The double challenge: Limiting electricity demand growth while pushing forward electrification of energy demand – lessons from recent low-carbon roadmaps and scenarios for the EU

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Abstract

Several low-carbon energy roadmaps and scenarios have recently been published by the European Commission and the International Energy Agency (IEA) as well as by various stakeholders such as Eurelectric, ECF and Greenpeace. Discussions of these studies mainly focus on technology options available on the electricity supply side and mostly omit the significant challenges that all of the scenarios impose on the energy demand side.

A comparison of 5 decarbonisation scenarios from 4 of the most relevant recent scenario studies for the EU shows that all of them imply significant efficiency improvements in traditional appliances, usually well above levels historically observed over longer periods of time. At the same time they assume substantial electrification of transportation and heating. The scenarios suggest that both of these challenges need to be tackled successfully for decarbonising the energy system.

With shares of renewable electricity reaching at least 60 % of supply in 2050 in almost all of the decarbonisation scenarios, the adaptation of demand to variable supply becomes increasingly important. This aspect of demand side management should therefore be part of any policy mix aiming for a low-carbon power system.

Based on a quantitative analysis of 5 decarbonisation scenarios and a comparison with historical evidence we derive the (implicit) new challenges posed by the current low-carbon roadmaps and develop recommendations for energy policy on the electricity demand side.

Introduction

The European Union (EU) has set itself a long-term target of reducing its greenhouse gas (GHG) emissions by 80 to 95 % by 2050 relative to 1990; by 2011 GHG emissions were reduced by 17 to 18 % (EEA 2012a). As the use of fossil fuels is responsible for about 80 % of the EU's GHG emissions (EEA 2012b), it is obvious that a fundamental transformation of the energy system by the middle of the century is necessary to meet the target.

A number of scenario studies on the energy system of the EU have been prepared within the past few years attempting to show how the transformation towards a largely decarbonised energy system might be achieved. Various stakeholders and government bodies, including industry associations, environmental NGOs and the European Commission have commissioned these scenario studies. All scenario studies describe at least one scenario in which the EU's fossil fuel CO_2 emissions are reduced significantly, although the specific reductions by 2050 vary between roughly 65 % and 95 %. However, there are significant differences between the scenarios on how these emission reductions could or should be achieved. Differences are particularly pronounced in power generation, which today is responsible for more than one third of energy-related CO_2 emissions, but also in the transport and industrial sectors.

Interestingly, discussions within the scenario studies as well as the political debate on low carbon roadmaps in general typically focus on the supply side of the power sector. While a focus on the power sector is justified due to its current as well as its expected future relevance to the overall energy system, it seems inappropriate to us that the electricity demand side as well as the power system's interactions with the energy system as a whole are mostly neglected in current debates on low carbon roadmaps. As we will highlight in this article, considerable changes will be required in electricity demand within the next few decades. These changes will be a major prerequisite to successful decarbonisation of the electricity supply as well as the whole energy system and they will need immediate and significant political action.

Specifically, the challenge on the demand side is expected to be two-fold, as we will derive from an analysis of five different decarbonisation scenarios from four scenario studies:

- The efficiency of using electricity in today's typical electric devices (what we call 'conventional' electricity demand) will have to increase much faster than in the past so as to stabilise and eventually reduce 'conventional' electricity demand. At the same time additional electricity demand from entirely new products and services will have to be avoided or at least strongly discouraged.
- Electrification of certain technologies currently using fossil fuels (especially vehicles and heating systems) should be encouraged, so as to enable the demand sectors to profit from an increasing supply of low-carbon electricity.

It should be noted that none of the models used within the scenario studies analysed here are pure cost-optimisation models. Instead, a number of cost and non-cost assumptions are made for determining investment decisions on both the supply side as well as the demand side. So costs as well as other factors like public acceptance are considered to varying degree by the authors of the studies. However, it obviously cannot be ruled out that strategies different from those described in the analysed scenarios may also be able to reduce CO_2 emissions to a similar extent and at similar or even lower costs (e.g. even stronger use of renewables with less efficiency improvements). That said, we believe it is notable that a number of studies from different research groups and different clients all expect considerably stronger efficiency improvements than in the past to be part of a realistic vision of a future low-carbon energy system from today's perspective.

Following this introduction, the analysed EU energy scenarios will be briefly introduced in section 2. The subsequent section 3 will show that 'conventional' electricity demand is stabilised in all of the analysed low-carbon scenarios. Section 4 is focussing the additional electricity demand caused by the common strategy within the scenarios of electrifying considerable shares of both road transport and heating, while section 5 will discuss the interrelationship between the described demand side strategies on the one hand and electricity supply on the other. Finally, section 6 concludes.

Energy scenarios analysed

For our analysis of how electricity demand within the EU 27 may develop provided ambitious energy sector CO_2 emission reduction targets are to be met until 2050, we analyse and compare various scenarios found in well known studies released over the past few years. Scenarios from the following four studies have been chosen:

The study 'Power Choices – Pathways to carbon-neutral electricity in Europe by 2050' (Eurelectric 2009) was published in 2009 by Eurelectric, the union of the European electricity industry. The study aims to examine how a 'cost-effective and secure pathway to a carbon-neutral power supply by 2050' can be realised. One of the purposes of the study is to analyse the policy measures that will be required to attain deep cuts in carbon emissions by 2050. The study provides one reference scenario as well as one decarbonisation scenario.[1] The latter is called the Power Choices scenario. As the commissioning institution and the name of the study imply, the study's focus is on the power sector, especially on the sector's supply side. However, the entire energy system has been modelled for the study's scenarios.

The study 'energy [r]evolution – A sustainable EU 27 energy outlook' (Greenpeace/EREC 2012) was published in 2012 by Greenpeace International and the European Renewable Energy Council (EREC). The lead developer of the study's scenarios was the Institute of Technical Thermodynamics of the German Aerospace Centre (DLR). With this scenario study (as well as with similar national and global studies within the 'energy [r] evolution' series) the two organisations aim to show that significant improvements in energy efficiency combined with a rapid expansion of renewable energy technologies can lead to a sustainable energy system by mid-century. The study provides one reference scenario and one decarbonisation scenario. In the latter scenario the use of nuclear power in the EU 27 is eventually phased out and there is no reliance on power plants using carbon capture and storage (CCS) technology.

In late 2011, the European Commission released its 'Energy Roadmap 2050' study (EC 2011a, EC 2011b, EC 2011c). It contains two reference scenarios as well as five decarbonisation scenarios. While these decarbonisation scenarios all show a similar level of ambition with regards to CO2 emission reductions by 2050, they have different views on the technology mix in power supply and the level of energy consumption: In the Energy Efficiency scenario more radical progress in energy efficiency is achieved than in the other scenarios. The Diversified Supply Technologies scenario assumes that CCS and nuclear power are both technically and economically sound technologies that are publicly accepted, while in the Delayed CCS and Low Nuclear scenarios either CCS technology will take longer to be commercially available or nuclear power will have low public acceptance. Finally, the High RES scenario envisions a scenario in which the expansion of the use of renewable energy sources is stronger than in the other scenarios.

Finally, the study 'Energy Technology Perspectives 2012' (IEA 2012a) was published in 2012 by the International Energy Agency (IEA). This study differs from the other three studies analysed as it develops scenarios for the global energy system. However, the study also depicts key results for various world

1. While the scenario study includes only one main decarbonisation scenario, assumptions regarding four key elements of the energy system are modified in a sensitivity analysis of that scenario. These four elements are the level of reliance on nuclear power, the time it will take until CCS technology is available, the level of acceptance for onshore wind power plants and the rate of success of energy efficiency measures.

regions, including the EU. The description of the EU energy system mainly focuses on two scenarios: One reference scenario that envisions only limited policy efforts to mitigate climate change (called the 4DS scenario) and one decarbonisation scenario (called the 2DS scenario), which would be compatible with global efforts to (likely) limit the increase of the average global temperature to no more than 2 °C compared to pre-industrial times.

Table 1 shows an overview of the decarbonisation scenarios analysed in this paper. We chose to include only two of the five decarbonisation scenarios of the European Commission's study as electricity demand in these scenarios hardly varies, except in the Energy Efficiency scenario. We therefore chose this scenario as well as the Diversified Supply Technology scenario for our analysis, the latter being representative for energy demand in the four decarbonisation scenarios other than the Energy Efficiency scenario. In addition we use each study's reference scenario[2] to compare the decarbonisation scenarios with their respective 'business-as-usual' counterpart.

The far right column of Table 1 shows that while the decarbonisations scenarios vary in regard to the fossil fuel CO_2 emission reductions they achieve within the EU, ranging from about 65 % (2DS scenario) to 95 % (energy [r]evolution scenario), there is much higher agreement that emissions from the power sector can and will have to be reduced proportionally more, by 93 to 99 %.

We have also looked at two additional scenario studies: The Roadmap 2050 scenario study (ECF 2010) by the European Climate Foundation (ECF) has not been included in our quantitative comparisons as the data provided within this study was not detailed enough for our analysis. The data is almost exclusively on the power sector and much of the useful data is only shown for 2050, not for earlier years. The IEA's World Energy Outlook 2012 (IEA 2012b) is an update within the most well known series of energy scenario publications. However, while some data is provided here for the EU, the scenarios' time horizon is limited to the year 2035, while our analysis' time frame is longer (up to 2050).

'Conventional' electricity demand to be stabilised in low-carbon scenarios

Electricity demand for 'conventional' stationary uses has steadily increased since 1990 in today's EU-27 at an average annual rate of about 1.4 %. This trend is expected to continue in the reference scenarios of the studies analysed here, albeit at a slightly slower rate of about 0.8 to 1 % per year (see Figure 1)[3]. The low-carbon scenarios, however, expect (non-transport sector) electricity demand either to roughly stabilise at current levels and decrease after 2030 or to increase by about 10 % above current levels and stabilise or decrease after 2030.

The end in the trend of increasing electricity demand implies significant electricity savings in all low-carbon scenarios over their reference. By 2030 these savings are relatively evenly split between sectors in most scenarios as Figure 2 shows. The most significant exemption are the Power Choices scenario by Eurelectric, which allocates savings mainly to the tertiary and agricultural sector, and the IEA 2DS scenario, which shows much lower overall savings against an already lower reference (the 4DS scenario). By 2050 sectors contribute to a different extent to electricity savings. By then about three quarters of savings are achieved in the residential and tertiary sectors, while industry contributes a smaller share in most scenarios. Relative to the respective reference scenario, electricity savings range from 13 to 20 % by 2030 and 27 to 37 % by 2050.

These substantial electricity savings can only be achieved if electricity intensity improvements are significantly altered over historical rates. Already in the reference scenarios, as Table 2 shows, it is assumed that electricity intensities will not follow past trends in all sectors, apart from industry.

In industry, electricity intensity declined by about 0.9 % per year on average over the last twenty years. Reference scenarios expect comparable reductions of 0.6 to 1 % per year over the next four decades. The low-carbon scenarios expect a significant strengthening of intensity improvements to between minus 0.9 and minus 1.8 % per year.

In the tertiary sector the picture is much different. Historically, electricity demand per unit of value added increased by about 1 % per year, due to inter alia a significant expansion of information and communication technology (ICT) in the sector. This trend is not expected to continue in the reference scenarios. Instead the reference scenarios expect a decline of electricity demand per unit of value added of between 0.8 and 1.2 % per year for the decades to come. A similar decline in the electricity intensity of the tertiary sector occurred in Germany in the past, where the decline was 1 % per year on average between 1990 and 2010. The 2010 value of 96 MWh per Million Euro value added (AG Energiebilanzen 2012, Statistisches Bundesamt 2012) is well below the 2010 EU average of 115 MWh per Million Euro value added (own calculation based on data from Eurostat 2012). In the low-carbon scenarios the decrease of electricity intensity is projected to be much stronger in the future, at 2 to 2.8 % per year.

A weakening of the historical growth trend of per capita electricity consumption of about 1.3 % per year is also expected for the residential sector. In the reference scenarios the growth slows down to about 0.9 to 1 % per year, while in the low-carbon scenarios it is expected that per capita electricity consumption can be stabilised roughly at current levels.

'Low carbon' electric appliances drive future electricity demand growth

As shown before, the low-carbon scenarios analysed here require the successful implementation of additional energy efficiency policy measures. All decarbonisation scenarios show a relatively stable and in some cases even declining electricity demand in 'conventional' electricity use, as depicted by the solid lines in Figure 3. However, on top of conventional electricity demand, all of them assume additional electricity demand from new 'low-carbon' appliances which are expected to play an increasingly important role in reducing CO_2 emissions in both transport (by using electric vehicles) and low-temperature heat

2. As the reference scenario of the European Commission's study we chose the 'Reference' scenario over the 'Current Policy Initative' (CPI) scenario, which essentially is also a reference scenario.

3. A similar trend – although at a much higher per capita consumption – can be seen in the US where electricity demand growth is expected to come down to very low levels (cp. Sioshansi, 2013).

Table 1. Overview of decarbonisation scenarios analysed in this paper.

	Scenario philosophy	Demand sectors differentiated and model used	Final energy intensity change / electricity intensity change (per unit of GDP, 2010–2050)	Share of renewables / nuclear / CCS in 2050 EU electricity generation	EU fossil fuel / power sector CO_2 emission reduction by 2050 (vs. 1990)
Power Choices (Eurelectric 2009)	Cost-effectiveness should determine pathway to reduce CO_2 emissions	4: Household, tertiary, industry, transport PRIMES, bottom-up model, simulation	-2.6% / -0.6%	38% / 27% / 30%	75% / 93%
energy [r]evolution (GP/EREC 2012)	Deep cuts in CO_2 emissions are possible without reliance on nuclear and CCS	3: Household & tertiary, industry, transport MESAP/PlaNet, bottom-up, simulation (only used for supply side)	-2.7% / -1.4%	97% / 0% / 0%	95% / 97%
Energy Efficiency (EC 2011)	Realising available efficiency potential reduces need for low-carbon energy supply	4: Household, tertiary, industry, transport PRIMES, bottom-up model, simulation	-2.8% / -1.4%	64% / 14% / 20%	84% / 98%
Diversified Supply (EC 2011)	Focusing solely on market costs would lead to diversified electricity generation	4: Household, tertiary, industry, transport PRIMES, bottom-up model, simulation	-2.6% / -1.1%	59% / 16% / 24%	84% / 99%
2DS (IEA 2012)	EU contributing its share in global efforts to reach 2 °C target	4: Household, tertiary, industry, transport ETP model framework, bottom-up, simulation (with partial optimisation)	-1.8% / -1.2%	67% / 24% / 6%	n.s. (roughly 65% / 96%)

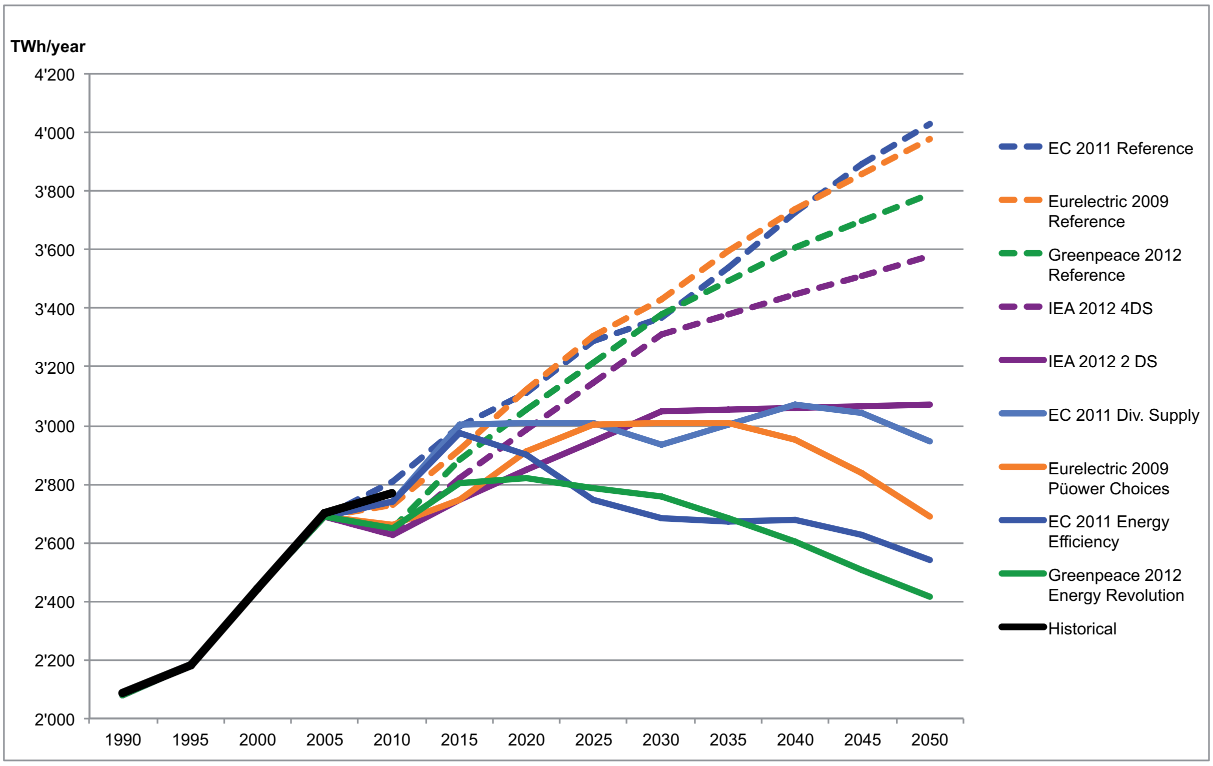

Figure 1. Electricity demand without transport sector, EU 27; Comparison of scenarios (dotted lines: Reference scenarios; bold lines: Low-carbon scenarios; values for IEA interpolated between 2009 and 2030 as well as between 2030 and 2050). Sources: Own figure, based on data from respective scenario studies and for historical data from Eurostat (2012).

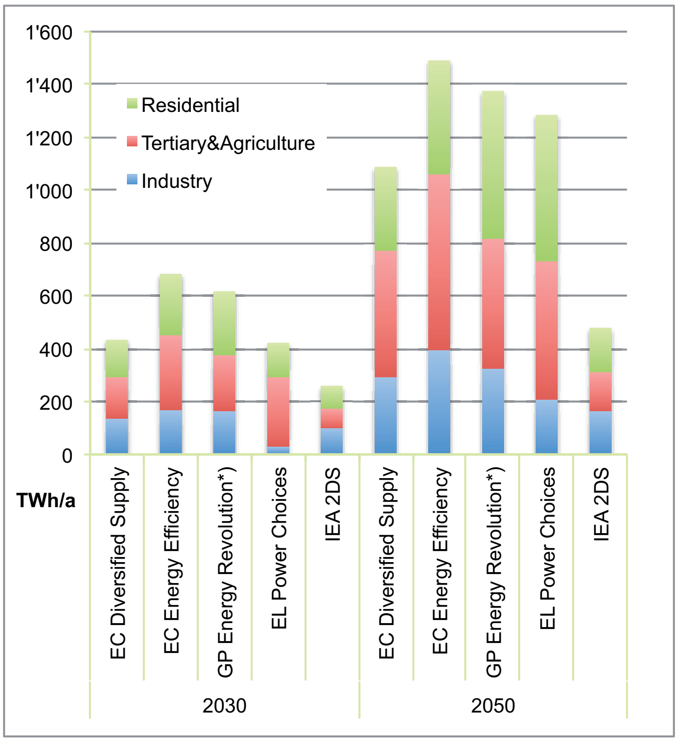

Figure 2. Electricity savings in low carbon scenarios vs. respective reference scenarios by demand sector without transport (EU 27). (*) Energy revolution: study does not separate residential and tertiary sectors, split estimated by the authors). Sources: Own figure, based on data from respective scenario studies.

Table 2. Annual change in electricity intensity*) by demand sector (EU 27).

	1990 –	2000 –	Reference Scenarios 2010 – 2050				Low Carbon Scenarios 2010 – 2050				
	2000	2010	EC	GP**)	EL	IEA	EC DS	EC EE	GP ER**)	EL PC	IEA 2DS
Industry	-0.8%	-0.9%	-0.9%	-1.0%	-0.6%	n.s.	-1.4%	-1.6%	-1.8%	-0.9%	n.s.
Tertiary& Agriculture	0.8%	1.2%	-0.8%	*n.s.*	-1.2%	n.s.	-2.0%	-2.8%	*n.s.*	-2.8%	n.s.
Residential	1.4%	1.3%	1.1%	*n.s.*	1.1%	0.9%	0.5%	0.2%	*n.s.*	-0.2%	0.5%

**) Industry; tertiary and agriculture: electricity use per unit of sectoral value added; Residential: electricity use per capita; **) for GP scenarios: study does not separate residential and tertiary sectors. Sources: Own calculations, based on data from respective scenario studies and on historical data from Eurostat (2012).*

supply (by using electrical heat pumps). Figure 3 shows that the scenarios project electricity demand to continue to grow – albeit at different paces – when electricity demand in the transport sector is included (dashed lines). This observation indicates the key relevance of developments in the transport sector for future total electricity demand.

The significant potential for additional electricity demand from the transport sector as well as from heat pumps can also be highlighted when looking at an individual household: Electricity demand in a future three-person household equipped with efficient appliances according to current best available technology can be assumed to be around 2,100 kWh per year – not taking any electric mobility or heating pumps into account (Wuppertal Institute 2009). Should this three-person household own an electric car, this car might consume an additional 3,400 kWh per year.[4] Assuming the household occupies a very energy-efficient building, its use of a heat pump might lead to an additional annual electricity consumption of 1,350 kWh.[5] Obviously the household can save significant amounts of fossil fuels like petroleum and heating oil or natural gas when it switches to electric mobility and/or a heat pump.

4. This number is based on the following assumptions: Private car travel per person of about 11,300 km per year (EC 2011), electric car energy consumption of 14 kWh/100 km (WWF 2009) and average car occupancy of 1.4 persons.

5. This number is based on the following assumptions: Dwelling area of household of 150 m2, annual heating demand of building of 15 kWh/m2 (Passive house), domestic hot water demand per person of 600 kWh per year and average annual performance factor of heat pump of 3.0. The household's annual electricity demand for space heating would be 750 kWh and for domestic hot water 600 kWh.

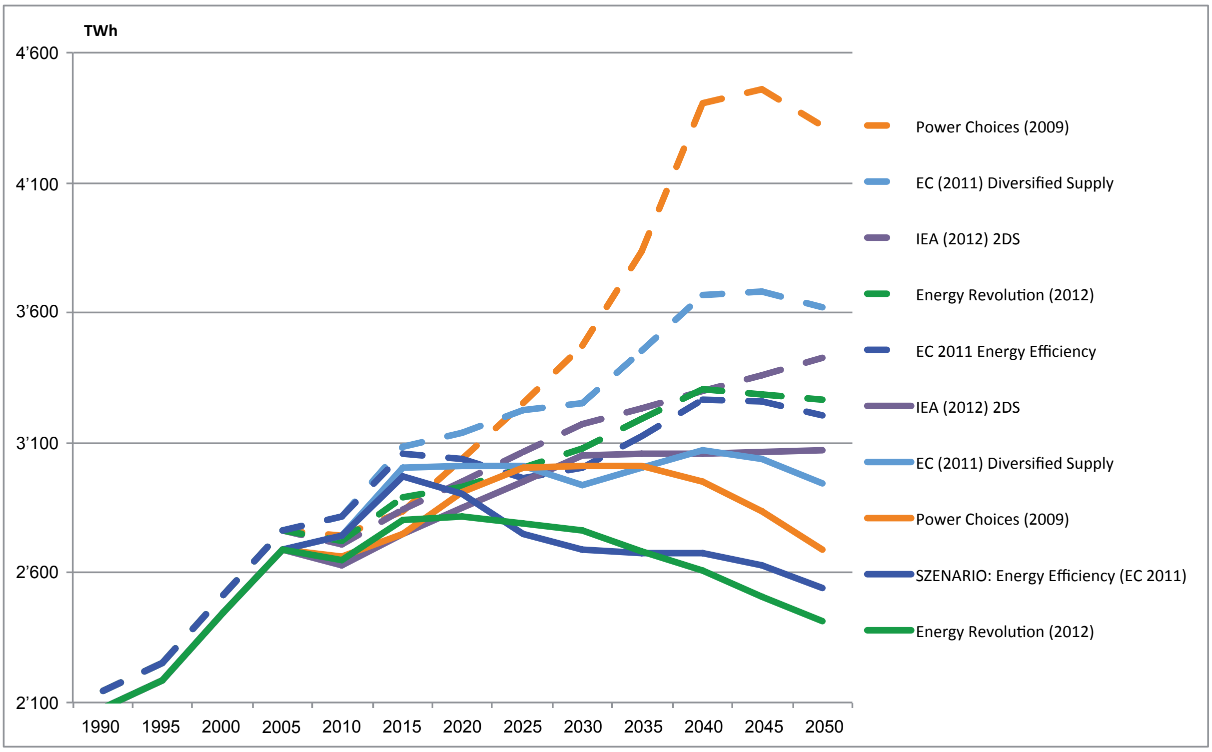

Figure 3. Electricity demand in the decarbonisation scenarios with (dashed lines) and without (bold lines) the transport sector. Sources: Own figure, based on data from respective scenario studies and for historical data from Eurostat (2012).

ELECTRIC MOBILITY AS MAIN DRIVER

While all decarbonisation scenarios show that additional electricity demand will arise in the transport sector, a closer look at Figure 3 shows there is considerable disagreement within the scenario studies on exactly how much electricity could be used in the transport sector in the decades to come. Table 3 highlights this disagreement. While transport electricity demand in the IEA's 2DS scenario will grow modestly (compared to the other scenarios) from 68 TWh in 2010 to roughly 370 TWh in 2050, the increase is much stronger in the analysed decarbonisation scenarios of the European Commission's Energy Roadmap 2050 study, where the sector's electricity demand reaches between 660 and 680 TWh/a by 2050. The increase is even stronger in the energy revolution scenario by Greenpeace/EREC, where demand reaches roughly 850 TWh/a and it is by far strongest in Eurelectric's Power Choices scenario, where more than 1,600 TWh/a (or 38 % of total final electricity demand) will be consumed in the transport sector by the middle of the century. While large-scale market penetration of electric vehicles is the main reason for this growth in electricity demand in all the decarbonisation scenarios, some modal shift from road and aviation passenger transport and from road freight transport to rail is assumed in many of the scenarios, especially in the energy revolution scenario and the 2DS scenario. In the energy revolution scenario most of the heavy-duty vehicle traffic is also shifted to electricity by 2050, either indirectly by using hydrogen or directly by using either overhead catenary lines or battery technology.

Not included here is the electricity required to produce hydrogen for the transport sector. Hydrogen use is negligible or small (less than 5 % of the sector's final energy demand) in all decarbonisation scenarios except for the energy revolution scenario. Here 30 % of the sector's final energy demand will be met by hydrogen by 2050, while its relevance is low before 2030 (less than 5 %). If the electricity used to generate the hydrogen were added to direct electricity demand, transport sector electricity consumption in the energy revolution scenario would be in a similar range as the Power Choices scenario.

Due to the electrification of road transport the share of electricity in the transport sector's total final energy demand increases in the decarbonisation scenarios from today's negligible share of less than 2 % to between 10 and 63 % in 2050.

Two main reasons can be given for the considerable differences among scenarios on transport sector's electrification and the respective demand:

- The first reason is the ambition level of decarbonisation of the transport sector. In the energy revolution scenario, for example, the sector's CO_2 emissions are reduced by 96 % between 2009 and 2050, while the Power Choices scenario and both of the EC's decarbonisation scenarios emissions reduce CO_2 by 77 % and 70 % respectively in 2050 compared to 2010. The IEA study does not provide a figure for the sector's CO_2 emissions, but as in the 2DS scenario in 2050 fossil fuels still provide about 7 EJ of final energy (which is roughly 50 % of the 2010 level), emissions can be expected to be only about 50 % lower in 2050 compared to 2010. Not surprisingly, those scenarios in which the overall CO_2 or GHG reduction target leads to more ambitious CO_2 reductions in the transport sector (energy revolution scenario and Power Choices scenario), also use more (low carbon) electricity (directly and indirectly via hydrogen) in transportation.

Table 3. Transport sector electricity demand and share of transport energy in the decarbonisation scenarios (in TWh/a / %).

	1990	2000	2010	2020	2030	2040	2050
Actual (from Eurostat)	63 2%	72 2%	68 2%				
EC 2011 – Diversified Supply Technologies				134 3%	316 8%	596 18%	675 25%
EC 2011 – Energy Efficiency				134 3%	316 8%	585 18%	664 25%
eurelectric 2009 – Power Choices				125 3%	462 12%	1.452 49%	1.628 63%
Greenpeace/EREC 2012 – energy revolution				111 3%	315 12%	701 35%	854 50%
IEA 2012a – 2DS				103 n.s.	120 n.s.	246 n.s.	372 10%

Sources: Data taken from respective scenario studies and historical data from Eurostat (2012).

- Secondly, assumptions vary considerably about the availability of biofuels, the alternative low-carbon transportation fuel apart from electricity and hydrogen. While biofuels supply about 30 % of the sector's final energy demand in 2050 in the two EC scenarios as well as in the IEA's 2DS scenario, their share is only 8 % in the energy revolution scenario, where biofuels are used solely for heavy-duty vehicles, ships and planes, but not in private cars. In the Power Choices scenario the share of biofuels is only 1 %.

Despite the differences in absolute growth, all analysed decarbonisation scenarios show the strongest increases (in absolute terms) in the sector's electricity demand in the two decades between 2020 and 2040. This means that they need a break-through of road-based electric mobility in mass markets around 2020.

When interpreting the shares of electricity in the transport sector's total final energy demand, provided in Table 3, it should be kept in mind that electric engines are considerably more efficient than fossil fuel engines. This means that the share of electricity in the transport sector, when expressed in terms of distance travelled, is much higher than the shares in final energy demand. For example, energy consumption of an average light duty vehicle in the EU is around 7 to 8 litres of gasoline (equivalent) per 100 km. In contrast, energy demand of a typical (pure) electric vehicle today is around 20 kWh/100 km or a little less, according to the literature (IEA 2011, WWF 2009), which equals roughly 2.3 litres of gasoline per 100 km. Even if we assume that until 2050 the average gasoline and diesel powered LDV in the stock will be considerably more efficient at 4 litres of gasoline-equivalent per 100 km, and electric vehicles will only improve more modestly to a consumption of 15 kWh/100 km (=1.7 litres of gasoline per 100 km) (WWF 2009), this would still mean electric vehicles are about 2.5 times as efficient as fossil fuel powered vehicles.

Assuming this relationship between fossil fuel use and electricity use holds in the entire transport sector, this would mean, for example, that the share of electricity in the decarbonisation scenarios of the European Commission in 2050 grows from 25 % when expressed as a share of final energy demand (see Table 3) to roughly 45 % when expressed as distance travelled. As air travel cannot be powered by electricity (though hydrogen-powered airplanes are possible) and electrification of heavy-duty vehicles in freight transportation is not foreseen in most scenarios, the share of electric vehicles in distance travelled by road passengers can be expected to be much higher still. For example, the study by the European Commission (EC 2011) mentions that in its decarbonisation scenarios, 'almost 80 % of private passenger transport activity is carried out with [plug-in hybrids or pure electric] vehicles by 2050'. This underlines the enormous transformation that is required in the scenarios in respect to passenger vehicle sales. All decarbonisation scenarios that provide information on passenger vehicle sales indicate that by 2050 at least 80 % of passenger vehicles sold would be either plug-in hybrid or pure electric vehicles or fuel cell vehicles.

FUEL SUBSTITUTION BY ELECTRIC APPLIANCES IN THE HEATING SECTOR AS AN ADDITIONAL FACTOR

Low-carbon electricity may not only be "exported" to the transport sector but may also be used in stationary appliances to substitute (fossil) fuels. Due to the conversion of the electricity supply the primary energy factor as well as the emission factors will significantly decrease in the future and thus make it much more attractive as a means to save energy and reduce emissions also in the heating sector. Particularly for low-temperature heat generation – which is mainly needed for heating purposes of (well-insulated) buildings – heat pumps can be up to three times more efficient in terms of final energy use than fuel combustion. The low-carbon scenarios therefore assume that parallel to the increasing availability of low-carbon electricity, significant amounts of electricity are consumed to substitute fuels used for stationary heat generation. However, most studies do not provide detailed information, neither on the amount of electricity used for heat pumps and similar technologies, nor on the market shares of these technologies.[6]

6. It should be noted that heat pumps are not the only option available for reducing the CO2 emissions of heating. Expanding the use of district heating may also reduce CO2 emissions as fuels can be used more efficiently (e.g. by using the waste heat of industrial processes or power plants). However, the deep emission reductions required in the long term are not feasible with fossil fuel based district heating due to a lack of zero carbon fuels, so only those countries with considerable biomass potential are likely to choose to significantly expand district heating in a

Table 4. Electricity use for stationary 'low carbon appliances' in different scenarios (2050, EU 27).

	Heat pumps in buildings*) (in TWh/a)	Heat pumps in industry (in TWh/a)	Total (in TWh/a)	Share of heat pumps in stationary electricity demand
GP/EREC (2010): energy [r]evolution scenario	24	33	57	2%
GP/EREC (2010): adv. energy [r]evolution scenario	78	55	133	3%
EC (2011): Energy Efficiency scenario	>350	n.s.	>350	>13%
ECF (2010): Alternative scenarios	500	200	700	14%

*Data are not made explicit in most scenario studies, therefore the table provides also data for studies not analysed here in detail; *) residential, tertiary and agricultural sectors. Sources: Heat pump data for the Greenpeace/EREC scenarios is based on personal communication (Pregger 2011), data for the EC scenario is own estimate based on data provided in that study (EC 2011a, b, c) and data for the ECF study is taken from that study (ECF 2010).*

Table 4 provides some data on electricity use for heat pumps that was either obtained or was estimated by the authors. It shows that the scenarios by Greenpeace/EREC (2010) assume electricity use for these new appliances to remain below 150 TWh, corresponding to 2 to 3 % of stationary electricity use by 2050. The EC efficiency scenario as well as the ECF alternative scenarios, however, assume higher shares of about 13 to 14 % of the electricity to be used by heat pumps. In spite of their relatively moderate share of electricity use, heat pumps play an important role for decarbonisation. In the EC Energy Efficiency scenario the share of electricity for heating and cooling will increase from less than 10 % to more than 20 % of final energy demand (EC 2011b). Assuming that the electricity for heating purposes is fully used by heat pumps, these pumps will supply more than 40 % of heating of all buildings, given their higher efficiency compared to other final energy carriers.

For industry the situation is slightly different. Here only a small share of heat is used for space and water heating purposes, where heat pumps can be operated efficiently. However, the majority of fuels in the industry sector is used for high-temperature processes which are not suited for heat pumps and thus the use of electricity typically is not associated with high efficiency gains. In steel making, for example, more electricity could be used instead of fuels depending on the quality of the steel needed. Large-scale fuel switching to electricity and/or to hydrogen could consume huge amounts of additional low-carbon electricity, provided this electricity is available. E.g. converting all of the current EU oxygen steel production of about 100 million tons per year (Pardo et al., 2012) to electricity-based steel production would lead to an additional electricity consumption of between 345 and 395 TWh (cp. Ahman et al. 2012)[7]. Such substitution processes, however, do not seem to be assumed (to a significant extent) in the low-carbon scenarios.

The relevance of low carbon electric appliances for the supply strategy

The described demand-side strategies within the policy scenarios are not only an important prerequisite for the decarbonisation of the energy system, but they also determine to a large extent the strategies on the electricity supply side.

- On the one hand they influence the future load profile of the electricity system with strong electricity savings in peak and middle load hours and additional demand from electric mobility and heating being smartly directed into base load times (cp. Eurelectric 2009).
- On the other hand they heavily influence electricity sales.

As shown in the previous chapters, the decarbonisation scenarios reveal two opposing trends in electricity demand.

- They assume a significant speeding up of electricity efficiency in order to achieve a decoupling of electricity demand from economic growth and stable or even declining conventional electricity consumption.
- This trend is contrasted with an increasing use of low-carbon electricity in transport and in low temperature heat supply as well as for generating hydrogen. The use of electricity for all three of these purposes is motivated by both, the increasing supply of low-carbon electricity and the higher efficiency of electric appliances in transport and low temperature heating (compared to the traditional fossil fuel powered alternatives).

While the specific assumptions concerning the further electrification of the transport sector can be identified relatively easily in the scenarios analysed here, the electrification of low temperature heat is not specifically documented within the scenarios. As shown before, by the middle of the century electric-

decarbonised future. In the Energy Roadmap 2050 mitigation scenarios (EC 2011) the share of district heating within overall heating in the EU 27 declines. In contrast, in the energy revolution scenario (Greenpeace/EREC 2012), the only other decarbonisation scenario providing explicit figures for district heating, the share of district heating increases based on the use of not only biomass but mainly of solar collectors and geothermal energy used in a district heating setup. The differences described in these two studies highlight that decarbonisation scenarios typically agree that both electricity (largely based on renewable energy sources) as well as renewables (biomass, geothermal and solar energy) will displace fossil fuels in the supply of low-temperature heat, but that there is uncertainty about both the future relative shares of these new fuels and the scales in which the new technologies will be used (individual household-level plants vs. district heating plants).

7. Ahman et al. (2012, 30f) cite an electricity consumption of 3.45 to 3.95 MWh per ton of steel for reduction hydrogen and 3.7 MWh for electrowinning.

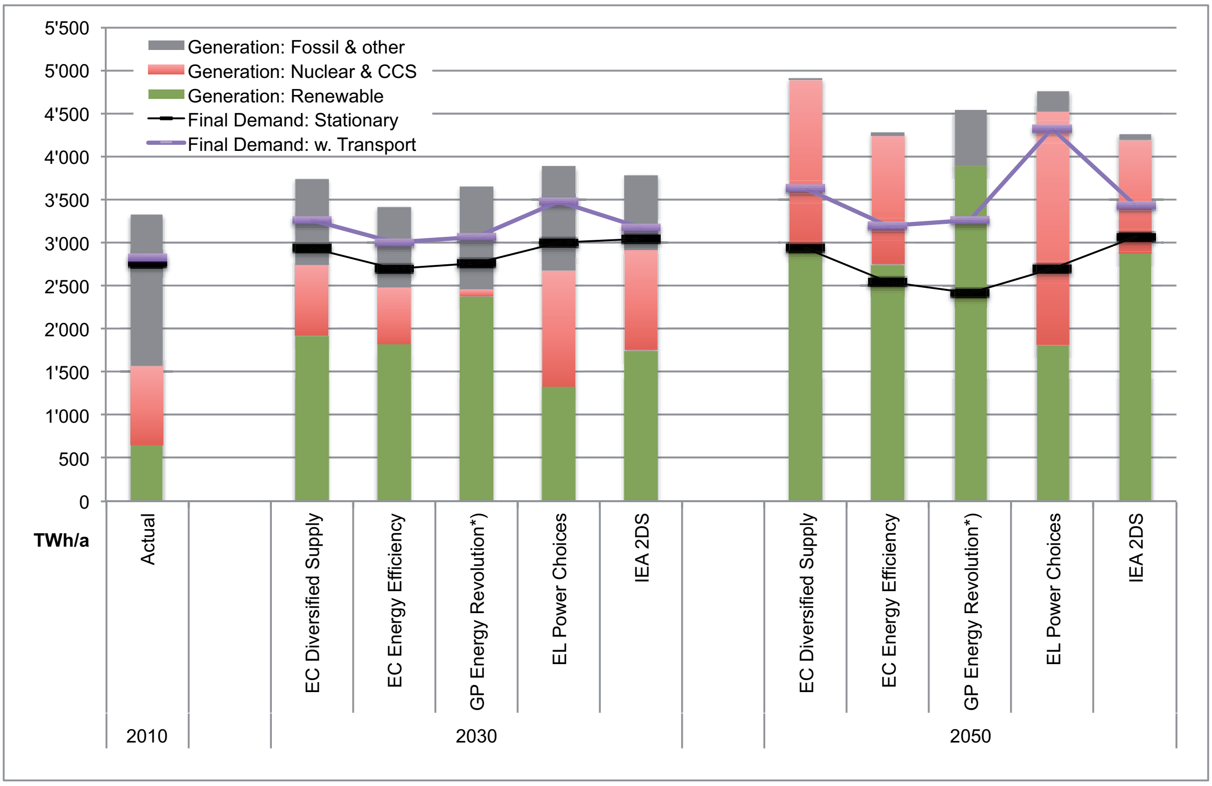

Figure 4. Electricity supply and final demand in decarbonisation scenarios for 2030 and 2050 (EU 27). Sources: Own figure, based on data from respective scenarios studies and for historical data from Eurostat (2012).

ity demand for low temperature heating could be up to 15 % of overall stationary electricity demand. A third way of 'exporting' low-carbon electricity is the generation of hydrogen for substituting natural gas or oil in all demand sectors, but mainly in industry and transport. This strategy, which may also be used for load management purposes (i.e. helping to balance electricity demand and increasingly fluctuating electricity supply), is employed in most of the decarbonisation scenarios after 2030 and is probably the reason for the higher difference in 2050 in most scenarios between final electricity demand and electricity generation (see Figure 4)[8].

Figure 4 shows again that stationary electricity use will not grow further in the low-carbon scenarios – even though these scenarios all include (although to a different extent) new stationary electricity appliances such as heat pumps. Given the expected expansion of renewable electricity, low- or zero-carbon electricity (i.e. electricity from renewables plus electricity from nuclear and CCS) will supply almost all of the final electricity demand of stationary uses by 2030. The remaining fossil fuel power generation will 'only' supply losses and additional transport demand. By 2050 RES electricity will suffice in three of the five scenarios to completely supply stationary electricity; leaving the remaining fossil (mostly with CCS) and nuclear generation to cover the additional electricity demand in transport, as well as electricity demand for hydrogen production and losses.

For the electricity supply this means that the demand side developments are an important enabler of higher RES shares in electricity generation due to their load balancing effects. However, as the scenarios show, by 2050 any non-RES electricity generation may only be necessary if a very strong expansion of the electricity market via the transport sector and hydrogen generation will be successful. Conventional power plant development should therefore rather focus on providing balancing capacity than on providing bulk supply of electricity. Depending on demand side developments it may thus prove unnecessary and costly to invest today in CCS and nuclear power plants, which both (but especially CCS plants) are technically and economically more suited to provide base-load instead of peak-load power.

Conclusion

The decarbonisation of the EU's energy system and particularly the electricity system is an important challenge. The discussions on respective strategies have been mainly focussed on the electricity supply system and the role of different low-carbon generation technologies such as nuclear power plants, fossil fuel power plants with CCS and technologies using renewable energy sources (see e.g. Finon 2013 and Lechtenböhmer & Luhmann 2013).

Our meta-analysis of five decarbonisation scenarios from four recent studies on the EU 27 energy system shows, however, that the electricity demand side is crucial for the successful realisation of these low-carbon scenarios. All of them assume

8. The Power Choices scenario (Eurelectric 2009) is the only one of the analysed scenarios in which hydrogen does not seem to play a role in the future energy system. Of the remaining scenarios, the Energy Revolution scenario (Greenpeace/EREC 2012) is the only one that provides separate and quantitative information on the final energy use of hydrogen.

a significant speeding up of electricity savings over historical trends in conventional electricity applications. This is particularly the case for the tertiary sector, which in the past has been a major driver of increasing electricity demand. This first observation highlights the fact that any decarbonisation strategy needs a strong integrated policy for electricity efficiency, which should be capable of leading roughly to a doubling of past rates of electricity intensity decreases in the industrial sector, of reversing the trend of increasing electricity intensity in the tertiary sector and of stabilising per capita electricity use in the residential sector despite a significant increase in the use of electric heat pumps. All studies analysed here agree on this finding – regardless of their different visions of low carbon electricity supply.

The challenge of saving significant amounts of electricity compared to the current trend is made more difficult by the fact that all scenarios envisage a significant growth of new 'low carbon' electricity use such as electric vehicles and electric heat pumps as an important element of the decarbonisation of the entire energy system. The challenge on the demand side will therefore be two-fold:

- Electricity use that is *not* substituting fossil fuels should be discouraged and the emergence of new such appliances should be reduced as far as possible. This could be achieved by high electricity prices for non prioritised electricity which might be combined also with legal requirements that impose tight standards on new appliances or those that are expanding e.g. air conditioning.
- At the same time the use of electricity for vehicles and heat pumps needs to be encouraged.

Policy instruments for these opposing challenges could be:

- Stronger price increases for transport and heating fuels compared to electricity prices.[9]
- Tailored legal measures such as minimum standards for all appliances that help to reduce their electricity demand.
- Specific regulation for buildings and transport in order to incentivise the (efficient) use of electricity in these sectors.
- Introducing white certificates which allow electricity suppliers to sell more electricity to their customers if they help customers reduce fossil fuel use. This would incentivise both, efficiency investments as well as measures that convert fossil fuel based energy services to electricity based energy services.

From a methodological point of view demand side strategies are not displayed as transparently as would be desirable, given their relevance for a successful decarbonisation of the energy system. Future studies should lay more emphasis on this part of the energy system and should also better disclose their respective data and assumptions, e.g. by using data rosters such as the one developed by Fischedick et al. (2012). Furthermore, studies are needed that analyse how energy efficiency strategies can best combine different policy measures in order to discourage the use of 'traditional' electricity use on the one hand while on the other hand encouraging the (efficient) electrification of certain areas of energy demand.

Overall, we conclude that demand side action concerning electricity use is urgently required to reach a low-carbon energy system. Its focus should initially be on significantly speeding up electricity savings in the 'conventional' use of electricity, as this is a paramount prerequisite for any successful energy system decarbonisation strategy. Subsequently, electrification of certain forms of energy demand should be aimed for, which is important to 'export' low-carbon electricity from the power generation sector to the demand sectors. These two demand side elements are – together with the expansion of renewable electricity generation – the most important elements for achieving a decarbonised electricity supply within a decarbonised energy system.

9. While increases in the price of electricity would help realise available efficiency potentials in traditional electricity applications, they would – on their own – discourage the substitution of fossil fuels through (increasingly low-carbon) electricity. Therefore it would be desirable to not only increase electricity prices but to also increase fossil fuel prices to an even stronger extent. (Obviously, any such strategy would have to include policy measures to help low income households cope with higher energy prices.)

References

Ahman, M., Nikoleris, A & L.J. Nilsson (2012): Decarbonising industry in Sweden an assessment of possibilities and policy needs. Lund University, Department of Technology and Society – Environmental and Energy Systems Studies, Report No. 77, Lund.

AG Energiebilanzen (2012): Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990 bis 2011, http://www.ag-energiebilanzen.de/viewpage.php?idpage=139.

Eurelectric (2009): Power Choices. Pathways to carbon-neutral electricity in Europe by 2050, www.eurelectric.org/PowerChoices2050/.

EC – European Commission (2011a): Energy Roadmap 2050, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0885:EN:NOT.

EC – European Commission (2011b): Energy Roadmap 2050 – Impact Assessment, Part 1/2, http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part1.pdf.

EC – European Commission (2011c): Energy Roadmap 2050 – Impact Assessment, Part 2/2, http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part2.pdf.

ECF – European Climate Foundation (2010): Roadmap 2050 – A practical guide to a prosperous, low-carbon Europe, Volume 1, http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf.

EEA – European Environment Agency (2012a): Approximated EU GHG inventory: early estimates for 2011, http://www.eea.europa.eu/publications/approximated-eu-ghg-inventory-2011/at_download/file.

EEA – European Environment Agency (2012b): Annual European Union greenhouse gas inventory 1990–2010 and inventory report 2012, http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2012/greenhouse-gas-inventory-2012-full-report.pdf.

Eurostat (2012): Eurostat database, http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

Finon, D. (2013): Institutions and electricity systems transition to decarbonisation. The hidden change of the market regime, Paper in print, Climate Policy, Special Issue: Low Carbon Drivers for a Sustainable World.

Fischedick, M. et al. (2012): Power Sector Decarbonisation: Metastudy, http://www.sefep.eu/activities/projects-studies/metastudy-full.pdf.

Greenpeace, EREC – European Renewable Energy Council (2010): energy [r]evolution – Towards a Fully Renewable Energy Supply in the EU 27, http://www.greenpeace.org/belgium/Global/belgium/report/2010/7/Energy_Revolution_En.pdf.

Greenpeace, EREC – European Renewable Energy Council (2012): energy [r]evolution – a sustainable EU 27 energy outlook, http://www.greenpeace.org/eu-unit/Global/eu-unit/reports-briefings/2012%20pubs/Pubs%203%20Jul-Sep/E%5bR%5d%202012%20lr.pdf.

IEA – International Energy Agency (2011): Technology Roadmap – Electric and plug-in hybrid electric vehicles, http://www.iea.org/publications/freepublications/publication/EV_PHEV_Roadmap.pdf.

IEA – International Energy Agency (2012a): Energy Technology Perspectives 2012 – Pathways to a Clean Energy System. Paris.

IEA – International Energy Agency (2012b): World Energy Outlook 2012, Paris.

Lechtenböhmer, S., Luhmann, H.-J. (2013): Decarbonisation and regulation of Germany's electricity system after Fukushima, Climate Policy, Special Issue: Low Carbon Drivers for a Sustainable World, Vol. 13, No. S01, S146–S154, http://dx.doi.org/10.1080/14693062.2013.754605

Lechtenböhmer, S., Samadi, S., Schneider, C. (2011): The Potential Role of Energy Efficiency in the Transition to a Low Carbon Society – A Critical Scenario Review. ECEEE 2011 summer study, Efficiency First, p. 125-136.

Pardo, N. Moya, J.A. & K. Vatopoulos (2012): Prospective Scenarios on Energy Efficiency and CO_2 Emissions in the EU Iron & Steel Industry, European Commission Joint Research Centre Institute for Energy and Transport, Luxembourg: Publications Office of the European Union, 2012

Pregger, T. (2011): Personal correspondence via email; Thomas Pregger of the DLR's Institute of Technical Thermodynamics kindly provided additional data on electricity consumption of heat pumps and electric cars in the Greenpeace/EREC (2010) scenarios.

Sioshansi, F.P. (2013): Why Demand Growth is Out, Energy Efficiency is in, and the Important Implications of the Two, IAEE, First Quarter 2013, 121–125.

Statistisches Bundesamt (2012): Volkswirtschaftliche Gesamtrechnung – Inlandsproduktberechnung, Lange Reihen ab 1970, https://www.destatis.de/DE/Publikationen/Thematisch/VolkswirtschaftlicheGesamtrechnungen/Inlandsprodukt/InlandsproduktsberechnungLangeReihenPDF_2180150.pdf?__blob=publicationFile.

Wuppertal Institute (2009): Sustainable Urban Infrastructure – Munich Edition – paths toward a carbon-free future, http://www.siemens.com/entry/cc/features/urbanization_development/all/en/pdf/study_munich_en.pdf.

WWF (2009): Modell Deutschland – Klimaschutz bis 2050, http://www.oeko.de/oekodoc/948/2009-054-de.pdf.