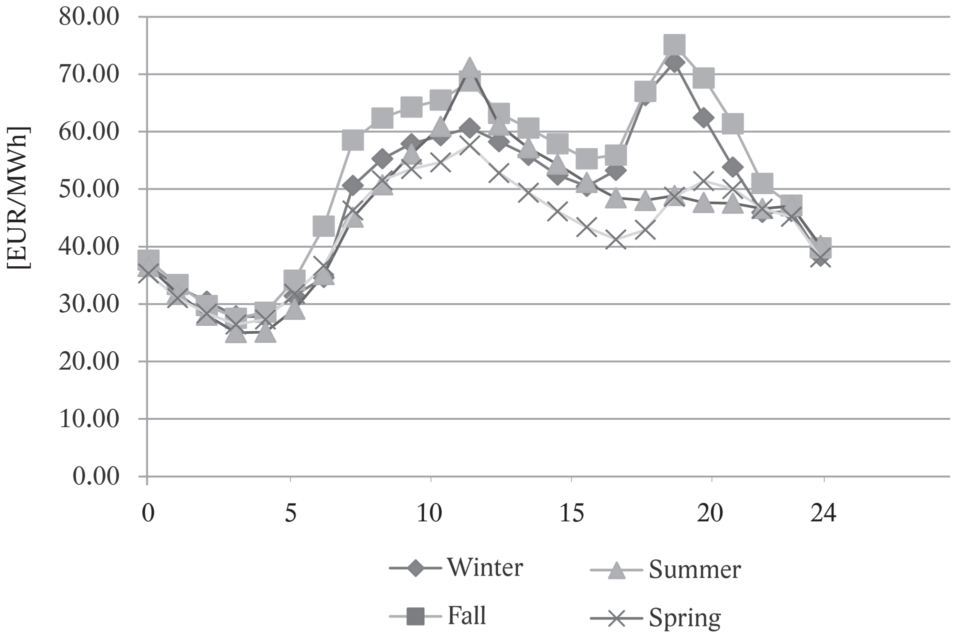
prices will only use the forecasting of the stochastic part, which will be summed at the end with the deterministic part to get the final electricity spot price.

7.2.2 Exogenous variables

Exogenous variables can be used to add new information about spot price development. These variables are very important for the price setting mechanism, because they describe the market conditions, which influence the realised price. Relevant exogenous variables can be:

- consumption (describes the electricity demand);
- temperatures (measured in the operating area of the exchange), which have an impact on the electricity consumption;
- wind power (measured in the area of the location of wind power plants);
- solar power (measured in the area of the location of photovoltaic power plants); and
- cross-border power flows (describing the situation between neighbouring power markets).

These data should, by their definition, increase the accuracy of the electricity spot price forecasting, but there is a need to compute the correlations between these exogenous variables and the stochastic part of the spot price to decide about the relevance of using these exogenous variables.



Source: own calculations

Fig. 3: Representation of the seasonality of spot electricity prices

7.3 Electricity spot price forecasting

Methods and models of forecasting electricity spot prices will be presented in this part. These models try to capture such specific features of the spot electricity price as mean-reversion, jump occurrence, patterns and seasonality, and forecast new values based on this information.

7.3.1 Mean-reversion model

This model has been widely used recently by both electricity traders and electricity producers. It is a basic model, which is simple to understand, simple for estimating the parameters, and easy to use. The reason for using this model is that electricity prices tend to return quickly to their mean value. The model is based on Brownian motion, but improves that approach with a mean-reversion component. The model can be described as follows:

$$\mathrm{d}Y_t = \gamma(\mu - Y_t)\mathrm{d}t + \sigma \mathrm{d}W_t, \quad t \geq 0 \tag{3}$$

where $(Y_t)_{t\geq 0}$ is the stochastic part of the price, $(W_t)_{t\geq 0}$ is the Brownian motion (Wiener process), γ is the rate of the mean-reversion (the rate of returning to its mean value), μ indicates long-term mean, and σ indicates volatility.

After an analysis of the equation, it can be seen that it consists of two components. The first one represents the return to the mean value (after a lower or higher value caused by jumps or volatility fluctuation), where the rate of the return is expressed by γ. This variable must be large enough to ensure a sufficiently rapid return to the mean, which is specific for electricity. The second component models the oscillation of electricity prices.

The shortcoming of this model is the impossibility of jump forecasting, which should be included in this model. This shortcoming can be eliminated by extending the mean-reversion model to a jump-diffusion model.

7.3.2
Jump-diffusion model

As said in the previous paragraph, the jump-diffusion model is a modification of the mean-reversion model. In addition to components that return to the mean and model the volatility, it has a third component, called the jump component. It is created by the Poisson distribution, which models the probability of occurrence of a jump, multiplied by the height of the jump. Thanks to this component, the jump-diffusion model can better model the evolution of the spot price of electricity. It adapts better to the natural behaviour of the electricity market, where jumps occur quite often and have to be included in the model. The model can be described as follows:

$$\mathrm{d}Y_t = \gamma(\mu - Y_t)\mathrm{d}t + \sigma \mathrm{d}W_t + q\mathrm{d}N_t, \quad t \geq 0 \tag{4}$$

where $(Y_t)_{t\geq 0}$, $(W_t)_{t\geq 0}$ and γ, μ, σ retain the same definition as earlier, and $(N_t)_{t\geq 0}$ is a homogeneous Poisson process. The height of a jump q has a log-normal distribution with a mean ν and a variance τ^2.

This model forecasts both the mean-reversion part and the jumps separately. To get the parameters of the Poisson process, there is a need to detect the jumps from the stochastic data. Two possible approaches will be presented here.

The first is to define a threshold, determining that prices with a value larger than this threshold are classified as jumps and prices with a lower value are classified as the normal behaviour. Another threshold should be set for negative jumps. However, this approach is inefficient due to the changing mean value of the spot electricity price.

This approach can be improved by defining a threshold of the price changes between neighbour values. The price changes are defined as follows:

$$r_t = y_t - y_{t-1}, \quad t = 1, \ldots, T \tag{5}$$

where r_t is the price change and y_t is the stochastic part of the price at the time t.

This threshold can be defined as 95% of the price changes. This approach can detect all the extreme positive and negative values and classify them as jumps.

7.3.3 Autoregressive model

This model is somewhat similar to the mean-reverting model in that it forecasts new values based on the previous values. The shortcoming of the mean-reverting model is that it uses only one lagged value, which is not enough, because of the strong patterns and seasonality of the spot electricity prices. It is proven by the correlation analysis that all the 24 lagged values are worth being used in the forecasting. The most commonly used model from the autoregressive branch of models will be presented in this chapter. it is the ARMA model, which can be split into two parts (both parts can be used separately as well).

AR

In this part, a new spot price value is forecast using the lagged historical spot price values. There is an assumption that the new price is influenced by the latent prices. This idea can be described with the following equation:

$$Y_t = c + \sum_{i=1}^{p} \alpha_i Y_{t-i} + \varepsilon_t \tag{6}$$

where Y_t is the spot price at the time t, c is a constant and ε_t indicates the error term. It can be seen from the equation that the actual value depends on the p lagged values. But that cannot be assumed so easily. The analysis of the data proved that the prices in the last 24 hours and the prices lagged by days in the last seven days have the biggest impact so the p will be:

$$p = 1, 2, \ldots, 24, 48, 72, 96, 120, 144, 176 \tag{7}$$

AM

This part of the model indicates that the price is not influenced only by its own lagged values, but also depends on the last error terms (errors in the forecast). This can be expressed in the equation as follows:

$$Y_t = \mu + \sum_{i=1}^{q} \beta_i \varepsilon_{t-i} \tag{8}$$

where μ is a constant. The forecast accuracy again depends on the choice of lagged values of the error terms q. The values of the q can be set the same as p.

By combining these two parts, we will get the ARMA (p,q) model, where the (p,q) describes the typology of the lagged values used, described as follows:

$$Y_z = c + \sum_{i=1}^{p} \alpha_i Y_{t-i} + \sum_{i=1}^{q} \beta_i \varepsilon_{t-i} \sum_{i=1}^{b} \gamma_i X_{t,i} + \varepsilon_t \tag{9}$$

where $X_{t,i}$ is a vector of the exogenous variables.

With this model, we can conclude the section on the stochastic and autoregressive models and move on to the regime-switching models.

7.3.4 Regime-switching model

The advantage of a regime-switching model is that it consists of two (or three) separate components (modes), each of which has a different process. An observed jump can be explained by a transition to another mode. The switching model is usually assumed to follow a time-homogeneous hidden Markov chain (see Cipra, 2008) with $k \in N$ possible modes representing k states of the system. The advantage of separation of modelling into different modes is that we can model each regime (for example jumps and base stochastic regime) separately and use different processes and different values of variables in these processes (such as mean-reversion rate, standard deviation, volatility). Here, we present regime-switching models with two and three independent states.

7.3.5 Regime-switching model with two independent states

A regime-switching model with two independent states distinguishes between a base mode ($R_t = 1$) and a jump mode ($R_t = 2$), where $(R_t)_{t\in T}$ represents a time-homogeneous hidden Markov chain. An observable stochastic process $(Y_t)_{t\in T}$ is now represented in a form $Y_t = Y_{t,R_t}$, $t \in T$, where the processes $(Y_{t,1})_{t\in T}$ and $(Y_{t,2})_{t\in T}$ are mutually independent. $Y_{t,i}$ expresses the current regime i at the time t. Transitions between modes can be described by the transition matrix π of the hidden Markov chain, which contains the probability $p_{i,j}$ of switching from regime i at the time t to mode j at the time $t+1$:

$$\pi = (p_{i,j})_{i,j=1,2} = (P(R_{t+1} = j|R_t = i))_{i,j=1,2} = \begin{pmatrix} p_{11} & 1-p_{11} \\ 1-p_{22} & p_{22} \end{pmatrix} \tag{10}$$

Finally, processes $Y_{t,1}$ and $X_{t,2}$ will be specified. Taking into account the typical behaviour of spot electricity prices, it seems reasonable to use the mean-reversion or maybe better the autoregressive process (model) as the base mode ($R_t = 1$). For the jump mode ($R_t = 2$), it is difficult to assign the appropriate process. I will assign it an independent, identically-distributed realisation probability distribution F, for which log-normal distribution is the best candidate.

As a result, the following two stochastic processes will be considered for the base mode (first equation) and for the jump mode (second equation).

$$Y_{t,1} = c + \alpha Y_{t-p,1} + \beta \varepsilon_{t-q}, \quad t \in N \tag{11}$$

$$Y_{t,2} \approx F, \quad t \in N \tag{12}$$

7.3.6
Regime-switching model with three independent states

This model is based on the previous model with two independent states. The difference is in the number of states. As mentioned above, the price jumps have a very short duration and after the occurrence of a jump (both positive and negative), there is a high probability of a reverse jump to return to the mean price level. So the states which will be used are: (1) the base mode ($R_t = 1$), for modelling the mean stochastic process of electricity prices, (2) the initial jump mode ($R_t = 2$), for modelling a sudden increase or decrease in the prices, and (3) the reverse jump mode ($R_t = 3$), for describing the return of the prices to a normal level after the occurrence of a jump in the reverse jump mode, in order not to remain in the jump mode. The process can be described by the mean-reversion or autoregressive process in the base mode and by the Poisson process in both the initial mode and the reverse jump mode, where the direction of the initial jump process is opposite to the reverse jump. The description of the processes will be:

$$Y_t = \begin{cases} c + \alpha Y_{t-p,1} + \beta \varepsilon_{t-q}, & R_t = 1 \text{ (normal)} \\ Y_{t-1} + \xi_t, & R_t = 1 \text{ (inial jump)} \\ Y_{t-1} - \xi_t, & R_t = 3 \text{ (reverse jump)} \end{cases} \quad (13)$$

Where $\varepsilon \sim N(0, \sigma^2)$ represents an innovation in the base mode and $\xi_t \sim N(\nu, \tau^2)$ represents an innovation in the jump modes, which are the price jumps. Of course, log-normal distribution of the jump modes can be replaced with another alternative distribution.

After defining this model, we can move on to forecast the volatility.

7.4
Electricity spot price volatility forecasting

In this part, we will focus on spot price volatility forecasting. As mentioned in the introduction, volatility forecasting is very important for both trade speculations and hedging purposes. Here we will present GARCH-type models. The EGARCH model is nowadays the most frequently used model for forecasting volatility. This model will then be extended by incorporating the realised measures in the forms of realised GARCH and realised EGARCH models. It has been proven that using realised measures improves the accuracy achieved in volatility forecasting.

7.4.1
EGARCH

This model was described by Nelson (1991) and can be defined in the EGARCH (p, q) form, where p is the number of its own lagged values used for forecasting and q is the number of lagged standard innovations used in the leverage function. So the EGARCH (1,1) can be described as follows:

$$\varepsilon_t = \sqrt{h_t z_t} \tag{14}$$

$$\log h_t = \omega + \beta \log h_{t-1} + \tau(z_{t-1}) \tag{15}$$

where ε_t follows IID(0, h_t), h_t is the latent conditional variance on the day t, z_{t-1} is the lagged standardised innovation, which follows IID(0, 1), and the leverage function, $\tau(\cdot)$, is given by $\tau(z_{t-1}) \equiv \tau_1 z_{t-1} + \tau_2(|z_{t-1}| - E|z_{t-1}|)$. According to the literature, the first equation will be called a mean equation and the second one, a variance (conditional) equation. The mean equation describes the setting of the volatility value based on the latent conditional variance and the standard innovation. The variance equation describes the transition of the latent conditional variance from the period $t-1$ to the period t based on the lagged latent conditional variance and the leverage function of the lagged standard innovation.

7.4.2 Realised measures

As mentioned in the introduction, intraday measures describing the price development during the day and add information about extreme price changes can be used for forecasting daily volatility. For this purpose, we will propose the use of two realised measures: realised variance and intraday range.

Realised variance

This variable can be described as the sum of the squared price changes as follows:

$$RV_t = \sum_{j=1}^{M} r_{t,j}^2 \tag{16}$$

$$r_{t,j} = y_{t,j} - y_{t,j-1}, \quad j = 1,\ldots,24, \quad t = 1,\ldots,T \tag{17}$$

where $r_{t,j}$ is the stochastic price change from intraday period $j-1$ to j on the day t, while $y_{t,j}$ is the stochastic price at the hour j on the day t.

Intraday range

The intraday range is defined as the squared difference between maximum and minimum values within the day as follows:

$$IR_t = (\max_j y_{t,j} - \min_j y_{t,j})^2, \quad j = 1,\ldots,M, \quad t = 1,\ldots T \tag{18}$$

where $\max_j y_{t,j}$ and $\min_j y_{t,j}$ denote the maximum and the minimum price within the day, respectively.

After defining these realised measures, we will introduce the realised GARCH and realised EGARCH models.

7.4.3 Realised GARCH

By incorporating realised measures, the variance equation can be extended and a new measurement equation can be created. So the Realised GARCH(1,1) can be described as follows:

$$\varepsilon_t = \sqrt{h_t z_t} \quad (19)$$

$$\log h_t = \omega + \beta \log h_{t-1} + \gamma \log x_{t-1} \quad (20)$$

$$\log x_t = \xi + \varphi \log h_t + \delta(z_t) + u_t \quad (21)$$

where ε_t, h_t and z_t have the same definitions as in the EGARCH model. x_t is the realised measure (such as intraday range or realised variance), the leverage function $\delta(\cdot)$ is given by $\delta(z_t) \equiv \delta_1 z_t + \delta_2(z_t^2 - 1)$, and the measurement error u_t follows IID(0, σ_u^2). These equations will be called the mean, variance and measurement equations.

7.4.4 Realised EGARCH

This model extends the Realised GARCH(1,1). The Realised EGARCH(1,1) model can be described as follows:

$$\varepsilon_t = \sqrt{h_t z_t} \quad (22)$$

$$\log h_t = \omega + \beta \log h_{t-1} + \tau(z_{t-1}) + \gamma' u_{t-1} \quad (23)$$

$$\log x_{k,t} = \xi_k + \varphi_k \log h_t + \delta_k(z_t) + u_{k,t} \quad k = 1, \ldots, K \quad (24)$$

where ε_t, h_t, z_t, and x_t have the same definitions as in the Realised GARCH model. The vector of measurement error $u_t = (u_{1,t}, \ldots, u_{K,t})'$ follows IID(0,Σ). The leverage functions, $\tau(\cdot)$ and $\delta_{k=1,\ldots,K}(\cdot)$, are given by $\tau(z_t) \equiv \tau_1 z_t + \tau_2(z_t^2 - 1)$ and $\delta_k(z_t) = \delta_{k,1} z_t + \delta_{k,2}(z_t^2 - 1)$, respectively. The equations are again called the mean, variance and measurement equations. The main difference is that now the leverage function $\tau(\cdot)$ enters directly into the variance equation. So now the current level of the latent volatility is driven by its own lagged value ($\beta \log h_{t-1}$), the asymmetric shock (leverage function) from the prior period ($\tau(z_{t-1})$), and the multiple volatility indicators of realised measures ($\gamma' u_{t-1}$), which give information on how informative the realised measures are about future volatility.

So far, we have defined models for both spot electricity prices and spot electricity price volatility forecasting, and at the end of this chapter it remains to define the criteria and methods that can be used for evaluation of the forecast accuracy and comparison of the different models.

7.5 Evaluation of achieved accuracy

First, we will present the criteria that measure the error of the forecast. All these criteria measure the difference between measured yi and forecasted fi values. These criteria are:

MAE (Mean absolute error): MAE = $\frac{1}{n}\sum_{i=1}^{n}|y_i - f_i|$

MSE (Mean squared error): MSE = $\frac{1}{n}\sum_{i=1}^{n}(y_i - f_i)^2$

MALE (Mean absolute logarithmic error): MALE = $\frac{1}{n}\sum_{i=1}^{n}|\log y_i - \log f_i|$

MAPE (Mean absolute percentage error): MAPE = $\frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - f_i|}{|y_i|}$

All the criteria can also be used with median instead of mean. The median based criteria are signed as **MdAE, MdSE, MdALE** and **MdAPE.**

For the expression of the impact of the examined model on the resulting values compared with the benchmark model, we can use the following equation:

$$Y_{t+1} = \alpha + \beta_1 f_{t+1}^{\text{Examined model}} + \beta_2 f_{t+1}^{\text{Benchmark}} + \varepsilon_{t+1} \tag{25}$$

where $\log Y_{t+1}$ is the measured value of the electricity spot price (or volatility) at the time $t+1$, which is forecast, $f_{t+1}^{\text{Examined model}}$ is the forecast made by the examined model for the time $t+1$, $f_{t+1}^{\text{Benchmark}}$ is the forecast made by the benchmark model for the time $t+1$ and ε_{t+1} is the error of the forecast for the time $t+1$. The comparison of both of the models is measured by the criteria β_1 and β_2 criteria, where a higher value indicates a higher impact while forecasting the electricity spot price or volatility.

The next step is to find out whether the model forecast is in the 95% confidence interval, which is measured by the envelope method presented by Moller and Waagepetersen (2004).

The envelope method involves repeating predictions of new values to get 39 samples. From the samples, the maximum and minimum values are chosen for each day, which form the envelope. If newly predicted data occur between the envelopes, it can be said that a two-sided 95% confidence interval is reached.

7.6 Conclusion

In this chapter, we analysed the spot electricity price by its most important descriptive statistics. The very important patterns such as intraday, weekday vs. weekend and seasonality were detected. On the basis of these patterns, the original spot price was split into a deterministic part, describing all the periodic patterns, and the stochastic part, modelling the random behaviour of the spot electricity price. This part was then modelled and forecast using a mean-reversion model, which was then improved to a jump-diffusion model. The data were then split into the jumps (very quick and high changes in the price) and the classic volatile behaviour. The jumps were modelled using the Poisson process with a log-normal distribution and the mean-reversion process, modelling the standard behaviour of the stochastic part of the spot data was replaced with an autoregressive model, which consists of the AR and the AM parts. This model gave us the best results in the field of the stochastic spot price modelling. At the end of the spot electricity price modelling part, we introduced a regime-switching model, using multiple regimes for describing jumps and the normal behaviour data separately. The occurrence of a price jump is described as a change in the regime from the base (normal regime) to jump regimes (positive or negative) using a transition probability matrix.

For modelling the volatility of the spot price, we introduced the basic EGARCH model, widely used by market participants. This model was then improved by using realised variables, which give us additional information about intraday spot price development while forecasting the daily volatility. These models are the Realised GARCH-type models, which outperform the benchmarking EGARCH model and give the best results.

We then introduced several methods for comparison of the forecast accuracy. The first group are methods taking the difference between forecast and realised spot prices and counting some descriptive statistics such as mean average error, mean squared error, etc. The next method compares the impacts of the examined model and the benchmark model and, on the basis of these impacts, concludes the quality of the forecast. The last method is the envelope method, which tries to find out whether the forecast values lie in the 95% confidence interval.

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8

Economic Evaluation of Energy Storage Using the Power Deviation Prices – the Load Diagram Pricing Method

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Abstract

The issue of evaluation of energy storage systems is currently a widely discussed topic. However, the economic evaluation methodology using load diagram pricing has not yet been satisfactorily resolved. There are several methods that can be used and we have chosen the approach using the deviation prices and energy exchange products. Our optimisation method uses previously mentioned products and is simplified to be feasible to complete calculations with standard hardware and commonly available spreadsheets. Detailed analyses of probabilities of electricity system deviations in the Czech Republic were conducted and resulted in the development of a stochastic model used for deviation/counter-deviation pricing. Finally, we verified our pricing model on a case study of battery energy storage in combination with photovoltaic power plants. The preliminary results show that, under current electricity market conditions, the economic benefits from energy storage cannot cover even the operating costs of the storage system. Therefore, several measures that could improve the economic balance of storage systems are suggested.

Key words: power deviation price, load diagram pricing method, energy storage, intermittent renewables

8.1 Introduction

An EU decision made in 2007 (European Commission, 2005 and 2009) set an overall compulsory target of 20% for RES generation for the whole of Europe. This overall target was then redistributed among all member states via national targets. This act caused a significant promotion of renewable sources, in particularly the intermittent RES, i.e., wind and solar power generation. However, the very nature of those intermittent sources is a limiting factor for their higher penetration using the current design of transmission and distribution grids. These sources are not fully controllable and they cannot be fully predicted. Because of these features, new mechanisms of power grid control are being developed. One of them is the utilisation of energy storage that can provide a balancing between the energy demand and the volatility of generation from RES.

Energy storage is an emerging field of study with various possible technical solutions that can provide numerous services for the transmission and distribution grid. However, a question comes hand in hand with the technical solution: what are the economic benefits of energy storage implementation? In the following, text we would like to propose one approach leading to a methodology for economic evaluation of energy storage.

8.2 Methodology

The main idea of our methodology is based on load diagram pricing. An electric load diagram can be valuated by several methods:

- The marginal cost method is suitable for finding a price of a diagram from the system point of view. The diagram is covered by the use of new energy sources, including an electric accumulation device.
- The second approach to diagram pricing is the cost-of-the-sources method. This method is appropriate for internal valuation within companies. Companies and their owners can control and manage the sources, and all the costs including opportunity costs, are known precisely. It is very complicated to get such data for external subjects so we will not use this method later in this text.
- For our purposes, use of public markets is the most suitable method. We can use prices from public markets. If the diagram is very small compared to the overall diagram of the market and the electricity system, there are many competitors on the market and prices from the market can be used for the diagram pricing. This small source cannot influence any price on the market; this approach is especially suitable for renewable energy sources.

The main principle of diagram pricing is the maximisation of production. The source operators plan and manage the source production in such a way that the revenues from the electricity sold are as big as possible. Perfect covering of the diagram is not possible in practice and some imbalances between the load diagram of the source and the products offered on the market occur. These imbalances decrease the value of the diagram because they have to be balanced. The source has to pay for both positive and negative imbalances. In some cases when the source helps the electricity system to balance the total imbalance of the system, some payment can be received. When the source uses an accumulation device, this device can be used to increase the value of the diagram as the accumulator is charged at a time when the price is low and discharged when the price is high. It is therefore obvious that for this

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method we need not only prices of electricity but also prices of the imbalances for the given area/country.

8.2.1 Optimisation model

The main energy market in the Czech Republic is the PXE. Several so-called "products" are offered on this market: annual, quarterly and monthly products in two variants, base and peak. The peak product represents electricity supply from 8 am to 8 pm from Monday to Friday. An optimisation model was created to cover the diagram by these products and it is a follow-up research to Knápek et al. (2009). Our diagram is defined for 52 weeks a year, i.e., 364 days or 8736 hours a year. The main criterion function for the electricity valuation is:

$$\sum_{t=1}^{8736}\left(\begin{array}{l} p_{ab}P_{ab}+p_{ap}P_{ap}+p_{qb,t}P_{qb,t}+p_{qp,t}P_{qp,t}+p_{mb,t}P_{mb,t}+p_{mp,t}P_{mp,t}+ \\ -p_{\Delta-,t}P_{\Delta-,t}-p_{\Delta+,t}P_{\Delta+,t} \end{array}\right)=\mathrm{MAX} \tag{1}$$

where

$p_{ij,t}$ price of the PXE product, the first subscript determines the period of the product validity (annual, quarterly, monthly), the second subscript indicates base or peak product, t is the number of hours within the year [CZK/MWh]

$P_{ij,t}$ electric power at the hour t of the year; other subscripts are the same as for $p_{ij,t}$ [MW]

$p_{\Delta\pm,t}$ price of positive/negative imbalance at the hour t [CZK/MWh]

$P_{\Delta\pm,t}$ power imbalance at the hour t [MW]

A planned production load diagram is the main constraint for the model:

$$\begin{array}{l} \forall t\in\{1,2,\ldots,8736\} \\ P_{ab}+P_{ap}+P_{qb,t}+P_{qp,t}+P_{mb,t}+P_{mp,t}+P_{\Delta-,t}-P_{\Delta+,t}=P_{\mathrm{diag},t} \end{array} \tag{2}$$

where

$P_{\mathrm{diag},t}$ planned power at the hour t [MW]

At the first sight, the model is very simple but the process of finding the solution can be very long because the number of variables is very large. The number of variables in the model is 52,450. It is obvious that the solution to the model has to be found using automatic calculation. We have another rule too: there is either a positive or negative imbalance in each hour or both in one hour. Such imbalance decreases the value of the criterion function so the imbalance in the hour has to be minimised.

The crucial issue in the model is forecasting of future prices on public markets. The volatility of these prices is very high and depends on other energy markets for crude oil, natural gas and coal. The change of prices within one year could be 30% under the current conditions and this volatility cannot be influenced by the source at all. Deviations in the production of the source are another kind of uncertainty. However, this uncertainty can be influenced in the planning process by the experience of the personnel but the planning is still threatened by the extreme fluctuation of weather.

Unplanned imbalances are valuated on a spot market organised by OTE. The volatility of these prices is high as well as that of the prices at the PXE. There is one advantage: the ancillary services covering the imbalances are traded in the long-term so the resulting price is an average over a period of time.

The value of the diagram of a source with an accumulating device and without it can be calculated as the difference between the value of the load diagram with an accumulator and without it. If the accumulator is efficient enough, payments for imbalances decrease and the value of this diagram increases. Another increase in the diagram value is caused by the decrease in the risk, i.e., the volatility of the diagram.

Another approach to the exploitation of an accumulating device is to make some profit on the short-term market. The main condition of success is to forecast the period when the electricity price will be higher than the currently expected price and the periods when the low price will be suitable for accumulator charging. Such an approach is quite risky because it expects that the source personnel will be able to "win" the market. That is the reason why we have decided to use the accumulator to minimise the total amount of imbalances only. This manner of accumulator use is always possible as it decreases the volatility of the load diagram, such sources are more valuable for the whole electricity system, and it will be achievable in the future as well.

8.2.2 Model for energy storage evaluation

The model described above is quite complex, the number of variables is high and special computer tools have to be used for solving this problem. We decided to use a two-step approach to simplify the solution finding. The load diagram is covered by a PXE product in the first step, the value of products is maximised but the imbalances are penalised in all the cases so they are kept at a low level. The accumulator device charging and discharging is solved in the subsequent step. The total value of the production will be higher if the volume of imbalances is lower. If the accumulator is used in a daily cycle, so that the charging and discharging energy is balanced within the day, the task with 17,472 variables can be separated into tasks with 48 variables (charging/discharging power in 24 hours). The daily optimisation of the accumulator can be described by the equation:

$$\sum_{t=1}^{24} (p_{\Delta-,t} P_{A,\Delta-,t} + p_{\Delta+,t} P_{A,\Delta+,t}) = \mathrm{MIN} \tag{3}$$

where

$P_{A,\Delta-,t}$ imbalance with accumulator use – discharging [MWh]
$P_{A,\Delta+,t}$ imbalance with accumulator use – charging [MWh]
$p_{\Delta+,t}$ price of positive imbalance at the hour t [CZK/MWh]
$p_{\Delta-,t}$ price of negative imbalance at the hour t [CZK/MWh]

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The criterion function is minimised as the payments for imbalances are included in it and these imbalances are decreased by an accumulator device operation. The larger the exploitation of the device, the higher the value of the load diagram. New imbalances are calculated as:

$$\begin{aligned} P_{A,\Delta-,t} &= P_{\Delta-,t} - P_{A-,t} \\ P_{A,\Delta+,t} &= P_{\Delta+,t} - P_{A+,t} \end{aligned} \tag{4}$$

where
$P_{A-,t}$ discharging power at the hour t [MW]
$P_{A+,t}$ charging power at the hour t [MW]

The charging and discharging process has to be balanced within one day:

$$\sum_{t=1}^{24} P_{A-,t} - \sum_{t=1}^{24} P_{A+,t} = 0 \tag{5}$$

There are some limitations to the accumulator device as well. The accumulator cannot be discharged to a negative amount of energy.

$$\begin{aligned} & t \in \{1\} \\ & E_{A,1} = E_{\text{start}} + P_{A+,1} - P_{A-,1} \geq 0 \\ & \forall t \in \{2,\ldots,24\} \\ & E_{A,t} = E_{A,t-1} + P_{A+,t} - P_{A-,t} \geq 0 \end{aligned} \tag{6}$$

where $E_{A,t}$ energy stored in an accumulator at the time t [MWh]
$E_{A,t-1}$ energy stored in an accumulator at the time $t-1$ [MWh]

The total capacity of an accumulator $E_{A\text{total}}$ must not be exceeded; the initial value of energy stored is E_{start}:

$$\begin{aligned} & t \in \{1\} \\ & E_{A,1} = E_{\text{start}} + P_{A+,1} - P_{A-,1} \leq E_{A\text{total}} \\ & \forall t \in \{2,\ldots,24\} \\ & E_{A,t} = E_{A,t-1} + P_{A+,t} - P_{A-,t} \leq E_{A\text{total}} \end{aligned} \tag{7}$$

Imbalances after accumulator device use and variables are restricted to:

$$\begin{gathered} \forall t \in \{1,\ldots,24\} \\ P_{A,o+,t} \geq 0 \\ P_{A,o-,t} \geq 0 \\ P_{A+,t} \geq 0 \\ P_{A-,t} \geq 0 \end{gathered} \tag{8}$$

All the variables are positive, so a linear model can be used for optimisation.

8.3
Calculations and Results – Czech case study

Before the actual calculation of economic benefits of any storage device, the valuation of imbalances pricing is needed. For our purposes, we have focused on the Czech case so that we can identify not only the proper values (prices) but also a general approach for how to find them.

8.3.1
Valuation of diagram imbalances

The system of penalties and bonuses used now in the CR is summarised in Figure 1. This system is based on the principle that the producer of electricity is penalised for the total system imbalance increase, i.e., the power of the source exceeds the planned diagram when there is an excess of power in the system or the source generates less than is planned in the case of a lack of power in the system.

The inverse situation occurs when the power source helps the system to set up the balance, i.e., the production is above the planned supply in the case of a lack of power in the system and, reversely, the source generates less power when there is an excess of power in the system.

Imbalance		**System**	
		+	−
Power source	+	Penalisation/imbalance	Bonus/counter-imbalance
	−	Bonus/counter-imbalance	Penalisation/imbalance

Fig. 1: System of payments for imbalances

This system has been in use in the Czech Republic by OTE since 2010[23]. Data accessible from the OTE database where analysed, and a probability analysis of imbalances was made in the first phase. The result is presented in the following figures, where the probabilities of an imbalance occurrence at the particular hour of the day are shown.

[23] *OTE organizes spot market with electricity: day/a/head and intraday markets.*

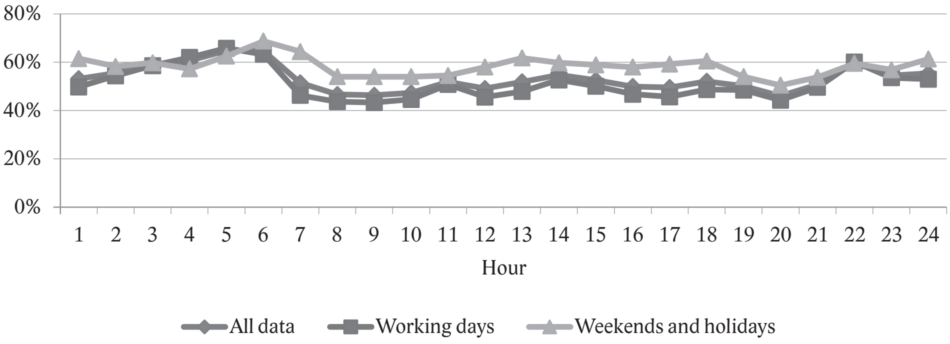

Fig. 2: Positive system imbalance probability – calculated based on OTE (2014)

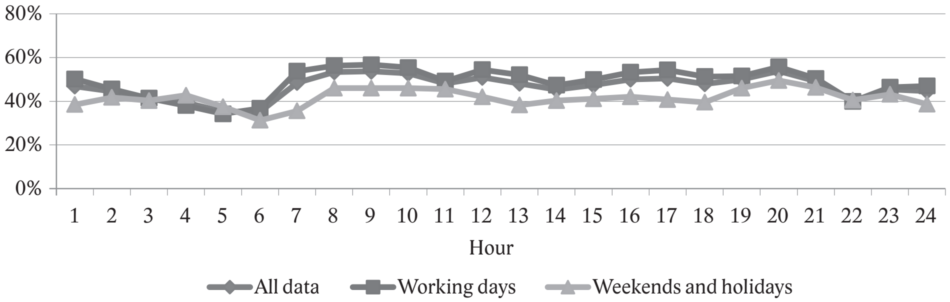

Fig. 3: Negative system imbalance probability – calculated based on OTE (2014)

It is obvious that there is no substantial difference in the probability of positive/negative imbalances in the period of a day. Also the difference in the probabilities between working days and weekends/holidays is insignificant from our point of view. Therefore, as a conclusion, the summarised data will be used for later calculations without other segmentation.

The influence of the number of the month on the imbalance probability is studied in the second phase of our analysis. The variation coefficient is more meaningful and we decided to create probability matrixes divided by months and hours of a day, i.e., a probability of positive or negative system imbalance occurrence for a given month and hour.

The probability valuation of imbalances and counter-imbalances has to be found in the last phase of the analysis. We have data from the OTE database for three years (from 2010 to 2012). The scatter diagrams for all the four states described in Table 1 are shown in the following figures. It is obvious that no convenient function can be used to describe the dependence particularly for the counter-imbalance. Therefore, a probability matrix for values of imbalances and counter-imbalances was created again and used in the final valuation model.

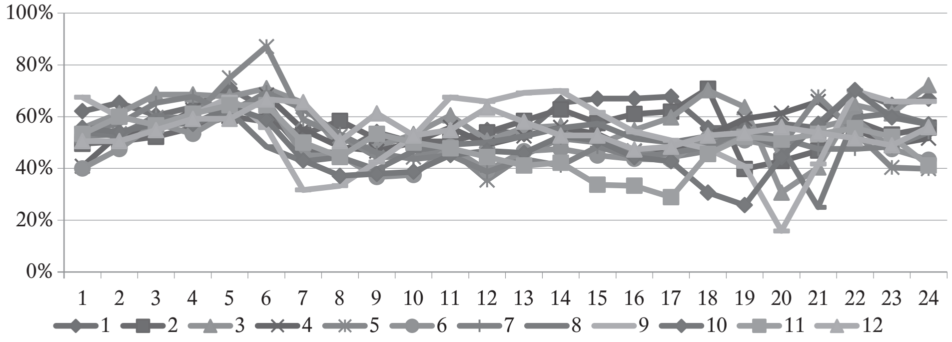

Fig. 4: Positive system imbalance probability by hours for each month – calculated based on OTE (2014)

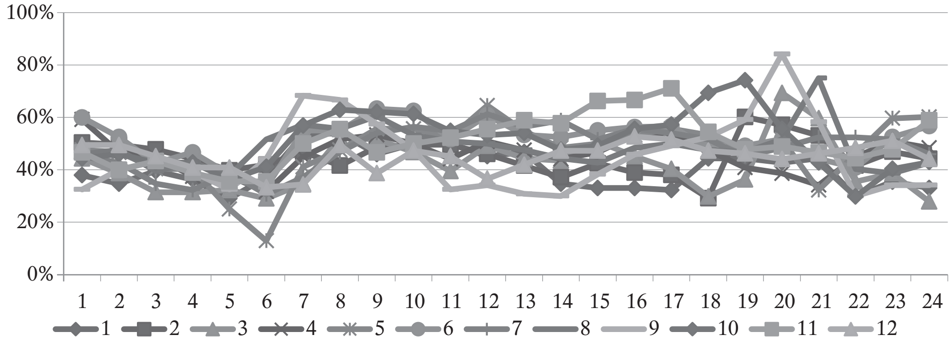

Fig. 5: Negative system imbalance probability by hours for each month – calculated based on OTE (2014)

8.3.2 Case study results

We tested our proposed methodology on a case study of energy storage working in combination with solar power plants in the Czech Republic with a compound capacity of 14 MW (typical installed capacity of each PV plant was in the region of several hundred kW, the maximum was slightly above 1 MW). We had a complete set of information about the solar power plant load diagrams during the last year at our disposal and we took it as an input for our model.

The storage units we have chosen are Li-ion batteries. The capability of quick discharging of Li-ion batteries is the primary reason for choosing them. This is crucial for the optimal operating regime of the storage system – we can utilise the batteries in hourly cycles and that allows us to maximise the "energy shifting" during each day and therefore to maximise the economic benefit/profit.

The market price of electricity was estimated based on the price development at the Prague Energy Exchange (Power Exchange Central Europe, 2014). The amount of electricity traded was also taken into consideration. We used the common energy exchange products (annual, quarterly and monthly) to cover our load diagram using

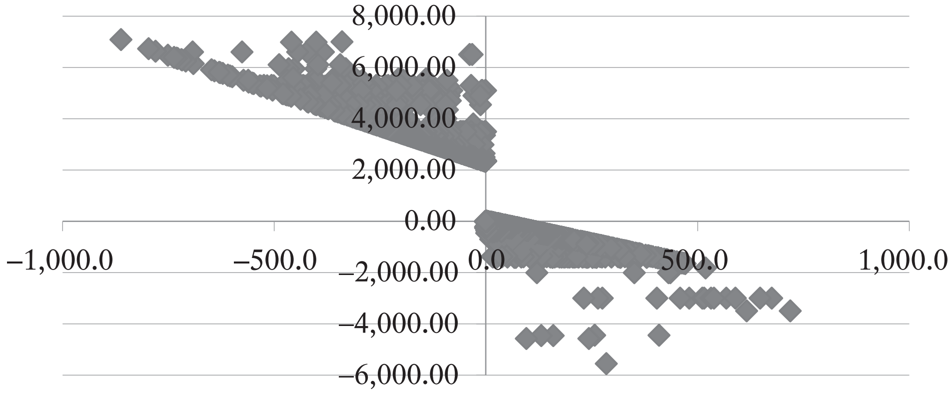

Fig. 6: Imbalance prices – Positive system imbalance – calculated based on OTE (2014)

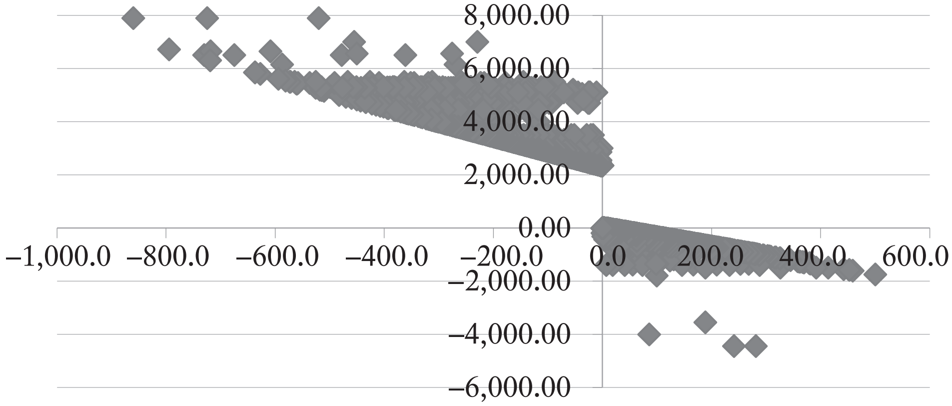

Fig. 7: Imbalance prices – Negative system imbalance – calculated based on OTE (2014)

our proposed methodology. It would also be possible to use electricity prices from short-term markets (e.g., the day-ahead market). The reason for that is a premise that solar power plants are not taken as base load sources and therefore their production should not be traded on the long-term market.

The total annual positive imbalance (electricity production of the solar power plants was higher than the contracted diagram) was 8450 MWh; the total annual negative imbalance was 2241 MWh. It is obvious that the total amount of imbalances is relatively high, especially if we compare these values with the annual electricity production of all the solar power plants which was approx. 13,655 MWh. This is also a good proof that solar power plants, as an example of intermittent renewable sources, are extremely unreliable from the system point of view and that higher penetration of intermittent RES requires additional technical solutions, such as energy storage. According to our calculation, a 3 MW storage unit should be able to reduce both the positive and negative imbalances by approx. 500 MWh/year each. That means that the

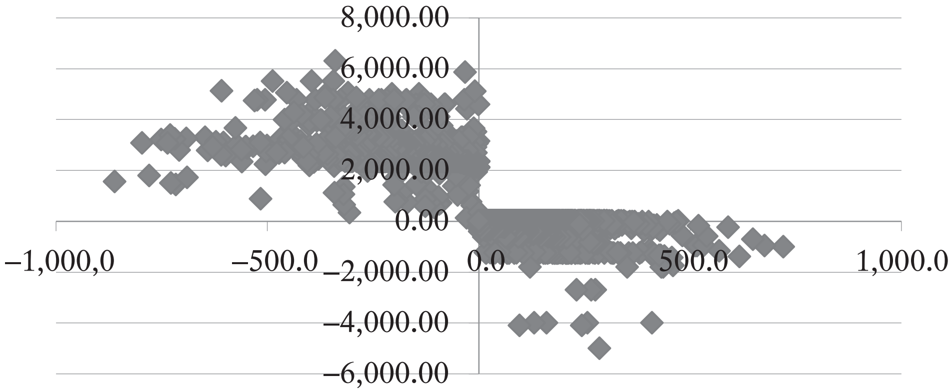

Fig. 8: Counter-imbalance prices – Positive system imbalance – calculated based on OTE (2014)

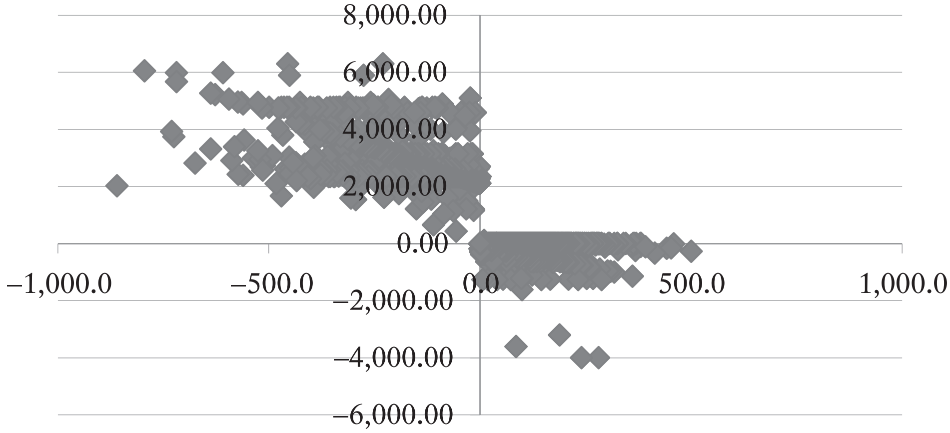

Fig. 9: Counter-imbalance prices – Negative system imbalance – calculated based on OTE (2014)

value of these 1000 MWh saved can be seen as one of the direct economic benefits of the energy storage system implementation.

These economic benefits are shown in the two following charts. These figures demonstrate the dependency of annual economic benefit on two variables:

– the installed capacity of the storage unit; and
– the level of the average operation charge of the storage unit.

It is obvious that the economic benefit is increasing with the capacity of the unit as well as with a decrease in the average operation charge of the storage unit. However, it must be stated that the expected lifetime of the Li-ion batteries depends on the level of discharging. That means that even though the option with the lowest average operation charge seems to be the most efficient one, the reality will be different. Therefore, future research focused on the optimal level of the average operation charge from the economic point of view is more than needed.

We have also analysed two scenarios. Results for the system of imbalance pricing currently in use are presented in Figure 10. This system is described in the previous text and allows price arbitrage. It means that, thanks to the probability distribution of random positive and negative imbalances, the electricity producers can benefit from intentional violation of contracted load diagrams.

This motivated us to create a second scenario using pseudo-real pricing of imbalances. The main aim of this second scenario is to eliminate the price arbitrage. We therefore introduce a premise that any deviation from the contracted load diagram is bad from the system point of view and this deviation should be penalised. We kept all the probability matrixes and the only change is that the electricity producer has to pay both imbalance and counter-imbalance. The final results are shown in Figure 11. It can be observed that the annual economic benefit is approximately 5 times higher. To be able to finish our calculation, we had to use a certain amount of simplification (e.g., we do not assume a drop of capacity during the lifetime). The majority of the simplifications work in our favour so in reality the economic benefits would be even lower.

However, the annual economic benefits are not able to cover the costs of energy storage deployment in both the scenarios. The estimated investment costs for 3 MW batteries are over CZK 100 million and the operation costs are over CZK 3 million per year. It is therefore obvious that other economic benefits of energy storage have to be identified and added to the final balance. Such additional benefits can be found, for example, with the help of a real option theory. Also, a proper design of the net metering system (setting the ratio between electricity production and consumption) could help significantly.

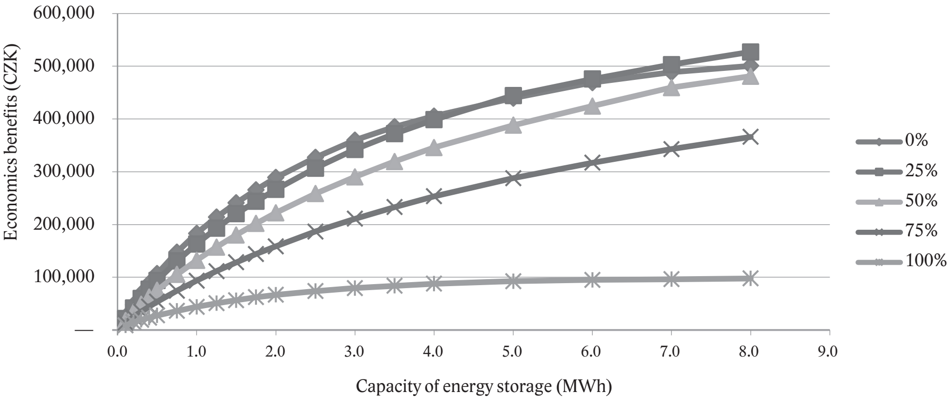

Fig. 10: Annual economic benefits of energy storage – real pricing of imbalances

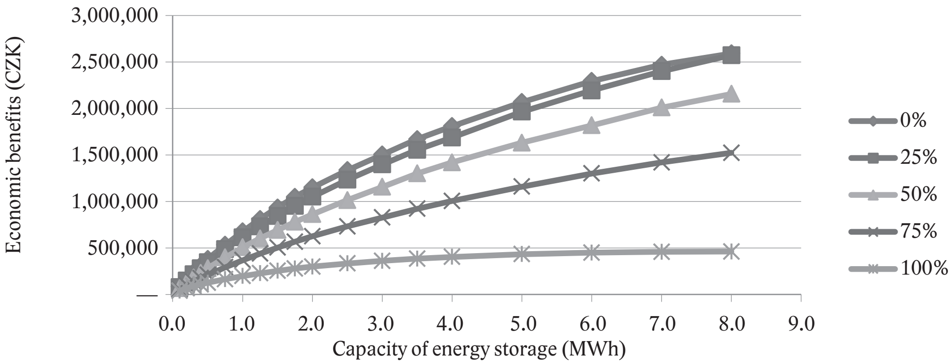

Fig. 11: Annual economic benefits of energy storage – pseudo-real pricing of imbalances

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9

Energy demand and greenhouse gas emissions of buildings in Austria

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Abstract

In Austria, the sector "space heating and other demand" contributes 28% to the final energy demand and 14% to the greenhouse gas emissions. Whereas the number of buildings and flats has been steadily increasing since 1961 from 2.2 million to 4.4 million flats, the final energy demand has been constant since 1996 and the greenhouse gas emissions have been reduced by about 18%. Due to climate change, the space heating demand will decrease by 20% by 2050, whereas the cooling energy demand will increase. The space heating energy demand will stay dominant for most of the buildings. The space heating energy demand of new buildings has been strongly reduced by technological progress. The energy requirements of building codes and subsidy schemes have been adapted accordingly. This will be pursued by the "nearly zero-energy" building requirements of the European Building Directive (2010). The main energy reduction will be achieved by high-quality renovation of buildings.

Greenhouse gas emissions will be further reduced by increased use of renewable energies. Solar thermal and photovoltaics will be mounted increasingly on free and favourably oriented building surfaces. Small heat pumps will be developed and widely used. Biomass will preferably be used for industry and mobility rather than in buildings. District heating networks will become less important due to lower energy demand of the buildings. The household electricity demand will decrease due to efficient technologies and smart grid applications but increase due to new electrical applications. Therefore, the total electricity demand will moderately increase.

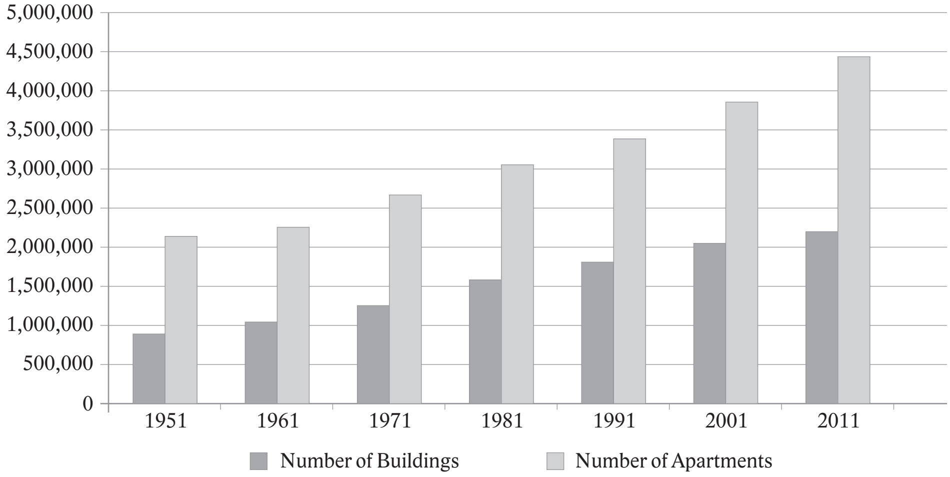
Under such boundary conditions, 90% of the space heating energy demand of buildings can be covered by renewable energy carriers in 2050.

Key words: buildings, energy demand, greenhouse gases, new buildings, renovation, laws, costs, scenarios, adaptation to climate change

9.1
Number and size of buildings and apartments in Austria

The base for all Austrian studies in the building sector is the inventories of Statistik Austria, comprising the state and the historical development of the number of residential buildings and apartments as well as the energy carriers and energy demand (Statistik Austria, 2013a) and the Mikrozensus (Statistik Austria, 2013). For non-residential buildings, only the number of buildings and a first study on the energy demand for different industries exist (Statistik Austria, 2011). Only lumped estimates about the greenhouse gas emissions for non-residential buildings are available.

The building sector is steadily growing in Austria. This is due to a growing population and a larger floor space per person. In total, 2.2 million buildings and 4.4 million apartments existed in 2011 (Figure 1).



Statistik Austria, 2013a

Fig. 1: Numbers of buildings and flats

About of all the buildings and 50% of the apartments are in single- and two-family houses. An another 3% of the apartments are in non-residential buildings. Unfortunately, there are uncertainties in the definition of residential and non-residential buildings and in the accounting of mixed-use buildings. About 19% of the floor space of residential buildings was built before the year 1919, 7% from 1919 to 1944, and 44% between 1945 and 1980 (Statistik Austria, 2001). Consequently, about 70% of the floor space have a low energy standard and are therefore of potential interest for thermal renovation.

9.2
Energy demand and energy carriers

Statistik Austria often includes the building sector in the sector "other energy demand", which comprises the following categories:

- private households;
- public and private services; and
- agriculture.

The energy demand of the private households is further grouped into:

- space heating (SH);
- domestic hot water production (DHW);
- cooking; and
- others (amongst others, electricity demand for household appliances).

In addition to the time series for the fuel demand of private households, evaluations for the fuel demand of non-residential buildings are available for the first time (Statistik Austria, 2011). The final energy demand for the sector "others" has been stagnating since 1996 at about 420 PJ/a despite the increasing number of buildings and apartments. The demands for transportation and mobility as well as industry were strongly increasing until 2007 and have been more or less constant since then.

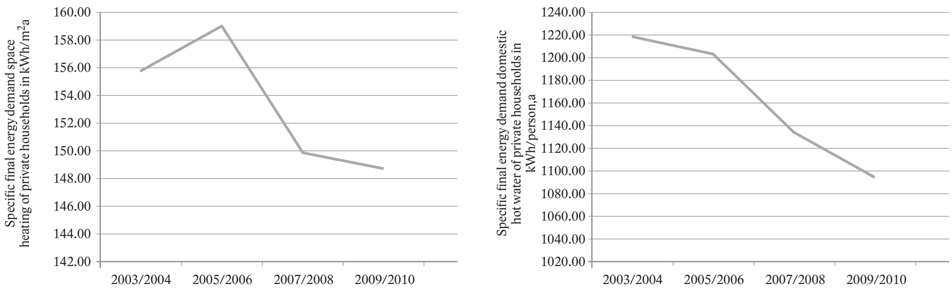
The share of private households and private and public services (excluding agriculture) in the total end-use energy demand is steadily decreasing and amounted to about 28% in 2010. In the sector "other energy demand", private households have a share of 62% (260 PJ/a) and private and public services about 31% (130 PJ) in the final energy demand. Agriculture finally has a share of about 7%. The additional energy demand of new buildings has been compensated by the thermal renovation of existing buildings since 1996.

The main part of the final energy demand in private households is related to space heating (about 71%, 195 PJ/a). Domestic hot water production amounts to 13% (35 PJ/a) and cooking to 3% (7 PJ/a). The rest of 37 PJ/a is mainly electricity demand for household appliances and heating/ventilation/cooling.

Whereas the absolute values of the energy demand of private households are constant, the energy demand related to floor area for space heating and domestic hot water production is steadily decreasing. The specific energy demand for space heating for all buildings was at about 148 kWh/m^{2}a in 2009/2010; for domestic hot water about 1100 kWh/person,a were needed (Figure 2).

The distribution of energy carriers used in private households is shown in Figure 3. A share of about 20% each was contributed by wood, natural gas, oil and electricity. 10% was the share of district heating and about 1.5% each the share of solar thermal energy and heat pumps, all three with an increasing tendency.

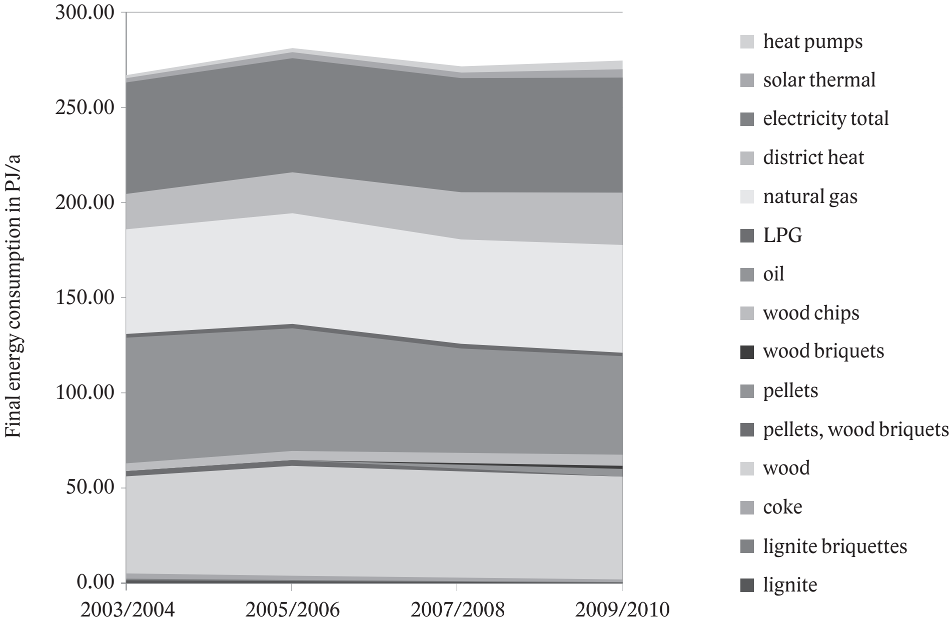
Between 2003 and 2010, the share of renewable energy carriers increased from 22.9 to 26.9% and the share of district heating from 6.9 to 9.9%. The share of oil was reduced from 25% to 19%, and coal is negligible with 0.5 to 0.2%. Natural gas kept constant with 20.5%. Therefore, a trend from oil to renewable energy carriers is visible. This can be partly traced back to the high volatility of the oil prices in the



Statistik Austria, 2012

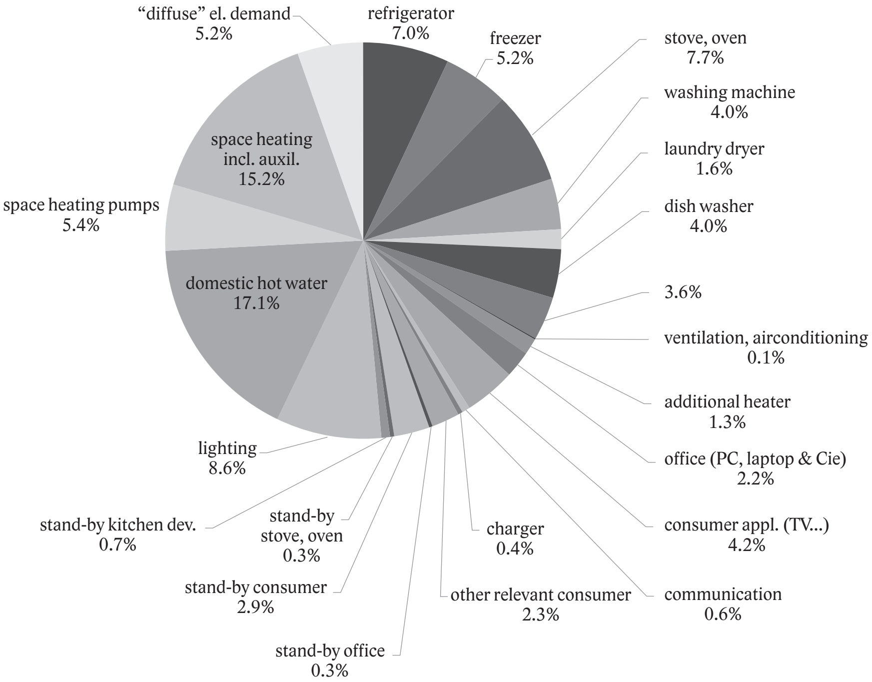
Fig. 2: Specific end use energy demand for space heating in kWh/m²a (left) and domestic hot water demand in kWh/person,a of private households (right)

recent years and the current availability of highly developed fully automatic boilers for renewable energy carriers. A more detailed analysis of Statistik Austria (2012) reveals that cooking is done with electricity with an 83% share, 10% with natural gas and 7% with wood. Household appliances (others) use 100% electricity. Summing up, space heating and domestic hot water production are served by wood, natural gas and oil with about 27% each, by district heat with about 14% and electricity with 9%. Solar thermal systems and heat pumps are slightly above 2%.



Statistik Austria, 2012

Fig. 3: Final energy consumption of private households by energy carrier in PJ/a



Statistik Austria, 2009

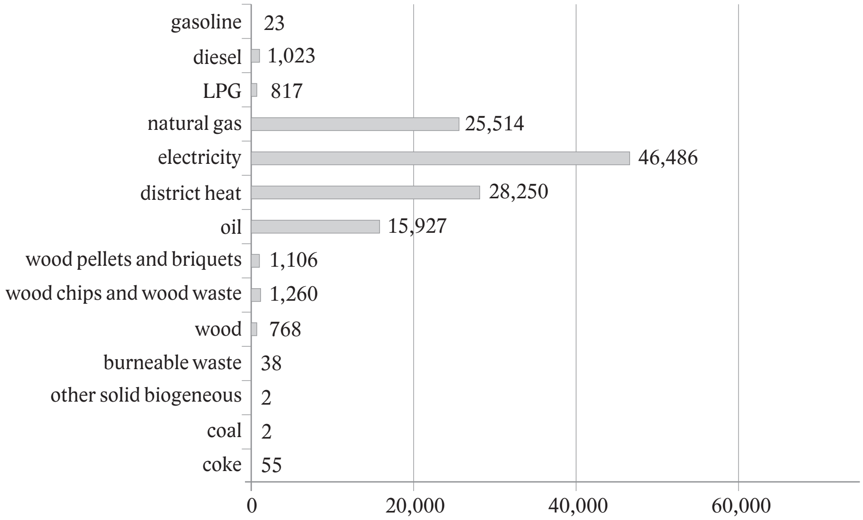
Fig. 4: Share of electrical appliances in total electricity demand of private households in %

Figure 4 shows the distribution of the electricity demand of private households. The main consumers are space heating and domestic hot water production with a total of 37.7%. Other relevant appliances are refrigerators and freezers (12.2%), lighting (8%) and cooking (7.7%).

The analysis of public and private services by Statistik Austria (2011) is shown in Figure 5. This is the first detailed investigation of the non-residential sector in Austria. The main energy carriers are electricity (38%), district heating (23%), natural gas (20%) and oil (13%). Biomass amounts only to 2.5%; other renewable energy carriers are not shown. The total final energy demand is given as 121 PJ/a.

Grid-connected energy carriers dominate the final energy demand of the public and private services sector with more than 80%. Coal, diesel, gasoline and liquid pressurised gas (LPG) as well as renewable energy and waste energy use have only 4.2% in total. Biogenous fuels such as wood pellets, wood chips, waste biomass, log wood and others have a share of 2.5% (Statistik Austria, 2011).

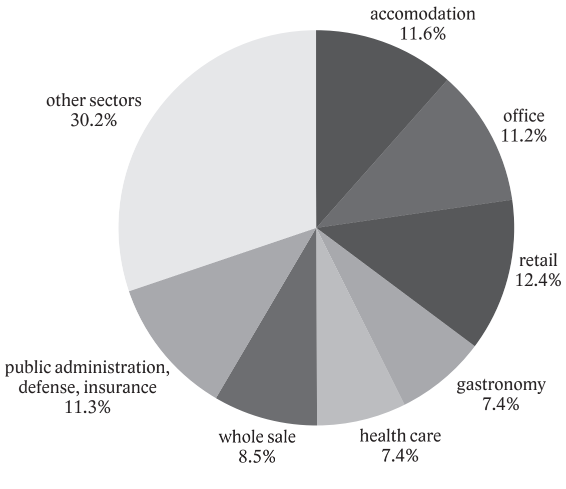
A breakdown of the final energy demand of the public and private services for different applications reveals that it is dominated by space heating energy demand followed by electrical energy for lighting, air conditioning, computing, other information and communication technologies such as copy machines, stoves, refrigerators, or bigger



Statistik Austria, 2011

Fig. 5: End-use energy demand of the commercial sector in TJ/a

electrical appliances such as baking ovens. Transportation is not considered as there is a separate balance in the sector "transportation" (Statistik Austria, 2011).



Statistik Austria, 2011

Fig. 6: Share of final energy demand of the commercial sector according to ÖNACE "Abteilungen" in %

Figure 6 shows the distribution of the final energy demand for different commercial sectors according to ÖNACE (2008) regulations. The main consumers for ÖNACE

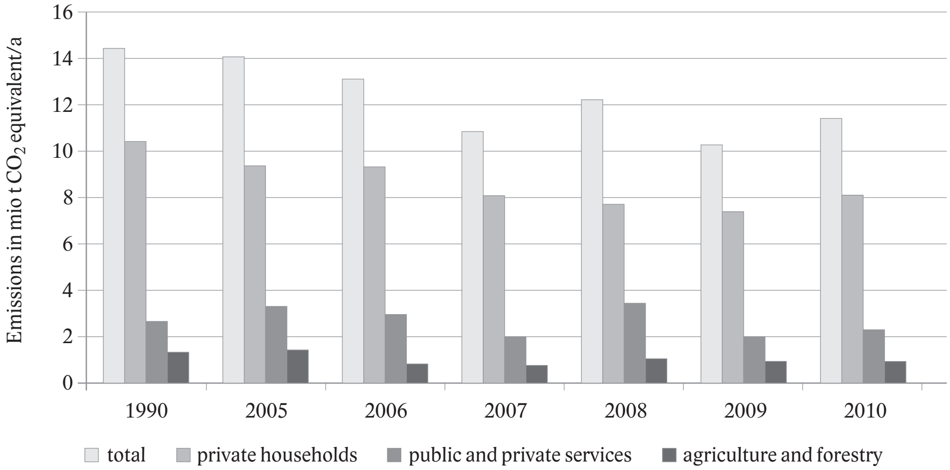
"Abschnitte" are trade (including maintenance and repair of vehicles) with 23.4%, accommodation and gastronomy (19.0%), public administration, defence and social insurance (11.3%), and health care and welfare (9.8%). At the level of ÖNACE "Abteilungen" public administration, defence and social insurance consume 11.3%, accommodation 11.6%, retail sale 12.4%, whole sale 8.5%, health care 7.4% and gastronomy 7.4%, which amounts to more than 60% of the final energy use in this sector. The study also defines the category of "office buildings", which covers a large part of all non-residential buildings. Office buildings cover many of the above mentioned ÖNACE "Abteilungen". Office buildings encompass all companies where the numbers of office workplaces comprise more than 80% of all work places and that are not part of public services, defence, social insurance, accommodation, retail and whole sale, healthcare, and gastronomy. The share of "office buildings" in the final energy demand is about 11.2% (Statistik Austria, 2011).

9.3 Greenhouse gas emissions in the Austrian building sector

The share of households in the Austrian CO_2 emissions is 25% in 2010 with 24 million t of CO_2/a. When the CO_2 emissions of biogenous fuels are calculated according to international conventions with zero emissions for all sectors, this reduces the sum to 16 million t of CO_2/a and about 23% (Statistik Austria, 2012a). About 50% of the emissions are due to space heating / other minor demand and 50% due to domestic hot water and electricity demand.

The sector of space heating and other minor demand of households contributes 14% to the Austrian greenhouse emissions (Umweltbundesamt, 2011). This is very low compared to the 28% of the final energy demand and due to the high share of biomass and district heating (partly from waste and biomass). Additionally, the production of district heating and electricity is allocated under energy production and not under households.

Figure 7 shows the development of the Austrian greenhouse gas emissions in the sector of space heating and other minor demand from 1990 to 2010. Until 2009, there is a decreasing tendency. This is partly due to a stagnating energy demand and a shift from oil to less greenhouse gas emitting fuels such as district heating and renewable energy carriers. The greenhouse gas emissions were in 2009 with 10.3 million t of CO_2 equivalent/a in the range of the Austrian goals of the Kyoto protocol (Lebensministerium, 2002: 10.5 million t of CO_2 equivalent/a for 2010). However, in 2010 there was an increase to 11.4 million t of CO_2 equivalent/a. Such fluctuations are common and due to weather conditions. In 2009 and 2010 the greenhouse gas emissions were lower than the goal values of the Austrian climate strategy (11.9 million t of CO_2 equivalent/a; Lebensministerium, 2007). This value was extended for the period 2008–2012 in the Austrian climate law (Klimaschutzgesetz, 2014). According to that law the emissions should be reduced by 2020 to 8.65 million t



Umweltbundesamt, 2009, 2011, 2012

Fig. 7: Greenhouse gas emissions of the residential and other sectors in million t of CO_2 equivalent/a

of CO_2 equivalent/a. Clearly evident is the reduction of the private households in Figure 8. This can again be explained by an energy carrier shift to less greenhouse gas emitting energy carriers. Private households are responsible for about 2/3 of the emissions from the whole sector. Public and private services are responsible for about 25% and agriculture and forestry (including all machinery) for about 9%.

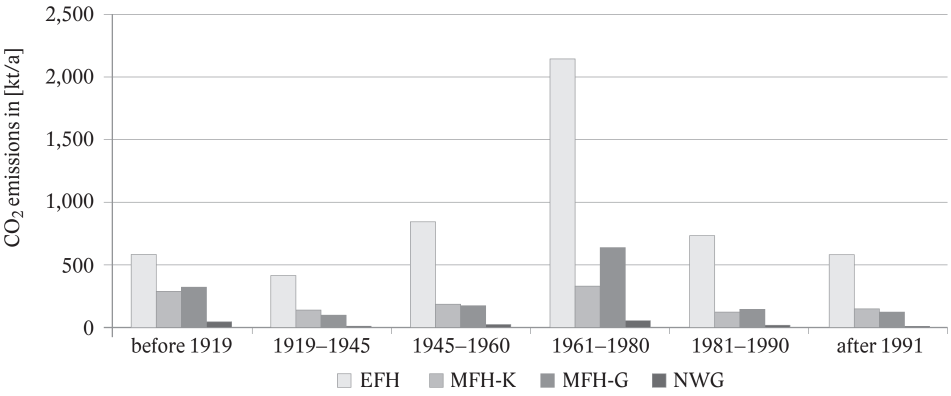


Fig. 8: CO_2 emissions of residential space heating in kt/a for building types and building age (Kletzan et al., 2006) (EFH: single family house, MFH-K: multifamily building small [$\leq$ 10 flats], MFH-G: multifamily building large [$>$ 10 flats], NWG: flats in non-residential buildings)

The highest CO_2 emissions arise from single family houses, as they have a low outer area to volume ratio and more often oil and natural gas as energy carriers. Looking closer at the year of construction, the period from 1945 to 1980 has the highest absolute emissions, as in this period many buildings were built after the destruction of the Second World War as cheaply as possible and the energy demand was not on the agenda (Kletzan et al., 2006). Figure 8 shows that the highest emission savings can therefore be achieved in single family houses, followed by multifamily houses. New buildings have a minor impact as the building codes and energy performance criteria for subsidies demand high energy efficiency levels. In future, the European Union even goes for Nearly Zero-Energy Buildings (see the next chapter).

The main driving forces for the positive development of the last two centuries were analysed by Environment Agency Austria (Umweltbundesamt, 2012) by comparing the emissions from 1990 and 2010. The main increasing force was the higher number of apartments and buildings, followed by an increasing living space per person. Reducing elements were the reduction of specific energy demand due to the high standards of new buildings and thermal renovation of old buildings.

9.4
Reduction of greenhouse gas emissions due to energy efficiency and the use of renewable energy carriers

9.4.1
Legal framework and subsidy schemes

The building sector in Austria is legally bound by the provinces. Therefore, 9 different building codes exist. The different building codes were harmonised in the year 2008. The basis was the Institute for Building Technology “Bautechnik” (OIB), which was founded by the provinces. The concept is composed of two parts:

– the legal rules (laws and regulations) contain only functional requirements that have long-term validity and are independent of concrete technical or planning solutions;
– for the implementation of these rules, concrete technical requirements (e.g., energy demands or construction items) are developed by the OIB and the provinces and defined in regulations. Most often the laws refer to these regulations (Mikulits, 2009).

This procedure is often called the “performance-based approach” (IRCC, 1998).

The OIB regulations are compatible to a great extent with EU regulations such as the Energy Performance of Buildings Directive (EPBD, EU Directive 2010/31/EU, 2010) and the Construction Products Directive (EU Directive 89/106 EEC, 1989).

Concerning the Construction Products Directive, the functional and technical qualities are not yet consistently fixed in Austria (Passer et al., 2009; Passer et al., 2010). Planning and completion of buildings can be performed with the standards following the Construction Products Directive “Bauproduktenrichtlinie” and the Construction Products Regulations “Bauproduktenverordnung” (Mikulits, 2011; Maydl et al., 2010). They define useful and useable construction products that bear in mind the interaction between the construction product and the structural design (Passer et al., 2009; Passer et al., 2010).

In the following, the Austrian EPBD regulation will be analysed in more detail, as it is the main basis for the building code in respect to energy efficiency and greenhouse gas emission reduction.

EU Energy Performance of Buildings Directive and Austrian by-laws

The EPBD released in 2002 (EU Directive 2002/91/EU, 2002) deals with the overall energy performance of residential and non-residential buildings. National standards for energy demand and voluntarily for the CO_2 emissions have to be set for all new buildings and buildings undergoing a major renovation with more than 1000 m^2 of floor space. Another important point is the energy certificates that have to be issued for new buildings and when buildings or parts of buildings are rented or sold or undergo a major renovation. In addition, regular inspection of boilers (20 kW) and air-conditioning systems (12 kW) is mandatory.

A revision of the Directive was issued in May 2010 (EU Directive 2010/31/EU, 2010). Relevant changes are:

- mandatory evaluation of possible use of renewable energy carriers for all buildings;
- all public buildings starting with 2018 and all other buildings starting with 2020 have to be “Nearly Zero-Energy” buildings. The definition of “Nearly Zero-Energy” is made by the member states;
- the energy certificate has to be shown for all buildings at construction, selling or renting;
- member states shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels. These cost-optimal levels are related to the lifetime of the building, including its operating costs.

The implementation of the EPBD in Austria was done by the Austrian Institute of Building Technology (OIB). Regulation 6 of the harmonisation of the building codes deals with the implementation of the EPBD. An easy-to-use spreadsheet program was developed as a benchmark for many software tools. Besides, a simplified method for estimating the energy demand of existing buildings was developed. Following the Directive, maximum permissible values for useful and final energy demand were defined for newly built and renovated residential and non-residential buildings as part of the building codes. The energy certificates were designed and the qualification of persons issuing the certificates and doing the inspections for boilers and air-conditioning systems were defined.

At the federal level, the Energieausweis-Vorlage-Gesetz (EAVG, 2012) regulates when an energy certificate has to be issued. The OIB directive for the calculation scheme of energy demand and CO_2 emissions has been adopted in all the Austrian provinces.

Maximum permissible values for new buildings and buildings undergoing a major renovation are given for

- heat transfer rates (U-values) of construction elements;
- useful energy demand for space heating (HWB) and cooling (KB) in dependence on the outer area/volume ratio;
- final energy demand for space heating and domestic hot water production (HEB) as well as space cooling (KEB).

The energy and emission classification of buildings in the energy certificate follows in Table 1. Four independent values are given in the certificate. The primary energy demand (PEB) and the CO_2 emissions use factors for different energy carriers (e.g., electricity: 2.62 kWh/kWh for PEB and 417 g of CO_2/kWh, Biomass: 1.08 kWh/kWh for PEB and 4 g of CO_2/kWh). Additional detailed energy values are given on the second page of the certificate. The maximum permitted energy demand values are given in Table 2.

The useful cooling demand is limited in a different way. Residential buildings have to prove summer overheating protection under ÖNORM B 8110, Part 3. This means that no overheating should occur even without the use of active cooling systems. Non-residential buildings have to prove the same or a cooling demand below 1 kWh/m^{3}a for new and 2 kWh/m^{2}a for renovated buildings but for the reduced internal gains of residential buildings (OIB Richtlinie 6, 2011). This means that, in general, buildings in Austria have to be built in a way that no cooling demand should occur due to the building structure. With this regulation, Austria has one of the strictest regulations concerning the cooling demand in the European Union.

The implementation of the EPBD and the issuing of the certificate at the permission phase will lead to more integrated planning of buildings, as many details of building structure, the building physics as well as the heating, ventilation and air conditioning (HVAC) system have to be defined in advance. All certificates will be collected in an Austria-wide database that is connected to a GIS system.

Act of tenancy law (Mietrechtsgesetz), condominium act (Wohnungseigentumsgesetz) and law for non-profit housing companies (Wohnungsgemeinnützigkeitsgesetz)

As shown in Chapter 3, the biggest potential for reduction of greenhouse gas emissions lies in the renovation of buildings. Legal boundary conditions between owners and tenants are very important for the renovation process. These laws define what percentage of the tenants or owners have to agree on the renovation and the use of existing or future reserve funds. Additionally, they define whether the rent (without energy costs of space heating) can be increased due to the thermal renovation. These laws are currently under discussion to allow an easier process for the renovation of buildings. Nevertheless, as these laws mainly concern multifamily houses, which have a lower impact on the greenhouse effect, such a legal change may have a lower effect on the greenhouse effect (Köppl, 2001).

Class	Classification related to gross floor area (BGF) and building site climate (SK)			
	$HWB_{BGF,SK}$	$PEB_{BGF,SK}$	$CO_{2,BGF,SK}$	f_{GEE}
Class A++	$\leq$ 10 kWh/m^{2}a	$\leq$ 60 kWh/m^{2}a	$\leq$ 8 kg/m^{2}a	$\leq$ 0.55
Class A+	$\leq$ 15 kWh/m^{2}a	$\leq$ 70 kWh/m^{2}a	$\leq$ 10 kg/m^{2}a	$\leq$ 0.70
Class A	$\leq$ 25 kWh/m^{2}a	$\leq$ 80 kWh/m^{2}a	$\leq$ 15 kg/m^{2}a	$\leq$ 0.85
Class B	$\leq$ 50 kWh/m^{2}a	$\leq$ 160 kWh/m^{2}a	$\leq$ 30 kg/m^{2}a	$\leq$ 1.00
Class C	$\leq$ 100 kWh/m^{2}a	$\leq$ 220 kWh/m^{2}a	$\leq$ 40 kg/m^{2}a	$\leq$ 1.75
Class D	$\leq$ 150 kWh/m^{2}a	$\leq$ 280 kWh/m^{2}a	$\leq$ 50 kg/m^{2}a	$\leq$ 2.50
Class E	$\leq$ 200 kWh/m^{2}a	$\leq$ 340 kWh/m^{2}a	$\leq$ 60 kg/m^{2}a	$\leq$ 3.25
Class F	$\leq$ 250 kWh/m^{2}a	$\leq$ 400 kWh/m^{2}a	$\leq$ 70 kg/m^{2}a	$\leq$ 4.00
Class G	$>$ 250 kWh/m^{2}a	$>$ 400 kWh/m^{2}a	$>$ 70 kg/m^{2}a	$>$ 4.00

$HWB_{BGF,SK}$ space heating demand (useful energy)
$PEB_{BGF,SK}$ primary energy demand
$CO_{2,BGF,SK}$ carbon dioxide emissions
f_{GEE} overall energy efficiency factor (efficiency from final energy to useful energy)

Tab. 1: Energy classification of Austrian buildings in the energy certificate (OIB Richtlinie 6, 2011)

Possibilities of residential housing subsidies (Wohnbauförderung)

The residential housing subsidy is a strong tool in Austria that exceeds the requirements of the building codes in terms of energy efficiency and the use of renewable energy carriers. Since 1988, the Austrian provinces have had the sovereignty over the budget of such subsidies.

In the last decades, the goals have been broadened by the topics of building ecology, barrier-freeness, and safety (Amman, 2004). The budget for the renovation of buildings has been stagnating at a share of 25% for the last 10 years. The total budget is around EUR 2.4 billion. Since 2006, the same maximum permissible values for the final space heating energy demand (HWB) for new buildings and renovations have been in force for all the provinces, fixed by so-called § 15a Agreement between the provinces and the state of Austria. In 2012, the maximum limits were lowered again (Art. 15a B-VG, 2009). Additionally, the limits for new public buildings were set close to the passive house standard. Also the U-values of buildings are limited. Additionally, the provinces can define even lower values individually.

Due to these subsidy schemes, the specific HWB of new residential buildings was reduced from 42 kWh/m^{2}a in 2006 to 30 kWh/m^{2}a in 2011. For totally renovated buildings, the reduction was from 67 kWh/m^{2}a in 2006 to 49 kWh/m^{2}a in 2011. In 2011, the reduction of CO_2 emissions was about 313,000 tonnes of CO_2, in 2010 it was 441,000 tonnes of CO_2. In 2011, 89% of the emission reduction was due to

	for A/V[1)]-ratio > 0.8	for A/V[1)]-ratio < 0.2
New residential buildings	HWBBGF	HWBBGF in
until end 2009, building code/subsidy in kWh/(m^2.a)	68 / 65	37 / 35
from 1 January 2010, subsidy in kWh/(m^2.a)	45	25
from 1 January 2012, building code/subsidy in kWh/(m^2.a)	54,4 / 36	37 / 20
Renovation residential buildings		
until end 2009, building code/subsidy in kWh/(m^2.a)	89 / 80	48 / 43
from 1 January 2010, building code/subsidy in kWh/(m^2.a)	76 / 75	38 / 35
New public buildings		
from 1 January 2010, building code/subsidy in kWh/(m^3.a)	17 / 15	9 / 8
from 1 January 2012, building code/subsidy in kWh/(m^3.a)	18,7 / 12	9 / 7
Renovation public buildings		
from 1 January 2010, building code/subsidy in kWh/(m^3.a)	26 / 26	13 / 13
from 1 January 2012, building code/subsidy in kWh/(m^3.a)	26 / 25	13 / 12

[1)] *A/V: ratio of outer surface to volume of the building*
between these values a linear interpolation for A/V has to be performed

Tab. 2: Austrian maximum permissible useful energy demand values in building code and subsidy schemes (Art. 15a B-VG, 2009)

thermal/energy renovation. The subsidised renovation rate is around 1%/a (renovated gross area per inhabitant / total gross area per inhabitant) (Lebensministerium, 2013).

9.4.2 Technical development of building efficiency

The following analysis uses several Austrian studies from the last 5 years (Schriefl, 2007; Bliem et al., 2011; Müller et al., 2010; Christian, 2011; Streicher et al., 2011; Umweltbundesamt, 2011; Köppl et al., 2011).

New buildings

The technological development of building materials and components related to energy efficiency has been quite large since 1980. Whereas 2-pane windows with air filling and a U-value of 2.5 W/m^{2}K were the standard in 1980, 2-pane glazings with a U-value of 1.1 W/m^{2}K are the standard today, and even 3-pane glazings with U-values down to 0.6 W/m^{2}K are not much more expensive. Additionally, the window frames and the installation details have been highly improved. A similar development has been registered for the thermal insulation systems, where today's cost optima are around 20 to 30 cm of insulation material amounting to U-values down to 0.1 W/m^{2}K. The building codes only demand 0.35 W/m^{2}K. Table 3 shows the development of the heat transfer coefficients (U-values in W/m^{2}K) for various building components for different periods in Austria.

	U-values in W/m^{2}K				
Building period	Upper ceiling	Wall to ambient	Window to ambient	Door to ambient	Basement ceiling / floor to ground
before 1919	1.1	1.0	3.1	2.5	1.5
1919 – 1944	1.2	1.2	3.2	2.2	1.4
1945 – 1960	1.2	1.35	3.3	2.0	1.1
1961 – 1970	1.2	1.25	3.0	1.8	1.1
1971 – 1980	0.3	0.7	2.2	1.7	0.9
1981 – 1990	0.3	0.6	1.9	1.6	0.63
1991 – 2007	0.25	0.45	1,7	1.6	0.6
2007 –	0.2	0.35	1.7	1.7	0.4

Tab. 3: Development of the heat transfer coefficients (U-values in W/m^{2}K) for various building components for different periods in Austria (Schriefl, 2007; values for 2007 from OIB Richtlinie 6, 2007 and 2011)

Additionally, many construction details to avoid thermal bridges and increase the tightness of buildings have been developed. Increasing the tightness reduces the infiltration rate and accompanying heat losses but increases the demand for active ventilation either by windows or a mechanical ventilation system. The building codes and subsidy schemes follow the technical development with some time delay to assure market availability of cost-efficient products.

Four different studies (Bliem et al., 2011; Müller et al., 2010; Christian, 2011; Streicher et al., 2011) estimate the rate of new buildings at 0 to 1.7%/year. The final space heating energy demand (HWB) is estimated between 40–70 kWh/m^{2}a, which represents today's building code, and 15 kWh/m^{2}a according to the passive house standard.

Renovation of buildings

Renovation of buildings can follow several strategies:

- renovation keeping the building structure;
- renovation changing the building structure;
- demolition and new construction.

The demolition rate is estimated between 0.20–0.33%/a (Christian, 2011), 0.4%/a overall (Streicher et al., 2007) and 0.78%/a for buildings older than 1919 and 0.12%/a for buildings younger than 1971 (Schriefl, 2007).

Technologically, there are numerous possibilities to renovate a building. Nevertheless, there is still a lack of cheap solutions for whole renovations where the tenants can stay in the apartments during the renovation phase. Additionally, all-in-one providers for overall renovation and financing are very seldom. Fortunately, there are several research and demonstration projects in Austria dealing with that item showing promising first results.

Efficiency in building service engineering

A further increase in energy efficiency of components and systems can also be expected in building technologies. Unfortunately, today's systems become more and more complex using more and more sensors, software, bus systems, etc., which theoretically could increase energy efficiency. In reality, complex systems quite often perform worse than simple systems, because the theoretical advantage cannot be used due to a lack of time and knowledge of the workers on site.

Heat pumps are a technology with a high potential of energy efficiency improvements. Modern gas or oil-fuelled boilers already run with efficiencies close to 100% and can therefore not be improved much. The new limits and regulations in OIB Richtline 6 (2011) demand examination for every new and overall renovated building to see whether renewable energy carriers can be used cost-efficiently. This may lead to new heating, ventilation and air-conditioning concepts. For lighting, the LED technology will most probably phase out the energy-saving lamps of today. This will lead to a further (slight) reduction in the electricity demand of buildings.

9.4.3
Total final energy demand of buildings

The total final energy demand of buildings until 2050 is estimated by different studies as follows in Table 4. All the studies assume a strong reduction in the energy demand of buildings.

Study	Private households	Services	Total	Reduction total
	PJ/a	PJ/a	PJ/a	%
2010: Starting value	287	122	409	
2020: Schriefl, 2007[1)]	250		140–240	4–44
2050: Müller et al., 2010[2)]	120	64	178	50
2050: Bliem et al., 2011	105	78	183	55
2050: Christian, 2011				
pragmatic	147	101	248	38
forced	62	47	109	73
2050: Streicher et al., 2011				
scenario constant			211	52
scenario growth			240	41
2020: Köppl et al., 2011[3)]			167	59

[1)] *until 2020, only space heating and domestic hot water for private households*
[2)] *until 2050, only space heating and domestic hot water, starting value 360 PJ for 2010*
[3)] *until 2020, only space heating and domestic hot water for private households and public services, according to different scenarios, sum of all wedges*

Tab. 4: Various scenarios of end-use energy demand of the building sector until 2050 by various studies (compiled by the author)

9.4.4
Use of renewable energy carriers in the building sector

Renewable energy carriers can be used in a wide range of building applications, e.g., space heating and domestic hot water and electricity production. When estimating the potentials of renewable energy carriers that can be used for buildings, the whole energy demand of a state, including mobility and industry, has to be considered, as e.g. biomass and electricity will be used by all sectors. If only buildings are considered, the potential use of biomass and electricity from renewables may be overestimated.

Different Austrian studies estimating the potentials of renewable energy carriers for Austria are available. Bliem et al. (2011), Christian (2011), and Streicher et al. (2011) take into account the whole energy system and aim for a 100% renewable energy supply for Austria; Müller et al. (2010) only takes into account space heating and domestic hot water demand of buildings, and Köppl et al. (2011) deals with a possible development until 2020.

The results of the three studies dealing largely with a decarbonisation until 2050 have quite similar results for the building sector:

- Biomass keeps its share for constant scenarios or even reduces its share for growth scenarios due to its use in other sectors (Bliem et al., 2011; Streicher et al., 2011). Christian (2011) is quite different, as he assumes 100 PJ more biomass potential mainly from biogas.
- As the study of Müller et al. (2010) deals only with the heat demand of buildings and not with the other sectors, biomass plays a far bigger role compared to the other studies.
- The use of solar thermal energy and heat pumps is strongly increasing in Bliem et al. (2011) and Streicher et al. (2011). In Christian (2011) this increase is far smaller as more biomass is assumed to be available.
- Electricity from renewables plays the main role for heat pumps for the household electricity demand.

Two studies deal with the future CO_2 emissions of the building sector until 2020 (Energiestrategie Österreich, 2010; Köppl et al., 2011). The emission reduction is estimated at 34% (Energiestrategie Österreich, 2010) and 64% respectively (Köppl et al., 2011), related to the starting value of 2009. The studies with full decarbonisation also for goods production show, of course, no greenhouse gas emissions for 2050.

Several measures to reach the greenhouse gas reduction goals in the building sector are proposed in studies and executed by subsidy schemes at the state level (Sanierungsscheck, Wifo, 2010) as well as the province level (Wohnbauförderung, Art. 15a B-VG, 2009):

- Thermal building renovation contributes between 37% until 2020 (Köppl et al., 2011) and 58% until 2050 (Streicher et al., 2011) to the greenhouse gas reduction.
- The replacement of boilers and switch to renewable energies contributes between 46% until 2020 (Köppl et al., 2011) and 19% until 2050 (Streicher et al., 2011) to the greenhouse gas reduction. The considerations until 2050 take into account the fact that far more buildings have already been renovated, which greatly reduces the energy demand. Therefore, the type of the heating system has far less influence.
- Solar thermal use amounts to 8% until 2020 (Köppl et al., 2011) and 14% until 2050 (Streicher et al., 2011) to the greenhouse gas reduction.
- New lowest-energy or passive house buildings add 9% until 2020 (Köppl et al., 2011) and 8% until 2050 (Streicher et al., 2011) to the reduction portfolio. As the current building codes are already quite strict, there impact is quite low.

– The effect of energy-efficient household appliances is estimated in a wide range in the studies. The main question is whether the increase in the number of devices (see Figure 4) can be overcome by the reduction due to energy efficiency. Köppl et al. (2011) presumes that both effects balance each other, Streicher et al. (2011) assumes a decrease in the electricity demand.

9.4.5 Costs and benefits of the greenhouse gas reduction in the building sector

Several estimations of costs and economic impacts of a greenhouse gas emission reduction in the building sector can be found in the literature. The Energiestrategie Österreich (2010) assumes that EUR 2.6 billion/year of investment is needed to reach a renovation rate of 3%/year for residential buildings until 2020. The triggered gross production value amounts to EUR 4 billion/year and about EUR 1 billion/year of funding is needed. To reach the same renovation rate of 3%/year for the non-residential buildings, an additional EUR 400 million/year of funding is needed. With this effort, about 4.1 million t/year of greenhouse gas emissions and about EUR 1.3 billion/year of energy costs can be saved. In addition, 37,000 new jobs can be created. Over a period of 10 years, about EUR 14 billion of funding would be needed. The costs of permanent emission reduction is EUR 3400/(t/year).

Köppl et al. (2011) estimate a reduction of 3.2 million t of CO_2/year for 2020 with an investment of EUR 4.7 billion/year from 2009 to 2020 compared to a reference scenario. Thereby, a renovation rate up to 5%/year in 2020 and a renovation standard of 50 kWh/m^{2}a HWB, the passive house standard for all new buildings (15 kWh/m^{2}a), the replacement of old heating systems with efficient ones using renewable energy carriers, and the use of solar thermal systems and photovoltaics.

Wifo (2010) summarises the experience of the Austrian federal subsidy action “Sanierungscheck” that was funded with EUR 61 million. In this action, surplus to the provincial “Wohnbauförderung” scheme funding was given for overall renovation and single measures with high energy efficiency levels and the switch to renewable energy carriers or condensing gas biolers. The funding was used up within 10 weeks. Measures in 14,000 buildings (about 0.5% of the useful area of all Austrian residential buildings) were supported and a total investment of EUR 485 million was invoked. The funding/investment ratio was 1:8. Energy savings were estimated at 1.2 PJ/year (0.7% of the total heating energy demand of 182 PJ/year) and a CO_2 emission reduction of 34,000 t/year. For a lifetime of 30 years, this amounts to 1 million t of CO_2 emission reduction. The same study claims that EUR 100 million investment in renovation of buildings will induce 941 new mainly domestic jobs. In total, the building renovation should have a net positive impact on the state budget.

Müller et al. (2010) define in their “business as usual” scenario yearly investment costs of EUR 1.2 billion/year for the change of heating systems towards renewable energy carriers. This scenario yields an emission reduction in the building sector of 67%.

None of the studies deal with secondary economic effects such as the impacts on district heating networks due to less heat demand or the need for smaller heat generators for single-family houses in the range of 0.5 to 1.5 kW.

9.5
Strategies for adaptation to climate change

It is most likely that the temperatures will increase in future due to the greenhouse effect. This will lead to a reduction of space heating demand but an increase in the cooling demand of buildings. Four relevant topics can be addressed due to that matter:

- influence on space heating and cooling;
- adaptation of legal and subsidy measures to the reduction in the cooling demand of buildings;
- technical measures for low cooling demand and passive cooling are a good mix of the following elements: thermal insulation of sun-orientated areas, building orientation (only little windows to east and west), moderate window areas, outside mounted sun shading, thermal mass, window night-cooling, energy-efficient household appliances (see, e.g., Reim, 2006; Treberspurg et al., 2006; Fink et al., 2002; Hausladen et al., 2005; Balcomb, 1992). Already today, the very low (down to zero) limits for cooling demands in building codes described above force planners to take these items into account; and
- adaptation of standards related to natural disasters and climate change.

Concerning the impacts of climate change on space heating and cooling, two studies are available in Austria.

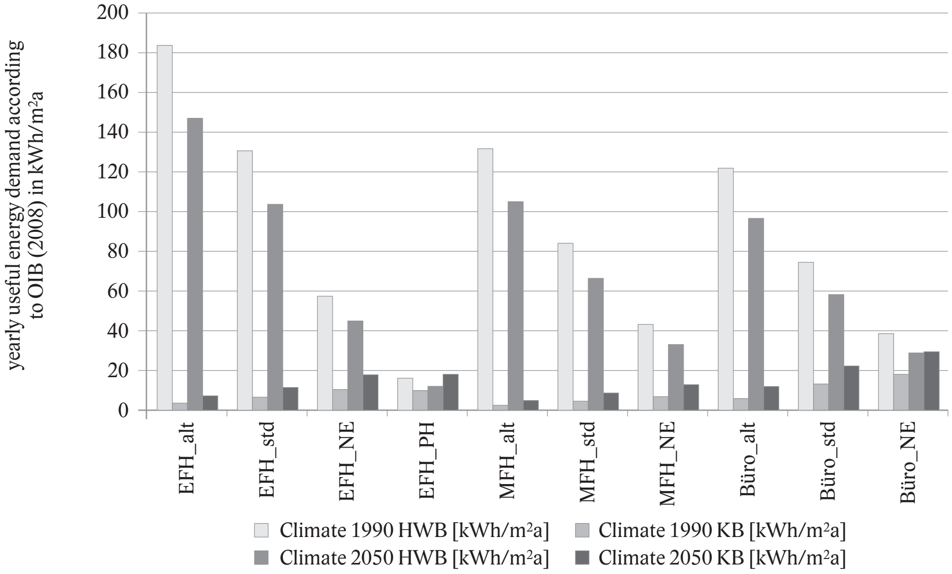
In Gobiet et al. (2009), regionalised climate data based on the IPCC Scenario IS92a (Legett et al., 1992; Nakicenovic et al., 2000) are used. The space heating and cooling demand for reference single-family, multi-family and office buildings with different insulation standards is calculated for 1990 and 2050 according to the OIB calculation scheme developed for the implementation of the EPBD in Austria. Based on this, the energy demand for buildings in 2050 is extrapolated for all of Austria.

Berger (2012) investigates the impact of the climate change on seven office buildings using regionalised climate data based on the IPCC Scenario A1B for Vienna. The space heating and cooling demand is calculated using a dynamic thermal building simulation tool.

Both the studies have very similar results. Figure 9 shows an increase in the cooling energy demand between 20 to 70%. This broad range is due to the current very low cooling demand. The space heating energy demand will be reduced by about 20% for all types of buildings. Still, space heating will be the dominating energy demand for most buildings in 2050.

Additionally, measures to reduce summer temperatures in cities may be applied. A well-known element is the wind permeability of cities for heat dissipation. Also colour of buildings and roads can be used to reflect a high amount of solar radiation rather than store it in thermal mass (e.g., Manon et al., 2009). Greening of roofs and maybe facades absorbs the solar energy but reduces the heating-up by water evaporation and shading. Whereas the first measure reflects the solar energy maybe to non-white adjacent buildings, the greening takes away the heat but may increase the humidity. Internationally, all these issues are dealt with as "urban climate" (e.g., International Journal on Urban Climate).

Also laws and standards are being adapted to climate change. The design temperatures for calculating the space heat load have been adapted in ÖNORM B8110-5 Beiblatt 1. The design snow loads on roofs and the so-called red zones for flooding and avalanche areas have been redrawn. Test procedures for the certification of roofs, windows, facades, thermal solar plants and photovoltaic panels use climate data in terms of mechanical wind loads (pull/push), hail and other mechanical forces, tightness against driving rain and wind, snow load and thermal loads. These loads have to be adapted according to climate change because the lifetime of such elements is mostly above 20 years (see, e.g., Leibetseder et al., 2012).



HWB: useful space heating energy demand, KB: useful cooling energy demand,
EFH: single family house, MFH: multifamily house, PH passive house, Büro: office building

Fig. 9: Specific space heating energy demand (HWB) and cooling demand (KB) for reference buildings in Graz climate in kWh/m^{2}a (Gobiet et al., 2009)

9.6
R&D demand, potential

In Austria there have been very successful research funding schemes for low-energy new buildings and renovation as well as the use of renewable energies for a long time (e.g., FFG and KLIEN, https://www.ffg.at/Energieforschung-das-Programm). Missing links are good energy statistics for non-residential buildings, urban climate and overall macroeconomic models to predict impacts of subsidy schemes and CO_2 emission reduction measures on the overall Austrian economy, including not only primary but also secondary and further effects.

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10

Comparing Major Trends in Passenger Car Transport in Austria and the Czech Republic

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Abstract

The transport sector is one of the largest emitters of GHG emissions, which are continuously increasing in opposite to other sectors. The largest part of these emissions comes from road transport, particularly from passenger cars. In this paper, we document and analyse historical developments in road passenger transport in Austria and the Czech Republic as well as major indicators and policies implemented.

Since both countries are EU Member states they have some common policies implemented which are set at the EU level (such as standards for CO_2 emissions from new passenger cars). However, there is also broad portfolio of national policies (such as taxes, promotion policies for electric vehicles, etc.) which are different in Austria and the Czech Republic.

Although in Austria the average numbers of vehicles kilometres driven per car is higher than in the Czech Republic as well as car ownership level, total energy consumption of cars in Austria and the Czech Republic is currently almost the same. This indicates that cars used in Austria have better fuel economy.

To cope with the environmental problems in transport sector both countries need further efforts related to the reduction of demand for cars as well as to the promotion of alternative fuels and automotive powertrains and other transport modes (e.g. public transport).

Key words: transport, car ownership, new registrations, indicators, Austria, Czech Republic

10.1 Introduction

The transport sector is one of the largest emitters of greenhouse gas (GHG) emissions, which are continuously increasing in opposite to other sectors; see Figure 1. The largest part of these emissions comes from road transport, particularly from car transport. Major reasons for this development are steadily rising car ownership levels, travel activity, and a continuous trend towards larger cars. However, there are significant differences between EU countries. Of specific interest in this paper are the differences between Austria and the Czech Republic.

In this paper, we document and analyse historical developments in road passenger transport in these two countries as well as major indicators and policies implemented. In this context, it is especially of interest to compare energy consumption in road transport, development of car fleets, travel activity, and fuel prices. Our core objective is to compare changes in car transport in Austria and the Czech Republic over the last few years, and to identify major drivers for these developments.

In this paper, an overview of the EU goals and energy and transport policies implemented at the EU level is provided at first. Next, we document the development of energy consumption in the transport sector and major indicators such as car ownership levels, average driving ranges, household expenditures on transport, etc. In addition to the description of the major EU policy measures, also national policies implemented in Austria and the Czech Republic are documented. Conclusions are provided at the end of the paper.

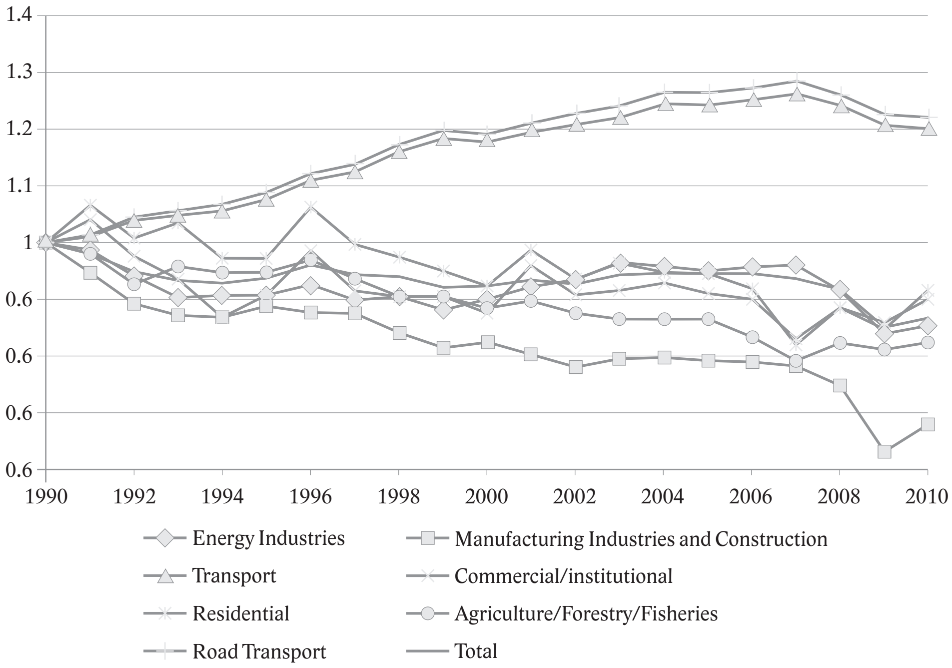

Fig. 1: Development of GHG emissions in EU-27 countries (EC, 2013, 1990 = 1)

10.2 Background

The aim of the EU's transport policy is to promote efficient, safe, secure and environmentally friendly mobility. Transport is responsible for around a quarter of the EU's GHG emissions. It is the second biggest emissions emitter after the energy sector. The largest part of these emissions is caused by road transport, especially passenger cars.

While emissions from other sectors are generally falling, those from transport have increased by 36% since 1990. The EU has policies in place to reduce emissions from a range of modes of transport, including aviation, such as the EU Emissions Trading System (EU ETS) and CO_2 emissions targets for cars. In this chapter major focus is put on passenger car transport.

Of special interest is promotion of alternative fuels and automotive technologies. In addition, important measures for reducing emissions in the EU are CO_2 emission standards for new passenger cars. The EU Regulation (EC, 2009) on passenger cars is directly applicable in all the Member States and does not need to be transposed into national law through national legal instruments. According to the Regulation, the average CO_2 emissions from cars should not exceed 130 grams of CO_2 per km by 2015 and should drop further to 95 g/km by 2020. The 130-gram target will be phased in between 2012 and 2015 (EU, 2014). The evaluation of CO_2 emissions from new passenger cars by association is shown in Figure 2 as well as the commitments undertaken by the European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturer associations related to average new car emission targets.

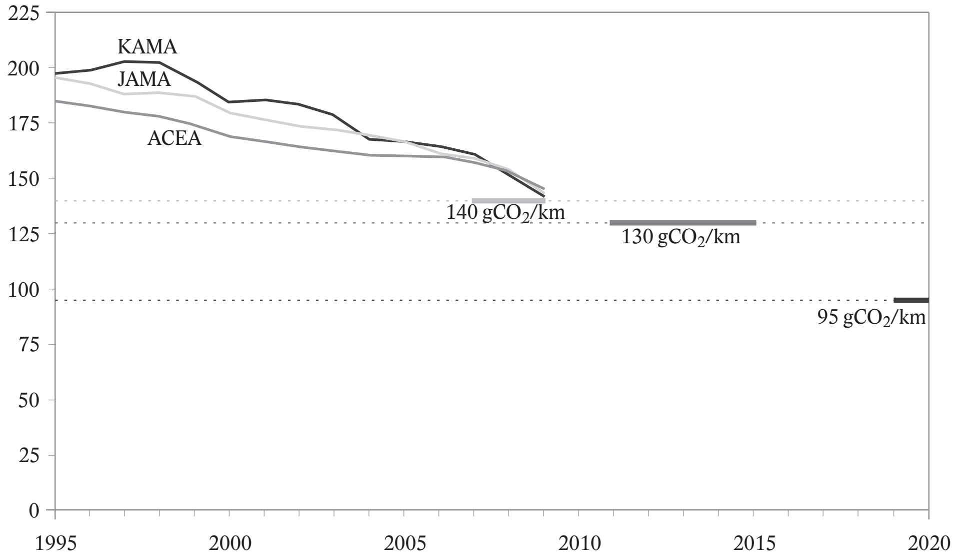

Fig. 2: Evolution of CO_2 emissions from new passenger cars by association (EU, 2014)

The first agreements with car manufactures were voluntary. Since the target of 140 g of CO_2/km by 2008 was not met on time (the average for the whole car market for 2008 was 153.7 g/km), the first mandatory CO_2 emission standards for cars were adopted in the EU in 2009 (Wilde/Kroon, 2013). Targets for 2015 and 2020 are 130 g of CO_2/km and 95 g of CO_2/km, respectively.

This means that each manufacturer gets an individual annual target based on the average mass of all its new cars registered in the EU within a given year. Since only the fleet average is regulated (this is a 'copy-paste' from the US regulation, the CAFE, in spite of criticism in the economic literature), manufacturers are allowed to produce cars with emissions above their indicative targets if these are offset by other cars which are below their indicative targets. Indicative emissions are established for each car according to its mass on the basis of the emission limit value curve. This curve is set in a way that a fleet average of 130 grams of CO_2 per km is achieved for the EU as a whole (EU, 2014). The limit value curve (LCV) for the 2015 target is calculated using the following equation:

$$CO_{2\_SP} = 130 + \alpha \cdot (M - M_0) \tag{1}$$

where $CO_{2_{SP}}$ are permitted specific emissions, M is the mass of a car in kg, M_0 is 1289 kg, and α is the slope of the LVC (0.0457). This curve is set in a way that emissions from heavier cars have to be reduced more than those from lighter cars.

Since the targets for 2015 and 2020 are mandatory, manufacturers will have to pay penalties if their average emission levels are above the target set by the limit value curve. The penalties will be based on a calculation of the number of grams per kilometre (g/km) that an average vehicle registered by the manufacturer is above the target, multiplied by the number of cars registered by the manufacturer. A premium of 5 EUR per car registered will apply to the first g/km above the target, 15 EUR for the second g/km, 25 EUR for the third g/km, and 95 EUR for each further g/km. From 2019 onwards, every g/km of exceedance will cost 95 EUR (EU, 2014).

As mentioned above, road transport is a major cause of increasing GHG emissions. The modal split of passenger road transport in Austria and the Czech Republic is depicted in Figure 3. The largest amount of passenger km is delivered by cars. In the Czech Republic in 2011, cars were responsible for 68% of the total passenger kilometres in road transport. However, this was a decrease of about 7% compared to the year 2002. In the second place were buses and coaches with 16%, followed by trams and metro (9%), and railways (7%).

In opposite to the Czech Republic, passenger kilometres driven by cars in Austria were continuously increasing in the period 2002–2011. In 2011, 75% of the total passenger kilometres in road passenger transport were driven by cars. The share of buses and coaches decreased in Austria in the period analysed.

The developments in the transport sector are also dependent on the total household expenditures on transport. Regarding this, there is a huge difference between Austria and the Czech Republic; see Figure 4. The fact is that final consumption of households for transport is increasing in both countries. However, the increase was 4% higher in

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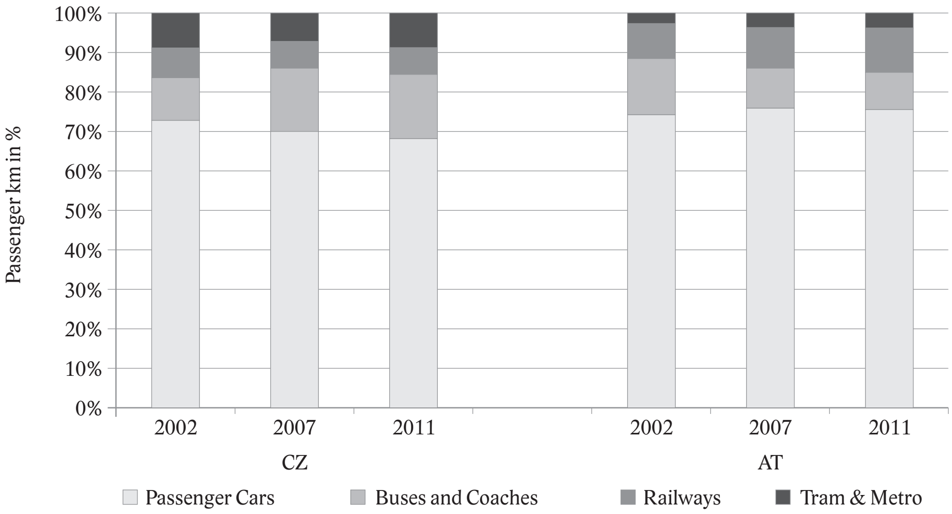

Fig. 3: Modal split of passenger road transport in Austria and the Czech Republic (EC, 2013)

Austria in the period 2005–2011. Also, the total amount of the expenditures in Austria in 2011 was about three times higher than that in the Czech Republic.

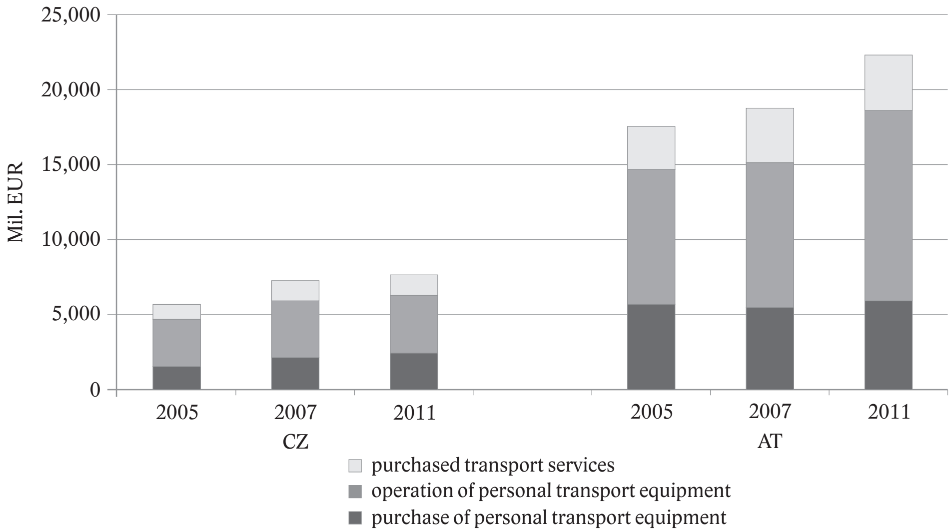

Fig. 4: Final consumption of households for transport in Austria and the Czech Republic (EC, 2013)

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10.3 Energy consumption in car passenger transport

The increase of GHG emissions shown in Figure 1 is the consequence of the increasing energy consumption in the transport sector. The development of the total energy consumption in road passenger transport over the last few years is shown in Figure 5. It is obvious that the energy consumption increased significantly in both the countries. The steepest increase was in the period 1995–2004. The energy consumption in road transport was slightly decreasing in both the countries after 2007.

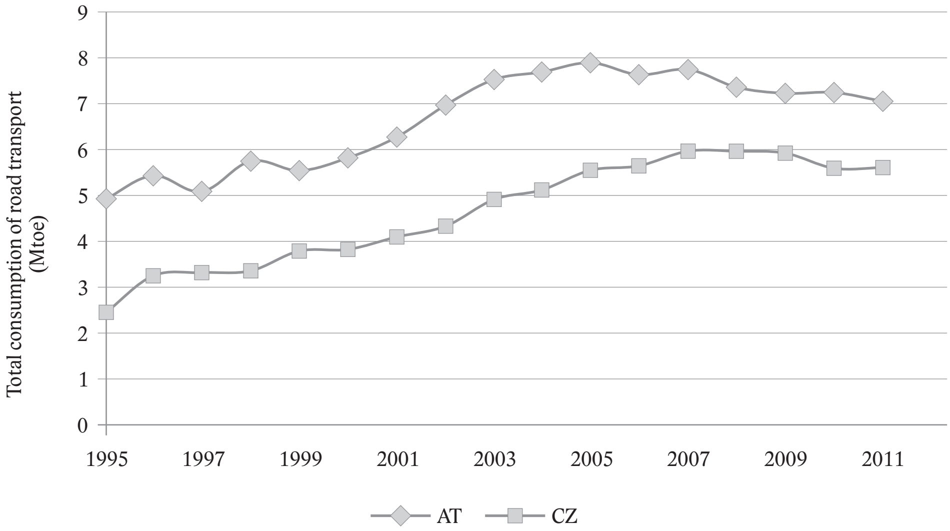

Fig. 5: Development of energy consumption in road transport in Austria and the Czech Republic (Data: ODYSSEE Database)

Figure 6 shows the development of the energy consumption of cars. The difference in the energy consumption of cars of about 1 Mtoe in Austria and the Czech Republic in 2000 was lost completely in 2007. In opposite to the stable development of energy consumption of cars in Austria, the increase in the Czech Republic was very rapid especially in the period 2000–2005.

10.4 Major indicators in car transport

The major parameters which have had an impact on the energy consumption in car transport are discussed in this section.

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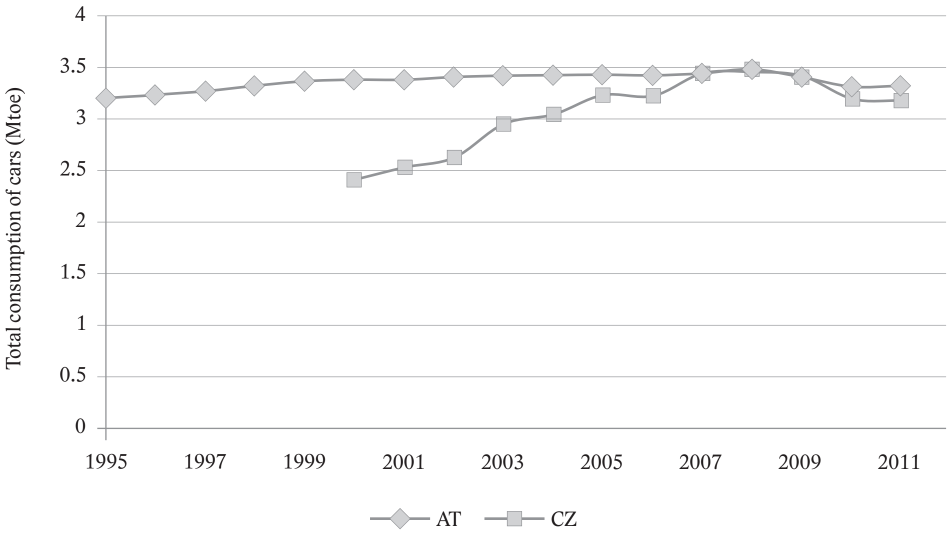

Fig. 6: Development of energy consumption of cars in Austria and the Czech Republic (Data: ODYSSEE Database)

One of the main contributors to the increasing energy consumption is the continuous growth of the car fleet. The development of the total stock of passenger cars in Austria and the Czech Republic is depicted in Figure 7.

The number of cars was increasing in both the countries in the period 1995–2011. This increase was 25% in Austria; it was even higher at 34% in the Czech Republic. There were about 70,000 more cars in the Czech Republic in 2011 than in Austria.

However, if we are looking at the numbers of cars per 1,000 inhabitants, the situation is different; see Figure 8. The car ownership level in Austria in 2011 was about 19% higher.

It is also interesting to look at the structure of the car fleet in Austria and the Czech Republic. Figure 9 illustrates the development of the car fleet in Austria by type of fuel used. A dieselisation process can be clearly recognised in Austria. In 2011, more than 55% of the total car fleet were diesel cars. The number of electric cars in 2011 was still very low, about 1,000. The number of LPG cars is slightly higher, about 3,500.

In the Czech Republic, the share of diesel cars in the total vehicle fleet is much lower compared to petrol vehicles. In 2011, the share of diesel cars was about 29%. Electro mobility is still negligible.

The number of new car registrations was relatively volatile in the last decades but increasing in both the countries after 2008; see Figure 11. During the period analysed, 50% more cars were registered on average in Austria than in the Czech Republic. In 2012, the average CO_2 emissions of new cars were 138 g of CO_2/km in Austria, and 171 g of CO_2 /km in the Czech Republic (ACEA-PG, 2013).

However, as shown in Figure 12, the total car fleet per GDP is much higher in the Czech Republic than in Austria, by about 55%.

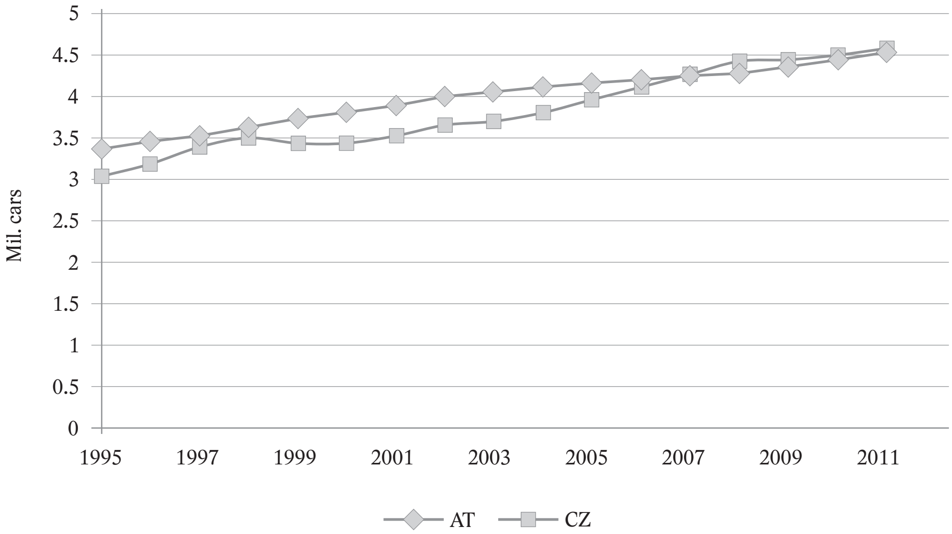

Fig. 7: Development of the stock of passenger cars in Austria and the Czech Republic (Data: ODYSSEE Database)

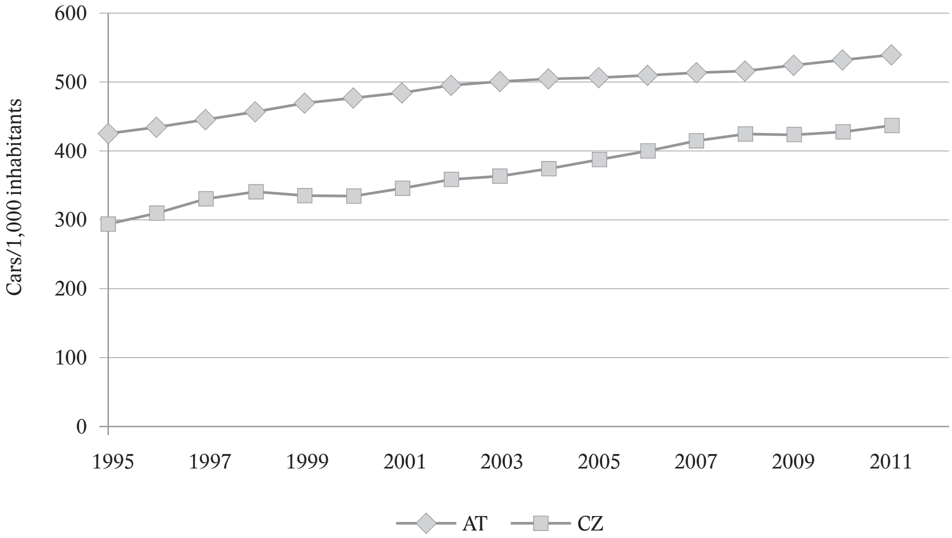

Fig. 8: Development of specific passenger car ownership in Austria and the Czech Republic (Data: ODYSSEE Database)

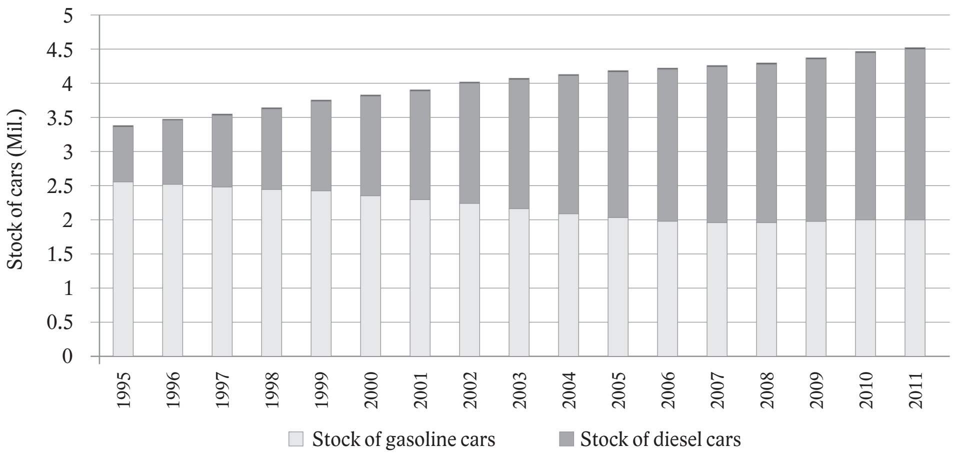

Fig. 9: Development of car fleet in Austria (Data: ODYSSEE Database)

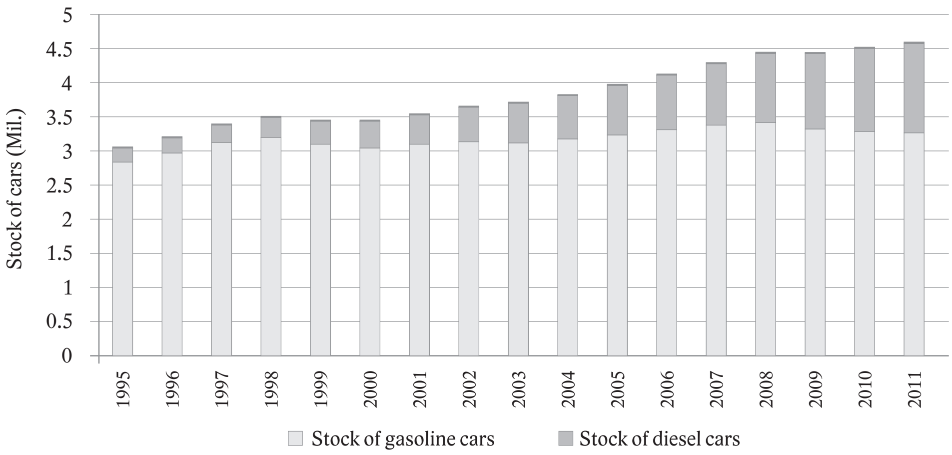

Fig. 10: Development of car fleet in the Czech Republic (Data: ODYSSEE Database)

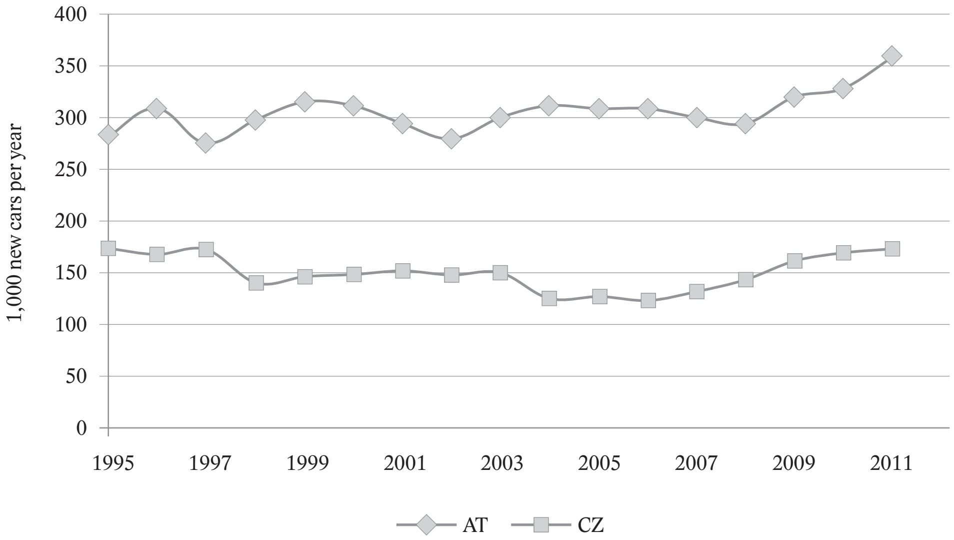

Fig. 11: The development of new registrations of passenger cars in Austria and the Czech Republic (Data: ODYSSEE Database)

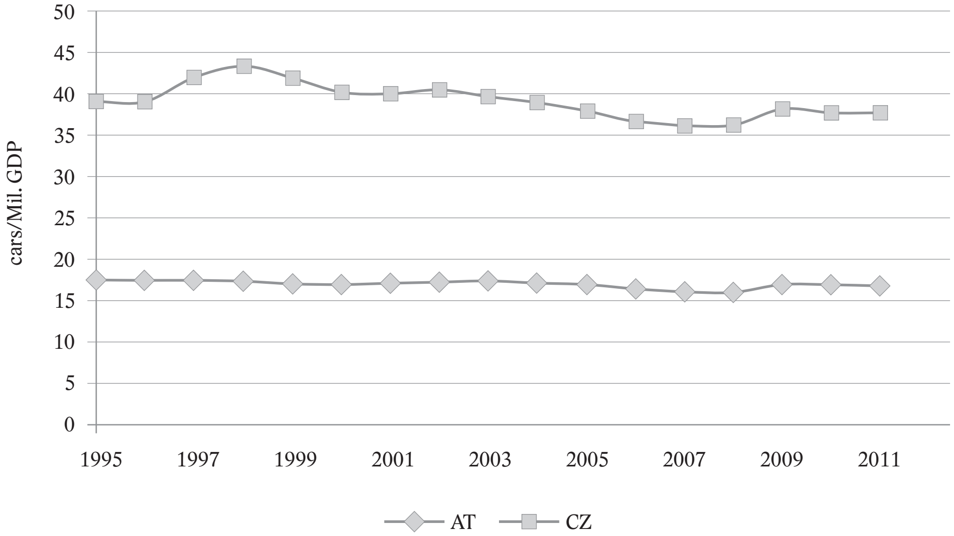

Fig. 12: Development of car fleet per million EUR of GDP in Austria and the Czech Republic (Data: ODYSSEE Database)

Taxes on acquisition		
Country	**VAT**	**Registration tax**
Austria	20%	Based on fuel consumption Maximum 16% + bonus/malus
Czech Republic	21%	None*
Taxes on ownership		
	Passenger cars	**Commercial vehicles**
Austria	Kilowatt	Weight
Czech Republic	Engine volume**	Engine volume/weight, axles***
Taxes on motoring		
EUR/1,000 litres	**Unleaded petrol**	**Diesel**
Austria	482	397
Czech Republic	512	437

Note:

** In 2009, the Czech Republic introduced a system of ecological taxes imposed on the first registration (imported cars) or the first re-registration (first sale from original first owner to next owner) of cars (four-wheeled cars up to 3.5 tonnes of weight) not meeting EURO 3 (and higher) emission standards. The tax ranges from CZK 10 thousand (EUR 400) for cars meeting only EURO 0 (cars manufactured before 1992), to CZK 5 thousand (cars with EURO 1 manufactured until 1995) to CZK 3 thousand (cars meeting EURO 2 manufactured until 2000).*

*** Liability insurance for cars, annual payment (possible system of bonus/malus) derived from the engine volume.*

**** Road tax imposed on any car used for entrepreneurial activities. Passenger cars pay based on engine volume and the time since the first registration (the tax is reduced by 48% during the first 36 months since the first registration, 40% during the next 36 months since the first registration and 25% during the third 36 months since the first registration. Cars with alternative fuels (LPG, CNG, electric cars, hybrid cars, E85) are exempted from the tax.*

Tab. 1: Motor vehicle taxation (ACEA, 2013)

Besides car fleet, travel activity also has an impact on energy consumption and consequently on GHG emissions from the transport sector. The development of average kilometres driven per car and year in the period 2000–2011 is illustrated in Figure 13 for Austria, and Figure 14 for the Czech Republic.

In Austria, the annual distance travelled by car was relatively stable over the last decade. The average numbers of kilometres driven by diesel cars and petrol cars were about 16,000 and 12,000 respectively.

In the Czech Republic, the travel activity by car was 4,000 km per year lower on average than in Austria. The difference in travel activity by petrol and diesel cars was also much higher, but decreasing after 2005.

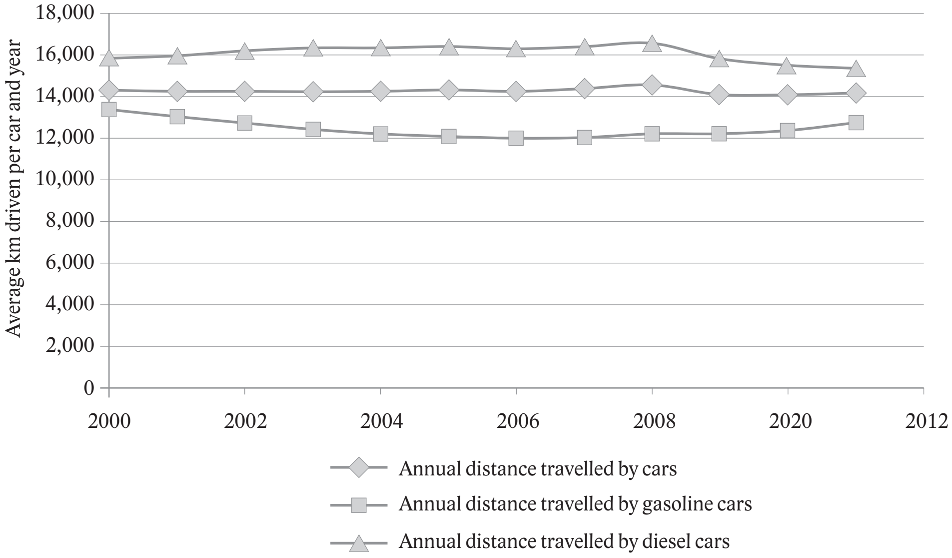

Fig. 13: Development of specific vehicle km driven in Austria (Data: ODYSSEE Database)

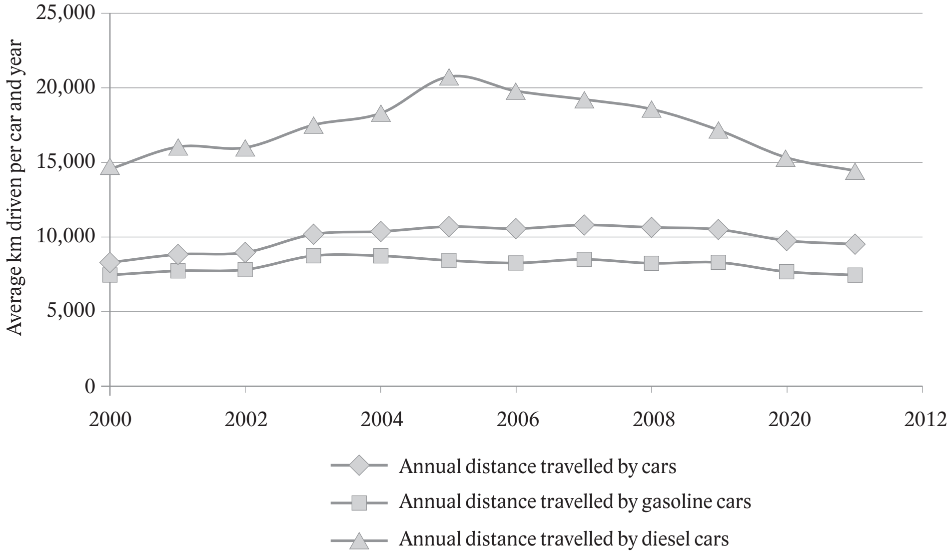

Fig. 14: Development of specific vehicle km driven in the Czech Republic (Data: ODYSSEE Database)

10.5 Energy policies

As discussed above, the transport sector is one of the largest emitters of GHG emissions. The major challenge for the EU climate and energy policy is to implement effective policies and measures to mitigate global warming, improve air quality and reduce energy consumption. To change the current trends and reduce the GHG emissions, the EU has set goals to increase the share of renewable fuels in transport and to improve energy efficiency. Some of the implemented measures are set at the EU level and are the same for all the EU countries, such as targets regarding CO_2 emissions from new passenger cars. On the other hand, there are many measures implemented at the national level which are very different from country to country. Also, the reasons for implementation of these measures as well as determination of the amount of the taxes are based on different criteria. Table 1 provides a comparison of acquisition, ownership and motoring (excise duties) taxes implemented in Austria and the Czech Republic.

10.5.1 Energy policies in Austria

In the period 2005–2011, GHG emissions from the transport sector in Austria dropped by about 13% (ECO, 2015). In the same period, emissions from newly registered cars decreased by 14%. One reason for these reductions is the fact that taxation of transport (exclusive fuels) in Austria is increasing and relatively high compared to other EU Member States – Austria is in the 7th place of all the Member States (Eurostat, 2012). A problem in Austria is the so-called "fuel tourism", which is responsible for about one third of the total transport GHG emissions according to the Austrian Ministry for Transport, Innovation and Technology. The major reasons for the fuel tourism are lower fuel prices in Austria than in the neighbouring countries as well as the country's geographic location.

Austria has implemented CO_2-based taxes with the goal to reduce its GHG emissions.

A fuel consumption tax (Normverbrauchsabsage or NoVA) is levied upon the first registration of a passenger car. It is calculated as follows:

– (CO_2 emissions in g/km minus 90 divided by 5) minus NoVA deduction/plus NoVA malus.

The deduction amounts to € 400 for petrol and diesel vehicles and € 600 for hybrid and other alternative fuel vehicles. Electric vehicles are exempt. The malus amounts to € 20 for each g/km emitted in excess of 250 g/km (ACEA, 2015).

Due to its high share of renewable energy in electricity generation, Austria has a very good basis for electro-mobility. In Austria, electric vehicles are exempt from the fuel consumption tax and the monthly vehicle tax. Hybrid vehicles and other alternative fuel vehicles benefit from an additional bonus under the fuel consumption tax.

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The EU Biofuel Directive (2003/30/EC) on the promotion of the use of biofuels and other renewable fuels for transport was transposed into Austrian national law in 2004. Since 2005, biofuels have been on the Austrian market, at first by mixing biodiesel with diesel and then since 2007 also by mixing bioethanol with petrol. In 2012, a total of 498,761 tonnes of biodiesel were used in the transport sector. The largest part, about 441,000 tonnes, was blended with fossil fuels and about 58,000 tonnes were used as pure biofuel or biodiesel with a higher biofuel component. Bioethanol was mostly used as an additive, in total about 106,000 tonnes. During 2012, the annual substitution target of 5.75% was surpassed at 6.77%. The promotion of biofuels is mainly based on quotas and tax exemptions (Winter, 2011).

Additional policy measures such as speed limits, a traffic control system and eco-driving are only partly implemented in Austria.

10.5.2 Energy policies in the Czech Republic

The carbon dioxide emissions decreased by 2.5% during the period 2005–2012 (reaching 17.74 million t of CO_2 in 2012) while the number of passenger cars increased by almost 19% (4.706 million cars in 2012) and the number of lorries increased by 43% (595 thousand lorries in 2012). The reasons for the carbon dioxide emission stagnation when the numbers of registered cars are quickly increasing is primarily the high average age of the registered cars (e.g., the average age of a passenger car was 14.29 years in mid 2014), continuous substitution of old cars with new cars and the increasing share of cars with diesel engines.

One of the biggest problems in the transport sector in the Czech Republic is the high average age of passenger cars and especially the very high share of cars older than 10 years and insufficient substitution of the passenger car fleet (the substitution rate with new cars is only 3.51%; if imported used cars are added, the total substitution rate is still only 7.19% – far below the recommended minimum rate between 8 and 10%).

The Czech Republic has recently introduced (since 2009) an ecological tax for old cars that is aimed at reducing the numbers of very old cars. The tax is imposed on the new owner (buyer) during the re-registration process (only first re-registration) or the first registration in the Czech Republic (imported cars). The tax ranges from CZK 3 to 10 thousand (see above for details).

Cars used for entrepreneurial purposes (regardless whether they are part of company property) are subject to a "road tax". The rate of the road tax is derived from the engine volume for passenger cars – e.g., cars with an engine volume between 1500 and 2000 ccm are obliged to pay CZK 3000 (EUR 135). New cars are eligible for a road tax reduction during the first 6 years; see above for details. Lorries are charged according to the number of axles and weight – e.g., lorries with 3 axles and a weight between 13 and 15 t should pay CZK 10.5 thousand/year (EUR 420), lorries with 3 axles and above 36 t pay CZK 50.4 thousand/year (EUR 2016). Vehicles with alternative fuels are exempted from the road tax; see above for details.

Excise tax is imposed on mineral fuels used in transportation (diesel, petrol). In October 2014, the Czech Republic re-introduced the system of "green diesel" – i.e., reduction of excise tax for diesel used in agriculture. The excise tax is currently (2014) CZK 12.84/l of petrol and CZK 10.95/l of diesel (EUR 0.514/l of petrol and EUR 0.438/l of diesel)[24].

Alternative fuels, such as LPG and CNG (compressed natural gass), are currently significantly preferred through reduced consumer tax compared to the taxation on petrol and diesel. The excise tax on CNG is currently (2014) CZK 34.2/MWh (or EUR 1.368/MWh), which is CZK 0.36/m^3 only (or EUR 0.0144/m^3) – the excise tax on petrol is approx 40 times higher. Despite the continuous growth of this excise tax (CZK 2.81/m^3, or EUR 0.1124/m^3 from 2020), the tax will be significantly lower than that on petrol and diesel. LPG is charged with CZK 3933/t, or EUR 157.3/t (which is only approx CZK 2.15/l, or EUR 0.086/l).

The total consumption of FAME[25] amounted to 228 thousand tonnes in 2013 (while the domestic production was 181.7 thousand tonnes). The domestic consumption of bioethanol (for transportation) amounted to 84.4 thousand tonnes (while the domestic production was 104.4 thousand tonnes). It is expected (according to the national action plan for sustainable biofuels for 2015–2020) that the Czech Republic will spend approx. CZK 11 billion (EUR 440 million) on biofuel support in the period 2015–2020.

10.6 Conclusions

The development of energy consumption in passenger transport in the Czech Republic and Austria shows similar trends. In both the countries, the energy consumption increased tremendously between about 1998 and 2010. Since then, there have been some signs of stagnation probably due to higher prices in recent years (and also due to the economic recession after the year 2008 when so called financial crisis started).

Regarding the development of the fleet of passenger cars in the Czech Republic and Austria, it is most interesting that in recent years the car fleet in the Czech Republic has grown much more steeply than in Austria and will probably surpass it this year (2014).

Since both countries are EU Member states they have some common policies implemented which are set at the EU level (such as standards for CO_2 emissions from new passenger cars). However, there is also broad portfolio of national policies (such as taxes, promotion policies for electric vehicles, etc.) which are different in Austria and the Czech Republic.

Although in Austria the average numbers of vehicles kilometres driven per car is higher than in the Czech Republic as well as car ownership level, total energy

[24] *Exchange rate of CZK 25/EUR.*

[25] *'Fatty acid methyl ester' (FAME, biodiesel) is a methyl ester produced from vegetable or animal oil or fat.*

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consumption of cars in Austria and the Czech Republic is currently almost the same. This indicates that cars used in Austria have better fuel economy.

To cope with the environmental problems in transport sector both countries need further efforts related to the reduction of demand for cars as well as to the promotion of alternative fuels and automotive powertrains and other transport modes (e.g. public transport).

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Abstract

The book is a follow-up on the three previous books published since 2005. The book is the result of activities of the joint Czech-Austrian Energy Expert Group, which has been functioning as a formal joint scientific group since 2002 (based on a Czech-Austrian intergovernmental accord). A substantial part of the book contents presents results of joint research projects of Czech and Austrian experts in the period 2011–2014. Topics for inclusion in the book have been selected so that they reflect current issues that are faced by the energy industry and are of considerable consequence in decision-making on the future orientation of energy systems of both the Czech Republic and Austria in the context of evolving energy markets in the EU.

The energy industry has been undergoing significant changes in the recent years. In particular, the electrical energy industry is the subject of fundamental changes both in terms of the arrangement of electricity markets and with respect to changes on the supply and demand sides. One of the key problems currently faced by the electricity markets is integration of electricity from renewable sources into the power market and the related technical and economic issues. Questions concerning the future form of electricity markets are becoming increasingly important, also under the influence of the "merit order effect", where the power supply curve shifts as a consequence of massive power generation from RES, resulting in decreasing prices of power from conventional sources. Unlike conventional sources based on fossil and nuclear fuels, electricity generation from renewable energy sources is characterised by being more or less dependent on uncontrollable external environmental circumstances (momentary wind speed, amount of solar radiation, etc.). This increases demands on controlling power distribution grids in real time (to ensure stability of operation and reliability of power supply), including prediction of electricity market behaviour for business purposes, but it also affects planning of long-term development of power distribution grids in terms of both supply sources and transmission capacities. Among other things, the massive advances in utilisation of renewable energy sources, for both electricity and heat generation and substitution of conventional fuels in the transport sector, requires solutions to issues of energy storage and effective support to the entire renewable energy source sector.

Chapter 1 makes a general introduction to the issues of energy mix and coverage of energy demand in connection with the energy intensity of national economies and related greenhouse gas emissions. The chapter analyses the development of consumption of primary energy sources in the Czech Republic and Austria, analyses factors influencing their amounts, and compares the Czech Republic and Austria's positions with those of the EU 28 countries.

Chapter 2 focuses on the issues of developing utilisation of RES for electricity generation. It includes an analysis of trends of RES development in the CR and Austria, including the EU energy policy context. At the same time, it analyses the economic context of developing electricity generation from RES from the point of view of both induced costs and effectiveness of various support schemes.

Biomass is currently – and in an outlook for several upcoming decades – regarded as a very important, if not the most critical renewable source. Among others, the key issues here are the size of the biomass potential for use as an energy source (for production of electricity and heat, liquid biofuels and solid biofuels for decentralised use), and the identification of factors influencing that size.

Chapters 3 and 4 recapitulate the current situation and the outlook for biomass utilisation in the CR and Austria (again in the EU context), and deal in detail with the issue of methods for determining the biomass potential for the study territory. Chapter 3 contains a detailed description of a proposed procedure for determining the biomass potential of agricultural land (both conventional agriculture and cultivation of energy crops) using geographic information systems, deriving the biomass potential from the climate and soil conditions of each land unit.

The key issue when considering the future development of biomass as an energy source is its economic competitiveness. Since sources of easily available (and relatively cheap) residual biomass are factually exhausted in the advanced countries, further biomass development is only possible under the assumption of cultivating biomass for energy purposes on agricultural land. This entails competition in land use between conventional agricultural crops and energy crops. Another aspect is the competitiveness of biomass produced from energy crops vis-à-vis conventional fuels.

Chapter 5 presents the methodological procedures for building economic models for estimating minimum prices of biomass produced for energy purposes and specifies a theoretical procedure for assessing its competitiveness against conventional crops and fossil fuels. Application of the theoretical approaches is demonstrated on an example of the Czech Republic and selected energy crops.

Chapters 6, 7 and 8 deal with electricity market issues.

Chapter 6 analyses changes on electricity markets in connection with the progressing liberalisation of electricity markets in the EU and identifies the basic parameters affecting the price of electricity. Based on this analysis, it then describes changes in the structure and functioning of the electricity market.

In connection with that, Chapter 7 deals with modelling electricity prices on short-term electricity markets. The chapter focuses on the theoretical mathematical tools for analysing the behaviour of spot electricity markets and options for forecasting future energy prices, including potential volatility. Application of the theoretical tools is demonstrated on a case study.

Chapter 8 deals with economic effectiveness of electricity storage in high-capacity batteries in connection with the electricity generation diagram of a photovoltaic power plant (PVPP). It introduces a theoretical procedure for analysing the PV electricity generation diagram and its assessment in connection with the short-term electricity market, including appraisal of deviations. The method presented is demonstrated on a case study analysing real-world behaviour of 17 PVPP in the Czech Republic and assessing the effectiveness of installation of high-capacity batteries in grid nodes.

Chapters 9 and 10 make an analysis of two sectors important for both energy consumption and environmental impacts: the residential and commercial building sector and the transport sector. Both areas are also set in the context of developing utilisation of renewable sources of energy.

Chapter 9 focuses on the need for energy to secure operation of buildings, analyses consumption trends and derives the quantities of greenhouse gases associated with securing operation of buildings, and analyses options for reducing them as a result of measures to increase energy efficiency of buildings and of utilisation of renewable sources of energy. The issue is documented with an analysis of the Austrian residential and commercial building sector.

Chapter 10 analyses the transport sector from the point of view of energy consumption trends and the related greenhouse gas emissions. The analysis focuses primarily on identification of factors influencing energy demand mainly of passenger cars in the CR and Austria (and in the context of EU policies and goals). The chapter also includes analyses of current Czech and Austrian transport-related policies.

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