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Oil resources and future supply

Although no decisive conclusions or quantitative assessments can be made with respect to the global oil resource base, the remaining resources appear to be sufficient to meet baseline demand up to 2030. Significant resources have already been discovered beyond the proven reserves, there is a large potential to enhance the recovery rate from fields already in production, many prospective regions remain to be fully explored, and there are vast volumes of recoverable unconventional oil. However, it is also clear that global supply of oil will continue to be tight, both in the medium term as well as in the long term, mainly as a consequence of above-ground factors, such as investment constraints, geopolitical tensions, limited access to reserves, and mature super-giant fields. The production of unconventional oil and synthetic fuels will probably not significantly alter this situation. Therefore, there is a distinct possibility that global oil production will peak or plateau in the relatively near future, not as a result of finite resources, but because too many factors over a long time have constrained investments in exploration and production. However, it is important to emphasise that this assumption is only valid for prevailing market conditions and policies, which may well change over time. For instance, a concerted global effort to mitigate climate change may, by itself or together with concerns for energy security, significantly reduce the long-term demand for oil.

The aim of the work presented in this chapter (cf. Kjärstad and Johnsson, 2009) is to disclose how much oil has already been discovered, how much more oil can be extracted from already discovered fields, and how much oil remains to be discovered. Therefore, rather than looking at proven oil reserves, we have concentrated on uncovering the total discovered resource base on the levels of: 1) country; 2) oil company; and 3) oil field. This strategy was chosen because the relevance of proven reserves has become increasingly inflated over time and it is evident that there is a continuous transformation of resources over time from sub-commercial reserves to commercial reserves. In addition, considerable effort has been put into investigating resource growth in existing fields and into locating remaining prospective basins for undiscovered oil. The present analysis is to a large extent based on the build-up of three databases: 1) an Oil Field database (OF db); 2) an Oil Field Project database (OFP db); and 3) a database that contains statistical data from some 30 international oil companies (OC db) (see Chapter 1 in the *Methods and Models* book). The databases were compiled because no such databases exist today that are publicly available, and since it was considered vital to acquire comprehensive and accurate knowledge of the oil market. Also, it was desirable to reveal the weaknesses and strengths of current estimates of the global oil resource base and projections of future production levels.

SUFFICIENT RESOURCES TO 2030

The oil resource base and the prospects for future oil supplies in light of demand scenarios from the IEA (2006, 2007), EIA (2006, 2007a), and ExxonMobil (2007) have been examined by assessing the available data and literature related to the oil market. Although no decisive conclusions or quantitative assessment can be made with respect to the oil resource base, resources appear to be sufficient to meet baseline demand up to 2030. This is due to several factors:

- Most of the investigated oil companies and countries have already discovered resources that are substantially larger than the proven reserves. Many of these resources will be transferred to reserves over time.
- There is still a large potential for resource growth in fields that have already been discovered.
- Several countries that have passed the peak production level may very well raise production in the future relative to current levels.
- Although it is impossible to quantify, the prospects of finding more oil appear promising.
- There are very large deposits of unconventional oil.
- There is a modest, albeit increasing, contribution from synfuels.

PROSPECTS OF OIL PRODUCTION

Figure 21.1 shows the cumulative global production of conventional oil between 1856 and 2005. Cumulative global production amounted to around 1080 bbls (billion barrels) at the end of 2005 (Figure 21.1 shows production from year 1900 but includes production from year 1856 onwards), and as projected by IEA (2006) up to 2030 with IEA's growth rate over the last period extrapolated to 2050, together with depletion of resources. It is assumed that there are between 3.3 and 3.7 trillion barrels (Tbls) of ultimately recoverable conventional oil, which corresponds to current high-end estimates of ultimate recovery.

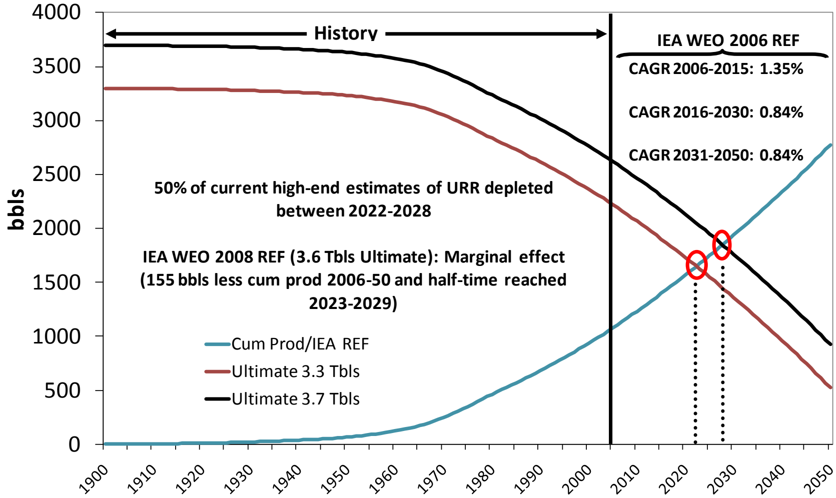


Figure 21.1. Depletion of conventional global oil reserves assuming 3.3 and 3.7 Tbls of ultimately recoverable reserves (URR) of oil as of January 1st, 2006 and assuming demand as outlined by the IEA (2006, 2008) up to 2030, with annual growth rate over the last period extrapolated up to 2050. (CAGR: Compounded Annual Growth Rate). Sources: EIA (2007b); BP (2007); ExxonMobil (2007); CERA (2006).

As indicated in Figure 21.1, 50% of all conventional resources will have been produced somewhere between 2022 and 2028, which implies that maximal or plateau production will be reached some years earlier, since most of the largest fields will be very late in their production cycles by that time-point. In the EU and Norway, the situation is even more alarming, with production having declined by almost a third since 1999/2000. Since production in Norway and the EU will continue to decline rapidly, the EU's dependency on imports is likely to remain at a high level, as envisaged in the Market and Policy Pathways.

Figure 21.2 shows three different cases of resource additions after a field has been discovered. In Figure 21.2a, real oil production in four Norwegian oil fields is illustrated by the red line, while the yellow area represents the estimated production when the Plan for Development and Operation (PDO) was submitted to the Norwegian Oil Department. Figure 21.2b shows the initial estimate of reserves in the Weyburn field in Canada (260 million barrels, mmbls) and how vertical and horizontal infills raised reserves by 80 mmbls, while an additional 120 mmbls is expected to be recovered through CO_2 injection, i.e., that reserves will be increased by over 75%. Figure 21.2c shows that cumulative oil production in the USA between 1977 and 2007 amounted to 75 bbls (red bar to the right), while over the same period, proven reserves declined by only 12.3 bbls (from 33.6 to 21.3 bbls). The bar to the left shows how these additional reserves (75 bbls minus 12.3 bbls) could be produced, illustrating that only 7 bbls were due to new field discoveries, while the remaining 56.7 bbls were attributable to extensions, adjustments, and new reservoir discoveries in already discovered fields.

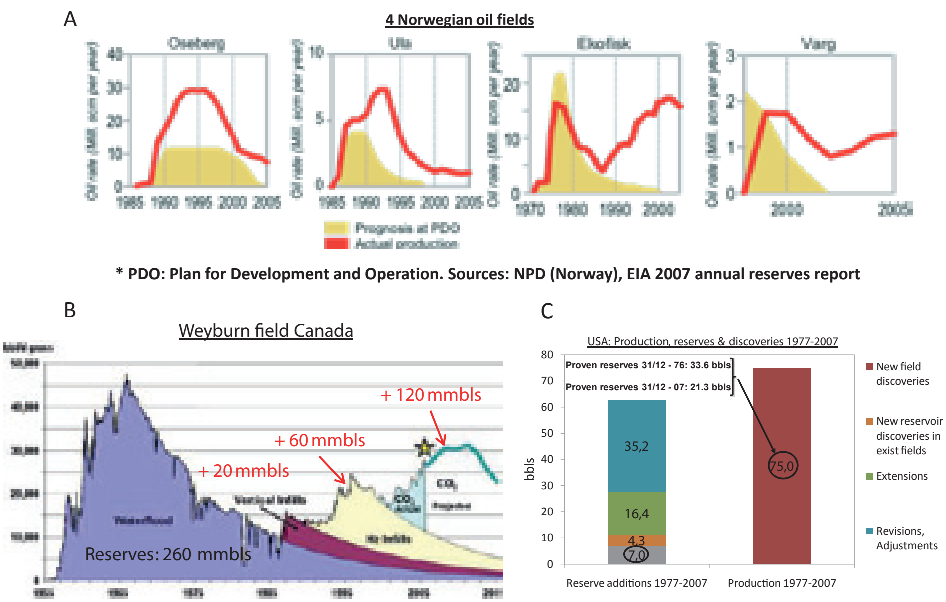


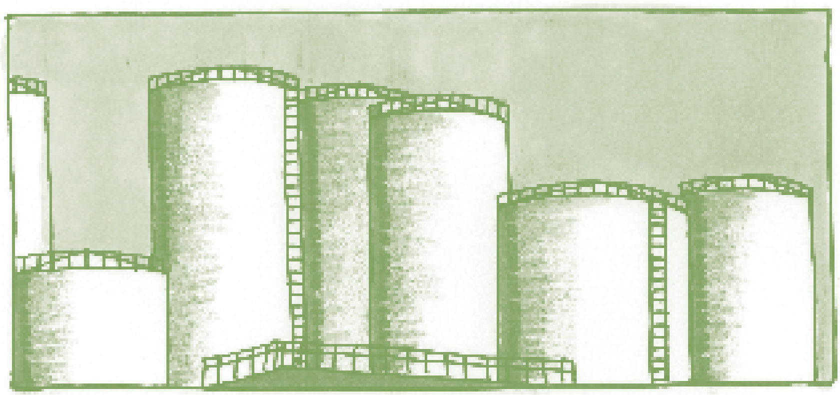
Figure 21.2. Growth in oil resources in: a) four Norwegian oil fields (from NPD, 2006, with permission); b) the Weyburn field in Canada (from IEA 2008, with permission); and c) the USA between 1977 and 2007 (EIA, 2008). For a detailed explanation, see the text above the figure.

LIMITATIONS OF THE OIL SUPPLY

Although the resource base appears to be large, the oil will have to be produced and transported to the market in a timely manner to meet increasing demand, which is a completely different matter. The global supply of oil will probably continue to be tight, not only in the medium term but also in the long term. The main reasons for this are the rapid decline in production levels in Mexico and the North Sea, slow progress of announced projects in some countries, limited access to large resources in the Middle East, Russia, and Venezuela, budgetary constraints for some large National Oil Companies, geopolitical tensions, unwillingness among producers to build up a costly surplus production capacity. There is also the fact that new oil will increasingly have to be produced from an increasing number of small fields and will have to be discovered and produced in more difficult environments. Furthermore, the present condition of several of the world's twenty ageing super-giant fields, which together account for almost a quarter of global production, are unknown. There are indications that, for instance, the super-giant fields in Iraq and Iran have been mismanaged in the past, leading to considerable problems in maintaining field productivity. The production of unconventional oil is likely to increase rapidly in Canada, while the prospects for growth in this area in Venezuela are more uncertain. Nonetheless, the share of global oil production represented by unconventional oil is unlikely to exceed projections, for instance those made by the IEA (2006), i.e., less than 5% in 2015 and 8% in 2030. The production of oil shale in the US will probably not have reached a significant level up to at least 2020, and possibly not until 2030. Likewise, the production levels of other synfuels, such as GTL (gas to liquid), CTL (gas to liquid), and BTL (biomass to liquid), will only have marginal contributions in the medium term, and it may be decades before the technologies for synfuel production play anything more than a marginal role in the global fuel supply.

Given the above analysis, it is difficult to project anything other than a continued tight supply of oil, even in the long term. It seems likely that global oil production will peak or plateau in the relatively near future, not as a consequence of limited resources, but because too many factors over a long period of time have constrained investments in the exploration and production of oil. However, it is important to emphasise that this assumption is valid only for prevailing market conditions and policies, which are subject to change over time. For instance, a concerted global effort to mitigate climate change may in itself or together with concerns for energy security, significantly reduce the long-term demand for oil. Concerns regarding energy security are already leading to efforts to curb growth in the demand for oil in China, USA, and Europe, and significant commitments to reduce CO_2 emissions will mean drastic measures to reduce the consumption of fossil fuels, including oil.

Oil production costs are expected to rise in both non-OPEC countries and the Middle East countries. Non-OPEC oil production costs are set to increase as oil increasingly will have to be produced in deepwater and Arctic regions and as the contribution from unconventional oil increases. Oil production costs are expected to rise also in the Middle East as an increasing number of smaller fields will have to replace production from declining super-giant fields, although the rise in costs will originate from a considerably lower base level than the costs in non-OPEC countries.



The lack of transparency within the oil industry prevents accurate analyses of future production levels and supply capabilities. Moreover, the ability to analyse the sector is likely to become more difficult as oil will increasingly have to be sourced from those countries that today have poor transparency in the oil sector. Countries in the western hemisphere will be increasingly dependent upon a few countries in the Middle East and Russia, not only for their supply of oil but also for the supply of gas, which to a large extent will be utilised for power and heat generation. Under these circumstances a responsible policy should seek to enhance energy security, which should be directed towards promoting energy efficiency measures (reduce demand) in combination with the increased utilisation of indigenous fuel resources, including coal. This should be in combination with Carbon Capture and Storage (CCS), so as to meet carbon emission targets.

For more information:

Jan Kjärstad
Energy Technology, Chalmers

Further reading:

Kjärstad J., Johnsson F., 2009. Resources and future supply of oil. Energy Policy 37 (2): 441-464.

22

Prospects for the European gas market

This chapter discusses the prospects for increased consumption of natural gas within the European Union (EU) up to 2030. Particular emphasis is placed on the power generation sector, in which the main growth in demand is expected to occur, on supply and infrastructural constraints, and on the future price of natural gas. Future gas demand in the EU will partially depend on the level of continued restrictions on CO_2 emissions, the penetration levels of nuclear and renewable energy, and the extent to which the option to store CO_2 in subsurface reservoirs will be exercised. Nevertheless, it is clear that the EU requirement for gas imports will increase substantially, driven by a combination of increasing demand and declining production. As a result, there will be an increased import dependency, which will affect the security of supply, not only in the gas sector, but also in the electricity sector. However, the number of suppliers will also increase, enhancing diversification and thereby contributing to improvements in energy security. An abundant supply to the EU markets and increased competition will mean that Russia will lose market share in the short term, particularly since piped Russian gas is not competitive on the main growth markets, i.e., Germany, France, Greece, Italy, Spain, and the UK. Nevertheless, in the long term, it can be expected that EU dependency on gas from Russia and the Middle East will increase. A critical factor is the large and timely investments that are required along the entire fuel chain to meet increasing demand, often in regions with uncertain investment conditions. An over-supply of gas in the near-term will continue to depress gas prices, possibly leading to increasing demand, in particular within the power sectors in the EU and USA as a consequence of efforts to mitigate climate change that may lead to a fuel switch from coal to gas. Traditionally, the price of gas has been linked to the oil price through long-term ToP (Take or Pay) contracts. If this linkage continues, a tight oil supply will create an upward pressure on the gas price.

Details on the methodology applied in the study presented in this chapter, are to be found in Kjärstad and Johnsson, (2007). The information on the supply sector was obtained by systematically examining each potential supplier to the global gas market with respect to the resource base, existing and planned short-term and long-term export channels, as well as the financial position and political environment of each supplier. The demand side was studied with respect to all aspects of the gas market within the six largest gas-consuming and gas-producing countries within the EU. It included past and projected gas demand structures, gas market and industry structures, transport and distribution infrastructures, level of liberalisation of the gas market, security of supply, and gas pricing issues. In particular, a comprehensive analysis was carried out on the past and future gas demand in the power sector, as the major growth in gas demand within the EU is expected to occur in this sector. For the other member states, the analyses were restricted to gas demand in the power sector. In addition, demand and supply were analysed for the North American market, since North America and the EU are the two main markets for the Atlantic LNG (liquefied natural gas) basin. The gas transmission sector was examined by investigating the existing and planned import channels with respect to capacity, vulnerability and security of supply and, for planned projects, the likeliness of the project being carried out. Finally, the information on the distribution sector was obtained by mapping and analysing the main pipelines and potential congestion points within each of the six largest gas-consuming EU countries. Since the information on the natural gas market is comprehensive and this market is currently undergoing a dramatic and dynamic transformation, the data had to be systematically collected and organised, which led to the establishment of several new databases, including a global gas field database, a global database for LNG and re-gasification plants, and a database of European pipelines (see Chapter I in the *Methods and Models* book for a more detailed description of these databases). In addition, the Chalmers Power Plant database (see Chapter 2 in the *Methods and Models* book) was applied to analyse future demand in the power sector.

DEMAND FOR NATURAL GAS

The global demand for natural gas has increased continuously over the last two decades, mainly driven by a drastic increase in the demand for natural gas in the power generation sector. However, natural gas markets have changed dramatically over the last few years, partly due to the fact that the global economic recession has weakened the demand. According to the IEA (2010), global demand for natural gas decreased by more than 3% in 2009, while European demand decreased by nearly 6%; the IEA does not expect European demand to recover to the 2008 level before 2013. In addition, increased production of unconventional gas, and the commissioning of several new LNG plants, have resulted in an abundance of natural gas on the market. As a result, spot prices for gas have plummeted, which has increased the pressure on long-term contracted prices and oil price indexing (see below). This situation is likely to continue for some years, as several countries, including EU Member States, have intensified the search for indigenous unconventional gas resources (see below) which, together with growing global LNG production capacity, is likely to lead to continued downward pressure on gas prices, thereby increasing the competitiveness of natural gas as the preferred fuel in the power sector.

The increased use of gas as a fuel in the power generation sector over the last decades is evident from the capacities of existing and planned thermal power plants, as distributed by fuel and age in Figure 22.1. The data in Figure 22.1 have been taken from the Chalmers Power Plant database, which contains all existing and planned power plants within the EU with a capacity of at least 10 MWe (see Chapter 2 in the *Methods and Models* book).

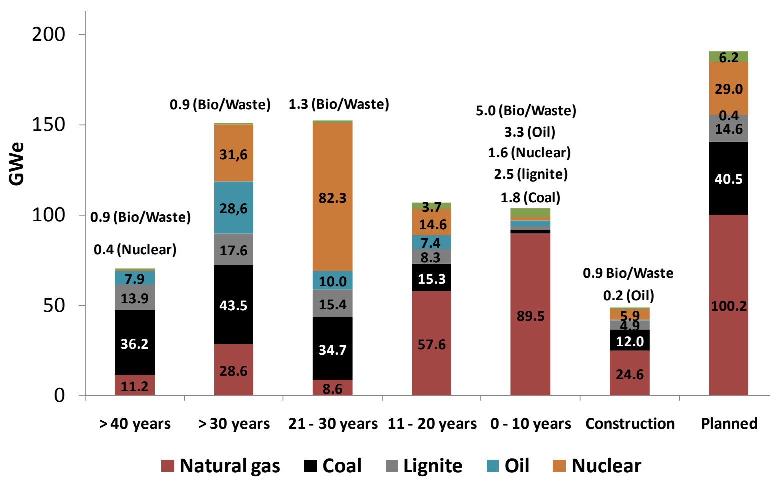


Figure 22.1. Capacity distributions by fuel and age for existing and planned thermal plants in the EU. Data obtained from the Chalmers Power Plant database, December 2010.

Currently, fossil-fuelled power plants with a combined capacity of almost 200 GW are either under construction or planned within the EU, of which about 125 GW will be fuelled by natural gas. Nevertheless, at least five factors will determine the continued growth in gas demand within the power sector in Europe:

- EU decisions on CO_2 emission restrictions.
- Development of nuclear energy.
- Level of penetration of renewable energy.

- Impact on demand from energy efficiency measures.
- If, when, and to what extent, the capture and storage of CO_2 (CCS) in sub-surface reservoirs will be implemented.

GAP BETWEEN SUPPLY AND DEMAND

EU indigenous gas production is declining rapidly, and in 2007, the EU produced only around 40% of its own gas consumption. It is expected that natural gas production will continue to fall within Europe and that the supply gap will increase over the coming decades, possibly moderated by rising production levels of unconventional gas after 2020. The main gas-producing countries within the EU are the UK and the Netherlands, while Germany, Italy, Denmark, and Poland also produce substantial amounts of gas. According to the IEA (2009), total EU gas production was around 214 bcm (billion cubic meters) in 2007, of which the UK (76 bcm) and the Netherlands (76 bcm) together accounted for 71%. The IEA (2009) expects EU gas production to fall to 167 bcm in 2015 and to decrease further to 103 bcm by 2030, increasing the supply gap from 312 bcm in 2007 to 516 bcm in 2030. The IEA's (2009) projections of demand, indigenous production, and supply gap are illustrated in Figure 22.2.

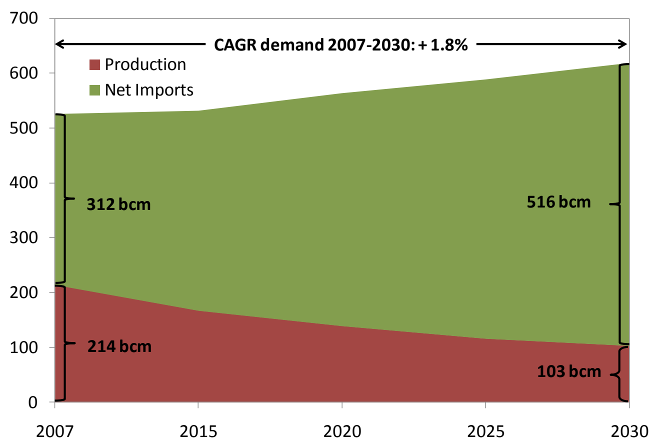


Figure 22.2. Forecasted supply-demand gap for natural gas the EU between 2007 and 2030 (CAGR: Compounded Annual Growth Rate). Data from IEA (2009).

The six largest gas-consuming countries within the union, i.e., Germany, France, Italy, the Netherlands, Spain, and the UK, dominate the EU natural gas market (together they accounted for almost 87% of gas production, 79% of primary gas consumption, and 82% of electricity generated by natural gas within the EU27 in 2008) (Eurostat, 2010). However, gas production in the UK, in particular, is expected to decline substantially over the next two decades.

IMPORT CAPACITY

The current annual (technical) EU import capacity is around 570 bcm, which relative to 2008 imports gives an import capacity-to-import ratio of around 1.7. To maintain the ratio at 1.7 relative to the supply gap, as projected by the IEA (2009), the EU will need to add, on average, around 16 bcm new import capacity each year between 2010 and 2030 reaching a total capacity of 880 bcm in 2030. Table 22.1 shows the existing import capacity as well as import projects under development. Pipeline capacity is shown by dispatch country, while LNG capacity is shown according to exit country.

Table 22.1. Existing and planned pipline/gasification capacity (technical) into EU27, bcm/yr.

	Existing	Under construction	Planned	Total
Entry point pipes:				
Algeria	53.0	-	8.0	61.0
Libya	11.5	-	-	11.5
Norway	147.8	-	-	147.8
Russia	190.0	27.5	90.5	308.0
Nigeria	-	-	30.0	30.0
Turkey	3.5	-	59.0	62.5
Total Pipes	**405.8**	**27.5**	**187.5**	**620.8**
Exit point LNG:				
Belgium	9.0	-	9.0	18.0
Greece	20.6	-	36.0	56.6
France	5.2	-	-	5.2
Italy	11.5	11.7	61.5	84.7
Netherlands	-	12.0	7.0	19.0
Portugal	5.5	2.4	-	7.9
Spain	60.0	11.3	42.2	113.5
UK	50.8	-	18.3	69.1
Others	-	-	9.8	9.8
Total LNG	**162.6**	**37.4**	**183.8**	**383.8**
Total Pipes + LNG	**568.4**	**64.9**	**371.3**	**1004.6**

Operating Pipelines Norway: Includes the 6.1 bcm Gjöa pipeline connected to the UK FLAG transportation system. Planned pipelines Rusia: Nordstream 2 and Southstream. Planned pipelines Turkey: Trans-Adriatic Pipeline, Nabucco, expansion of the Turkey- Greece interconnector. Planned LNG terminals Spain include a number of expansions of existing terminals including future expansions at the terminal under construction in Gijon as well as two smaller terminals on Canary Islands. Other LNG plants under planning include the Shannon plant in Ireland, the Polish terminal at Swinoujscie and a smaller terminal in Cyprus.

According to Table 22.1, there seems to be sufficient capacity under development to meet demand as projected by the IEA (2009). However, some projects included in Table 22.1 must be considered as speculative, like the Trans-Saharan Pipeline from Nigeria, as well as a number of proposed LNG terminals in foremost France and Italy. Also, it is not certain that all pipelines entering the EU from Turkey will be built given that they probably will compete for the same gas. In total, possibly as much as 100 bcm import capacity included in Table 22.1 may be considered as speculative, which still gives a sufficient import capacity margin given that the supply gap evolves as projected in IEA (2009). Finally, even though total import capacity to the EU may appear sufficient, problems may still occur within the individual markets.

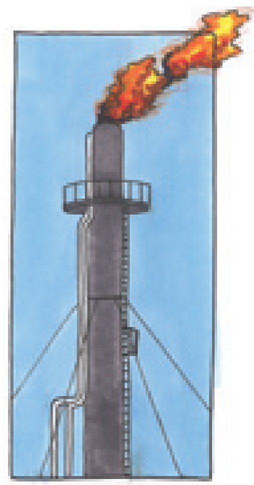
SUPPLY OF NATURAL GAS

Although Algeria, Norway, and Russia will continue to be the main suppliers to the EU well into the current decade, substantial volumes are expected to be supplied from a number of additional countries, mainly in Africa and the Middle East. In addition, the Caspian states may emerge as suppliers. In other words, while increasing import dependency will lead to lower energy security, an increasing number of suppliers and transport routes will lead to greater diversification of the supply, thereby enhancing the security of the supply. While Russia will probably struggle to increase its share of total exports to Europe over the current decade, North African suppliers and Norway will have the possibility to increase their market shares, given their locations close to markets with high growth potential (Italy, Portugal, Spain, and Greece for North Africa; and Belgium, Denmark, Germany, the Netherlands, and the UK for Norway).

Recently, the increase in unconventional gas production, mostly in the US, has had a global impact, and many countries have over the last two years intensified their efforts to raise domestic production levels of unconventional gases. In Australia, several LNG facilities based on the production of unconventional gas are under development, while in the US, LNG importers are instead seeking to export LNG. Apart from Australia and the US, Canada, China, India, Indonesia, Russia, Poland, France, Germany, the Netherlands, and the UK are all looking into possibilities to raise their production levels of unconventional gases. In addition, interest in underground coal gasification is growing, notably in Poland and the UK, which possess significant coal resources located at depths that render conventional production uneconomic. There is little doubt that the potential of this resource is significant, also in Europe, although the production of unconventional gas is complicated and puts severe strains on local environments. Therefore, it is not certain that it will have any significant effect on gas production in Europe. Nevertheless, it is likely that the production of unconventional gas will increase globally and therefore, with consequent impact on the European market. As mentioned above, in addition to increased supply of unconventional gas, significant LNG capacities will come on line over the next few years and in Europe, the North Stream gas pipeline from Russia to Germany will be inaugurated.

After 2020, it seems likely that the Middle East (mainly, Iran and Qatar) will emerge as the main supplier of gas (together with Russia). By that time, Saudi Arabia and Iraq may also have started exports to Europe. There is also the possibility that Norwegian gas production will start to increase again, pending the development of reserves in the Barents Sea. On the other hand, unless Norway discovers significant new gas reserves in the near future, Norway's gas production may start to decline already soon after 2015, further enhancing EU's import dependency on Russia.

NATURAL GAS PRICE DEVELOPMENT



As a result of declining demand, increased production of unconventional gases, and the commissioning of many new LNG plants, there has been an over-supply of gas on global markets since the beginning of 2009. As a consequence, there has been a strong downward pressure on spot gas prices, particularly in the Atlantic basin, which comprises the European and North American markets. Although the price of gas has traditionally been linked to the oil price, increased spot trading and an abundance of gas have meant that importers in Europe have forced suppliers to renegotiate long-term ToP (Take or Pay) contracts, and there are signs of a decoupling from the oil price indexation in long-term contracts, with switching to gas spot price indexation (IEA, 2010). The abundance of gas on global markets is likely to persist for some years as demand slowly recovers. The long-term impacts of continued low gas prices may be increased demand and under-investment in the gas supply infrastructure. For instance, fuel switching from coal- to gas-based power generation has a large greenhouse gas (GHG) mitigation potential in both the EU and US. As shown in Figure 22.1, more than 110 GW of coal- and lignite-based power generation capacity is older than 30 years in the EU, while the corresponding capacity in the US is more than 230 GW (EIA, 2006). Switching from an old coal-based power plant with a conversion efficiency of 35% to a gas combined cycle with a conversion efficiency of 58% would reduce GHG emissions by approximately 66%. If the linkage to oil prices continues, the tight supply of oil will create an upward pressure on the gas price.

FUTURE PROSPECTS FOR NATURAL GAS

The future demand for gas in Europe will partially depend on the level of continued CO_2 emission restrictions, the penetration levels of nuclear and renewable energy, and the extent to which the option to store CO_2 in subsurface reservoirs will be explored. Nevertheless, it is clear that EU gas-import needs will increase substantially compared to current levels, driven by a combination of increasing demand and declining production. As a result, there will be an increased dependency on imports, which will affect the security of supply, not only in the gas sector but also in the electricity sector. In contrast, the numbers of suppliers and transport routes will also increase, thereby enhancing the security of supply. The abundant supply of gas to the EU markets and increased competition mean that Russia will lose market share in the short term, particularly since piped Russian gas is not competitive on the main growth markets, i.e., Germany, France, Greece, Italy, Spain, and the UK. Nevertheless, in the long term, it can be expected that the EU dependency on gas from Russia and the Middle East will increase. The abundance of gas in the near term will continue to press gas prices, possibly leading to increased demand, in particular within the power sectors in the EU and US, where there is a significant potential for GHG emission reductions through the replacement of old coal plants with new gas-fuelled power plants. Traditionally, the price of gas has been linked to the oil price through long-term ToP contracts. If this linkage continues, the tight oil supply will create an upward pressure on the gas price.

For more information:

Jan Kjärstad
Energy Technology, Chalmers

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Resources and future supply of coal: implications for climate change mitigation

In this chapter, the global coal resources and reserves are reviewed in detail, and the implications of future coal consumption, with regard to CO_2 emissions and energy security, are discussed. This review reveals that global coal resources and reserves are extensive, with a CO_2 emission potential that significantly exceeds the emission levels established for retarding climate change. Moreover, the geographical distribution of coal resources in populous countries with low per capita energy consumption makes it likely that global coal consumption will continue to increase, at least during the current decade. In addition, it is difficult to see how coal can be replaced as the primary fuel for the electricity sector without major implications for energy security. In China, some 300 GW of coal-based power generation capacity has been added on a net basis between 2004 and 2008. In terms of base-load, these plants will emit 1.7 $GtCO_2$ per year, which is equivalent to the entire greenhouse gas (GHG) emission reduction targeted by the EU in 2020 (relative to 1990), assuming that the EU chooses to reduce emissions by 30%. The current review indicates that the expansion of coal-based power in China will continue, and that there will be a massive expansion of coal-based power also in other countries, such as India, Indonesia, South Africa, and Vietnam. The results show that the substantial capacity of old coal-based power plants in Europe and USA, together with the recent and future development of large new coal-based capacities in Asia, will hinder efforts both to meet strict CO_2 emission reduction targets and to ensure security of supply. These findings stress the importance of the early introduction of costs associated with emitting CO_2. If this does not happen, it seems unlikely that the medium-term emission reduction cuts, required to limit the global temperature increase to 2°C, will be met.

The aims of the present investigation were to describe the global coal markets and the potential role of coal in climate change mitigation efforts. The following questions were addressed: 1) How much coal is available on a global scale?; 2) What is the existing global consumption pattern for coal?; 3) How will the use of coal affect global efforts to mitigate climate change?; and 4) What role will coal play in a carbon-constrained Europe?

The analysis is based on data from the Chalmers Infrastructure databases for coal mines and coal fields (CF db), coal ports (CP db), and coal-based power plants (CPP db) in key coal-producing countries (for a detailed description of these databases, see Chapter 1 in the *Methods and Models* book).

RESERVES AND RESOURCES OF COAL

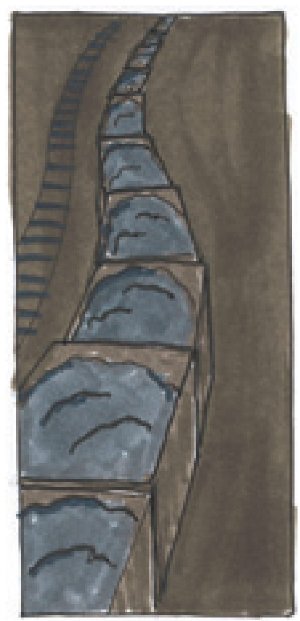
Several recent reports (CCRT&RA, 2007; Energy Edge, 2007; EU, 2007; EWG, 2007) have raised concerns over the accuracy of widely accepted assessments of coal reserves and resources. Different sources, countries, and regions within the same country, as well as different companies apply different definitions and terminologies when classifying coal types, reserves, and resources. Nevertheless, the term proven (or recoverable or measured) reserve appears to be frequently applied by most sources to quantify coal that: i) has been measured with the greatest degree of certainty; and ii) can be mined commercially under prevailing market conditions. In spite of the uncertainties, global coal resources were estimated at the end of 2007 by the BGR (Bundesanstalt Geowissenschaften und Rohstoffe BGR, 2009) to be almost 20 000 billion tonnes, of which approximately 75% was hard coal and 25% was lignite. This resource estimation includes proven reserves of around 710 billion tonnes of hard coal and 280 billion tonnes of lignite. However, it should be noted that five countries account for 75% of global proven reserves and almost 90% of global resources, namely, China, Russia, the USA, India, and Australia. Although Europe has substantial resources, most of its hard coal is located at great depths, which makes mining uneconomic, apart from the reserves in Poland and the UK. Commercial lignite reserves in Europe are substantial, and on-site electricity production based on lignite could probably be increased significantly, thereby enhancing energy security within Europe. In contrast, in order to meet GHG emission targets, increased use of coal has to occur in combination with CO_2-capture, a technology that may become available in 2020 at the earliest.

One interesting observation is that the coal reserve values appear to refer to raw coal, while the production values in most cases appear to refer to saleable coal (BGR, 2008; Geoscience Australia, 2008; WEC, 2008). According to BGR (2008) and WEC (2008), this is because there is no proper definition of coal production figures in the international mining statistics. There is, for instance, a 20% to 25% difference between the values for raw coal production and saleable coal in Australia and South Africa (Geoscience Australia, 2008, SAMI, 2007), which indicates that the widely applied reserves-to-production ratio, the so-called R/P-ratio, is not meaningful when applied to coal.

COAL CONSUMPTION

Global coal consumption reached 6.1 Gt in 2006, up 4.7% on the year. It has increased, on average, by more than 5% annually since 2000. China, the USA, and India together account for 62% of global coal consumption and almost 75% of global steam coal consumption. Demand for coal has more than doubled in China between 2000 and 2006, and it has increased by 60% in India over the same period. In just five years (from 2004 and 2008), 300 GW of coal-based power generation capacity was added in China on a net basis, i.e., after the deduction of 45 GW for old inefficient plants that were decommissioned during the same period (IEA CCC, 2009). In terms of base-load, these plants will emit around 1.7 GtCO_2, which corresponds to the entire GHG emission reduction target set by the EU by 2020, assuming that the EU commits to a 30% reduction compared to year 1990. In October 2010, it was announced that China's Electricity Council was planning for an additional 290 GW of coal-based power to be installed during the 12th five-year plan (2011-2015) (Industrial Info Resources, 2010). Likewise, a survey conducted between January 2007 and August 2009 of coal plants under development in India revealed that 125 GW of coal-based power were under development. Large additions to coal-based power plant capacity are also underway in other countries, such as Indonesia, Pakistan, Malaysia, South Africa, Thailand, and Vietnam.

While the growth of coal power is significant in emerging economies, the construction of new coal power plants is facing increasing local opposition in the western countries. In the US, for example, more than 60 GW of coal-based power generation capacity under development were abandoned by the developers during 2007 and 2008. Future demand for coal in the US is highly uncertain due to the uncertainties related to climate change mitigation and CCS. In Europe, the Large Combustion Plant Directive (LCPD), together with increasingly stricter CO_2 emision limits and possibly rising local opposition, will probably lead to a decline in coal-based generation up to 2020. This is further substantiated by analysing power plants under development, which clearly indicates that gas will continue to dominate new builds, at least up to 2015. However, the magnitude of the phase-out of coal-based power may be moderated by fuel cost considerations, concerns for the security of supply, interest in maintaining operational flexibility, and the possible phasing out of nuclear energy in



Germany, and to some extent also in Belgium. After 2020, when CCS is generally believed to become commercially available, we may experience a renaissance in coal-based power generation within Europe, the scale of which will depend on tightening CO_2-caps, fuel prices, the penetration of CCS, local resistance, and issues related to market dynamics and the fuel supply chain. From a security of supply perspective, increased use of lignite as a fuel, in combination with CCS technology, should have a positive effect. Both the Policy and Market Pathways, suggest declining demand for coal in Europe up to 2020. Whereas the Policy Pathway implies a continued decline in coal demand after 2020, the Market Pathway assumes rising demand for coal after 2020. In spite of the difficulties facing new coal-based power in the US and in Europe, the growth in global coal demand is expected to continue. Factors that will contribute to increase global demand for coal in the future, particularly in China and India, are: continued economic growth coupled with increasing urbanisation; population growth; substantial domestic resources of coal; increased difficulty of accessing international oil and gas resources resulting in escalating fuel prices; modernisation; and increasing per capita energy and electricity consumption levels.

IMPLICATIONS FOR FUTURE CO_2 EMISSIONS

From 1990 to 2004, global GHG emissions increased by 24%, reaching approximately 49 Gt in 2004. Slightly more than 80% of all GHG emissions refer to CO_2 emissions, and 76% of all CO_2 emissions are energy-related, i.e., CO_2 emissions from the energy sector account for around 61% of all GHG emissions (IPCC, 2007; IEA, 2008). Between 1990 and 2007, global fossil fuel-related CO_2 emissions increased by 36% (CDIAC, 2010). The average annual growth rate more than tripled between 2000 and 2007, as compared to the period between 1990 and 2000. Apart from Russia, all five largest emitters increased their emissions between 1990 and 2007, by 9% and 20% in Japan and the USA, respectively, and by 133% and 166% in India and China, respectively. Russia's emissions bottomed out in 2002 but have since increased by 7% (CDIAC, 2010). In the EU, energy-related CO_2 emissions have decreased by 4.2% since 1990, mainly as a consequence of the arrival of new member states from Eastern Europe (EEA, 2008), i.e., not as a result of explicit climate mitigation efforts. In 2006, the USA and China accounted for 21% and 19% of global energy-related CO_2 emissions respectively, the EU accounted for 13%, while Russia and India each accounted for 5% (CDIAC, 2010). Consequently, any meaningful attempts to mitigate climate change will have to include all the above-mentioned countries and regions. However, since almost 40% of global GHG emissions derive from non-energy-related sectors, these efforts will also have to involve significant reductions in emissions in these sectors, such as agriculture and forestry (deforestation) (both CO_2 and other GHGs).

From a climate change perspective, the large coal reserves and resources should be of major concern, since the total CO_2 emission potential widely exceeds the global carbon budget required to stabilise the atmospheric concentrations of GHG at 550 ppm. Figure 23.1 shows the CO_2 emission potentials for coal, gas, and oil reserves and part of the resources, along with the carbon budgets for the 21st century, which are required to achieve a mean temperature increase of 2.9°C, as stipulated by the IPCC (2007). Clearly, coal has by far the largest emission potential. Figure 23.1 also includes more recent estimates of the carbon budget up to 2050 that will be needed to achieve with reasonable probability the 2°C target (Meinshausen et.al., 2009). The emission potential has been calculated by applying average global fuel-specific emission factors across all sectors derived from the IEA (2008); the calculated values are therefore probably slightly higher than future emission factors, at least if CCS is not considered, which instead will have the opposite effect, i.e., reducing the conversion efficiency.

As mentioned above, strong efforts to mitigate climate change obviously have to involve China, India, Russia, and the USA. However, none of these countries have yet made any commitments to GHG emission reductions. A key issue will be how to deal with the approximately 340 GW of coal-fired plants in the EU and USA that were commissioned 30 or more years ago. If these plants are

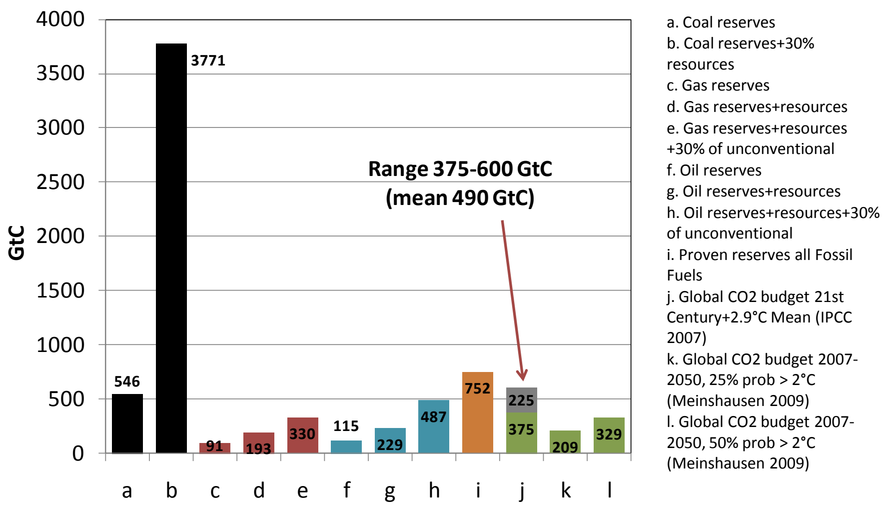


Figure 23.1. CO_2 emission potentials in gigatons of carbon (GtC) for various consumtion levels (reserves and resources) of coal (black), gas (red), and oil (blue), as well as for provenreserves of all three fossil fuels (orange), compared with the estimates of global CO_2 budgets specified by the IPCC (2007, grey/green) and Meinshausen et.al., (2009, green). Source: Kjärstad and Johnsson, 2010.

replaced by new coal plants, they will obviously have to be installed with CCS to meet future emission reduction requirements. However, CCS is unlikely to be commercially available until after 2020. Further expansion of fossil-based power in China and India will be difficult without CCS if these countries are to contribute to the substantial CO_2 emission reductions required to meet the 2050 emission reduction targets linked to limiting the global temperature increase to 2^oC. This implies that substantial coal-based capacity either will have to be retired before it has reached the end of its economic lifetime or will have to be retrofitted with CCS.

Further reading:

Kjärstad J., Johnsson F., 2010. Fossil fuels and climate change mitigation. Paper to be submitted.

For more information:

Jan Kjärstad
Energy Technology, Chalmers

Defining the pathways from sector specific scenarios

Two different European Energy Pathways are defined in this project: the Policy Pathway and the Market Pathway. The Policy Pathway relies more on targeted policies that promote energy efficiency and renewable energy; the measures in this pathway are primarily demand-side-oriented. In contrast, in the Market Pathway, the measures are more supply-side-oriented and the cost to emit CO_2 is the predominant policy measure. These two Pathways are based on the results from the sector-specific scenarios and analyses described in Chapters 1-46 of this book.

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Projections for demand and indigenous production of fossil fuel within EU

In the long run, indigenous fossil fuel production within the EU27 countries will most likely decrease. However, with concerted efforts to produce as much as possible, the decrease in production can be mitigated. Indigenous coal production may even increase if the lignite coal resources are utilised. Concerted efforts to maximise fossil fuel production in combination with decreased fuel demand in the Market and Policy Pathways promise to strengthen the security of supply. For instance, the EU can become self-sufficient for coal and close to self-sufficient for gas. However, oil will still need to be imported during the studied period.

ANALYSIS OF FOSSIL FUEL PRODUCTION WITHIN THE EU

Concise analyses of the reserves, resources, and other premises for fossil fuel production within the EU27 have been carried out within the Pathways project (see Chapter 21-23). Based on these facts, projections of future fossil fuel production for a baseline scenario, as well as for a scenario with concerted efforts to maximise fossil fuel production within the EU have been constructed. In this chapter, these production projections are compared with the fuel demands of the Policy and Market Pathways, as well as with the baseline scenario.

THE EU CAN BECOME SELF-SUFFICIENT FOR COAL

Based on the analysis of the situation and the trend regarding steam coal production in Europe, it is reasonable to expect a continued decline in Europe's indigenous production of steam coal. This assumption is supported by the coal production prognosis from the report "European Energy and Transport: Trends to 2030" (EE&TT) (EC, 2008). Assuming a similar trend for coking coal, a baseline production of hard coal is established (grey bars in Figure 24.1). To this baseline production, the production increase attributed to concerted efforts to maximise fossil fuel production can be added. According to the analysis of coal production in the EU, a production level higher than that in the baseline scenario is possible; although a slight decrease seems inevitable, steam coal production could level out at about 95 Mt/year. Assuming that the production of coking coal levels out in a similar way, the potential for increased production of hard coal can be established (green bars in Figure 24.1). It should be noted that increased production of hard coal might require an increase in the price of coal or specific policy measures.

Lignite production is also expected to decrease in the baseline scenario (brown bars in Figure 24.1). However, the total reserves of lignite are large and it is possible to increase its production. Concerted efforts to increase lignite production within the EU (red bars in Figure 24.1) might ensure that the total coal production within the EU increases.

In Figure 24.1, the demands for coal in the Policy and Market Pathways and the baseline scenario are presented. The baseline level of production would be enough to meet the demand outlined in the Policy Pathway from year 2020 onwards. To meet the demand set in the Market Pathway, a major percentage of the potential production increase would be required. However, in the baseline scenario, the need for imports would increase even though production would be stretched to the limit.

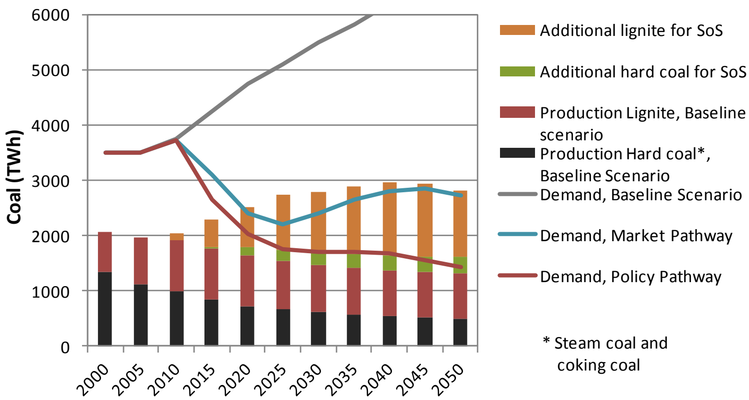

Figure 24.1. Projected coal production and demand levels to 2050.

THE EU CAN COME CLOSE TO BEING SELF-SUFFICIENT FOR GAS

The production of gas within the EU has declined by almost 20% since 2000, reaching around 200 bcm in 2007. The decline accelerated in 2007 when production went down by almost 7% in one year. The production level of conventional gas is expected to continue to decline (Table 24.1).

Table 24.1. EU conventional gas production in 2008 and projected production levels for 2009-2050 (bcm)

	2008	2010	2015	2020	2025	2030	2035	2040	2045	2050
UK	75.4	57.9	46.4	38.0	31.1	25.5	20.9	17.1	14.0	11.5
Nether-lands	75.8	81.9	66.7	55.8	32.5	20.1	12.7	8.	5.0	3.2
Denmark	9.7	8.2	5.9	4.8	3.7	2.3	1.5	1.0	0.6	0.4
Germany	16.5	15.7	13.8	9.6	6.7	0.0	0.0	0.0	0.0	0.0
Italy	8.8	7.5	5.1	3.5	2.4	1.6	1.1	0.7	0.5	0.3
Romania	10.7	10.2	9.0	8.0	7.1	6.3	5.5	4.9	4.3	3.8
Others	11.0	10.7	10.0	9.4	8.7	8.2	7.6	7.2	6.7	6.3
EU-27	**208.0**	**192.2**	**157.0**	**129.0**	**92.2**	**64.0**	**49.3**	**38.9**	**31.3**	**25.6**

The total production of conventional gas from Table 24.1 is presented as dark-grey bars in Figure 24.2. From about 2020, the production of unconventional gas may start to mitigate the fall in production of conventional gas. The EU resources of unconventional gas, i.e. tight gas, shale gas, and coal bed methane (CBM), are considerable. Moreover, there is a huge potential for underground coal gasification (UCG). The current production levels of unconventional gas are, however, very marginal, with no commercial production of shale gas or gas through UCG. Insignificant volumes of CBM are produced in the Ruhr basin in Germany and in the UK. There is possibly "a not-insignificant production of tight gas", which simply refers to production from reservoirs with very low permeabilities. However, the production figures are probably included in conventional gas production. The following conclusions can be drawn with respect to unconventional gas in Europe:

1) The potential for this resource is significant, but uncertain, as exploitation is at an early stage.
2) In the past two years, there has been a dramatic increase in licenses awarded for the exploration and assessment of unconventional gas resources in Europe.
3) The increasing interest in this resource shown by major multinational companies, i.e., ExxonMobil, Shell, ConocoPhillips, and Chevron, can be considered as a promising sign.
4) To date there has been only marginal pilot-scale production, apart from CBM in the Ruhr basin, where several power plants with a combined capacity of 70 MW are being run on CBM.

5) Apart from CERA (2009), no production forecasts have been published.
6) It will take several years to appraise the reserves, commence production, and ramp-up production levels.

According to CERA (2009), unconventional gas may add some 50 bcm per year of additional production by 2030. Based on this and the conclusions outlined above, a possible development pattern for the production of unconventional gas is outlined (red bars in Figure 24.2).

Somewhere between the production rates with and without unconventional sources, the production projection of the EE&TT (EC, 2008) (extrapolated from year 2030 to year 2050) is found. The EE&TT production rate is assumed to be the baseline production level for the scenarios. In addition to EU production levels, Norway can contribute substantial gas production to the European energy system, especially in the near future.

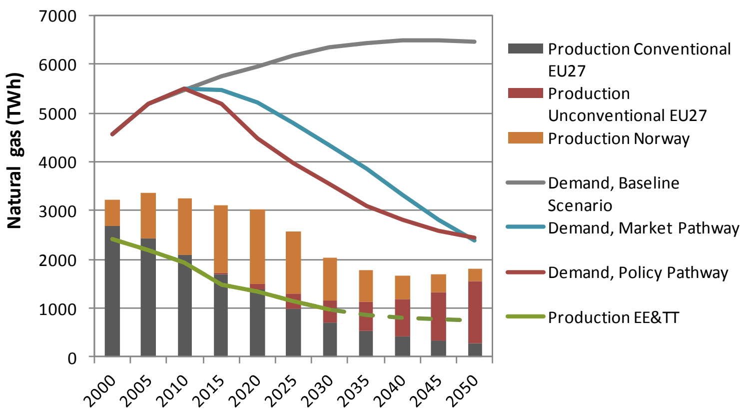

Figure 24.2. Projected gas production and demand levels to 2050.

The gas demands in the two pathways towards sustainability decrease from 2010. By year 2050, the gap between demand and production covered by imports will be just a fraction of the current one, assuming that unconventional resources can be utilised. However, to cover the demand in the baseline scenario, imports need to be increased.

DEMAND FOR OIL IMPORT WILL REMAIN

The production of conventional oil within the EU27 will most probably decrease rapidly to just a fraction of current production levels by 2050 (Table 24.2). The production trend outlined in Table 24.2 is in accordance with that of the EC (2008), and is set to the baseline in Figure 24.3. The projections for Norway's production are similar, even though the decrease is not as rapid.

Table 24.2. Conventional oil production in 2008 and expected conventional oil production levels in 2010-2050 (Mt)

	2008	2010	2015	2020	2025	2030	2035	2040	2045	2050
Denmark	14.2	12.8	11.3	6.2	3.1	1.5	0.8	0.4	0.2	0.1
Germany	3.1	2.6	1.7	1.1	0.7	0.5	0.3	0.2	0.1	0.1
Italy	5.2	4.9	4.1	3.4	2.9	2.4	2.0	1.7	1.4	1.2
Nether-lands	2.2	1.9	1.4	1.0	0.7	0.5	0.4	0.3	0.2	0.1
UK	71.5	64.3	53.5	46.9	41.1	31.0	23.3	17.6	13.3	10.0
Others	9.0	8.2	6.7	5.5	4.5	3.6	3.0	2.4.	2.0	1.6
EU-27	**105.1**	**94.7**	**78.7**	**64.0**	**52.9**	**39.5**	**29.7**	**22.5**	**17.1**	**13.1**

Within the EU, there are opportunities for unconventional oil production mainly in the form of shale oil. Shale oil is produced from oil shale, which is a mixture of clay and calcium carbonate and contains no oil but kerogen. Heating the kerogen in the absence of air creates synthetic crude oil or shale oil. Some 18.3 Gt or 125 bbls (billion barrels) of unconventional oil reserves are located in Europe, distributed across many countries, but mainly in Italy, Estonia, and the UK (WEC, 2007). The prospects for the production of unconventional oil are associated with significant uncertainties, but even with an optimistic projection a dramatic decrease in total production is to be expected. To project the future production of shale oil in Europe, the following assumptions have been made:

1) Shale oil production in the EU starts with Estonia's shale oil plant producing 290 ktonnes in 2012, increasing to 1.3 Mtpa in 2016.
2) Concerted efforts to increase shale oil production within the EU will not have any impact until after 2020.
3) From 2020 onwards, shale oil production is projected to increase by 3.5% per year.

The projected production levels of unconventional oil are presented as dark-blue bars in Figure 24.3. As is evident from the figure, no major mitigation of the decrease in oil production is expected within this time-frame.

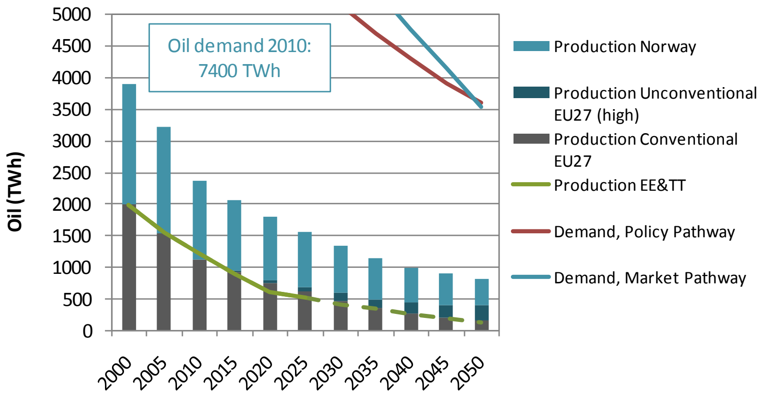

Figure 24.3. Projected oil production and demand levels to 2050.

The current total oil demand of the EU27 countries is about 7800 TWh, of which just a minor proportion is covered by indigenous production. This pattern will continue to be true also for the two pathways towards sustainability, even if the demand for oil decreases to less than half of the current level.

For more information:

Erik Axelsson, Profu
Jan Kjärstad, Energy Technology, Chalmers

Further reading:

Axelsson, E., Rydén, B., and Colpier U., 2010, "EMER model results: Two Pathways to Sustainable European Energy System", Pathways Internal report 1/2010. See also www.energy-pathways.org

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Biomass potentials in Europe: comparing sizes of different sources and put in a global perspective

In this chapter, potential biomass supplies on an European levels are discussed, and put in a global perspective. In the near term, generated residue flows in the agriculture and forestry sectors could support increased bioenergy use in Europe. In the longer term, dedicated production of bioenergy plants may become increasingly important. Assuming favourable development, large areas of suitable land may become available for bioenergy feedstock production in the longer term. Scenario-based estimates indicate a technical bioenergy resource potential for Europe (including Ukraine) corresponding to about 20 EJ/yr by 2030. The share of this potential that might become realized depends on many factors, not the least cost factors and whether society will find it desirable to convert a considerable proportion (up to one-third) of Europe's present agricultural land area to bioenergy plantations.

Biomass (mainly wood) presently contributes energy amounting to 50 EJ/year, or 10% of the global primary energy supply, and is the most widely used renewable energy source. Most of this contribution involves so-called 'traditional bioenergy use', i.e., the use of charcoal, wood, and manure for cooking, space heating, and lighting, although about 20% involves 'modern bioenergy use' (for industry, power generation or transport fuels), and this share is growing rapidly in response to various policies.

Studies (e.g., IEA Bioenergy, 2009) of the future global biomass supply potential indicate that it may be possible to produce several hundred EJ/year of biomass for energy within decades, which can be compared to the current global primary energy demand of about 500 EJ/yr or 70 GJ/capita/yr (IEA, 2009). A comparison with biomass production in agriculture and forestry gives some perspective as to the prospective bioenergy supply in relation to what is presently harvested through land use. Current global industrial roundwood production corresponds to 15-20 EJ/yr, and the global harvest of the major crops corresponds to about 60 EJ/yr (FAOstat, 2010). Thus, the levels of biomass extraction in agriculture and forestry will have to increase substantially, in order to provide feedstock for a bioenergy sector that is sufficiently large to make a significant contribution to the future energy supply.

Nevertheless, the considerable residue and waste flows generated in the agriculture and forestry sectors can make an important contribution, especially in the near term, since it will take time before systems for the dedicated production of bioenergy plants become established on a large scale (i.e., assuming that such development is judged to be desirable, and that policies are established to stimulate it).

AGRICULTURAL RESOURCES

In agriculture, straw is a residue product that is already used to a certain extent for energy purposes. Global cereal production accounts for 60-70 % of the global production of food and animal feed crops (measured in energy terms). Usually, less than half the biomass production above ground consists of seed, the rest being straw. However, not all of the straw can be used for energy purposes; some must be left on the fields and some is utilised for other purposes, such as bedding in livestock production. Nonetheless, waste products are generated that might be used for energy production when cereals are processed in the food industry and other residues can also be utilised, such as straw in oil-seed production and bagasse, which is obtained during the production of sugar (or ethanol) from sugar cane.

Therefore, cereal production can, in addition to giving an indication of straw production in different countries, provide a rough estimation of the amounts of residues and waste products generated within agriculture that might be used for energy purposes in the countries of the world (Figure 25.1). The per capita primary energy use in the EU25 is about 150 GJ/yr, and in Sweden the primary energy use corresponds to about 270 GJ/capita/yr. Although per capita primary energy use varies considerably across the EU countries, it is clear that the residue flows in agriculture are rather limited compared to the sizes of the energy systems.

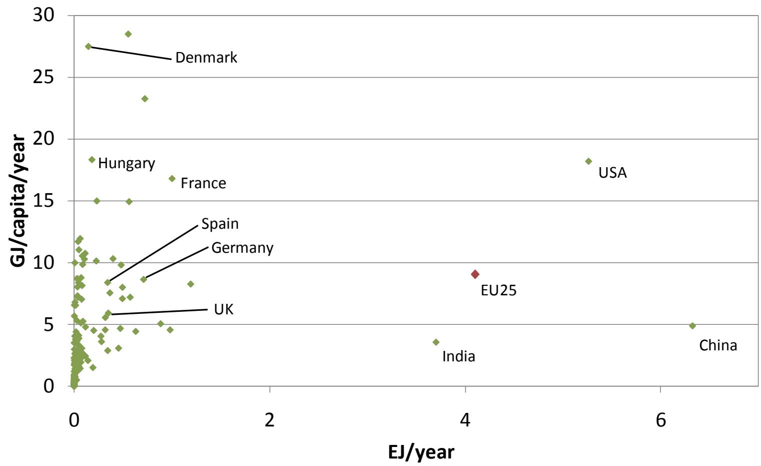

Figure 25.1. Cereal production in various countries, converted to energy units, assuming energy content of 16 GJ/tonne of cereal. The figure shows the dominant cereal producers in the world and specific European countries. Annual cereal production in Sweden corresponds to about 10 GJ/capita.

FOREST RESOURCES

Considering forest biomass (with the focus on Europe) gives a somewhat different picture. Figure 25.2 shows the current wood removals from forests, as well as the prospects for increased removals from European forests. Current removals from forests available for wood supply (Figure 25.2, x-axis) consist of: (i) the proportion of fellings removed from the forest; and (ii) removal of trees killed or damaged by natural causes, such as windblow, insects, and diseases (natural losses). This excludes silvicultural and pre-commercial thinnings and cleanings left in the forest, as well as natural losses that are not recovered.

In the same way as for agriculture, the volumes of wood removals are indicative of the magnitude of the biomass flows in the forest sector that might be available for energy purposes, since the by-flows (felling residues, silvicultural (forestry) and pre-commercial thinnings, and process by-flows in the forest industry, such as sawdust and black liquor) are of the same magnitude as the biomass flow in the form of products. The products, having served their primary functions, are used to a significant extent for energy production. The current levels of removals are compared to the domestic gross energy consumption, which means that data-points (countries) further to the right in Figure 25.2 have higher current removals in relation to their gross energy consumption.

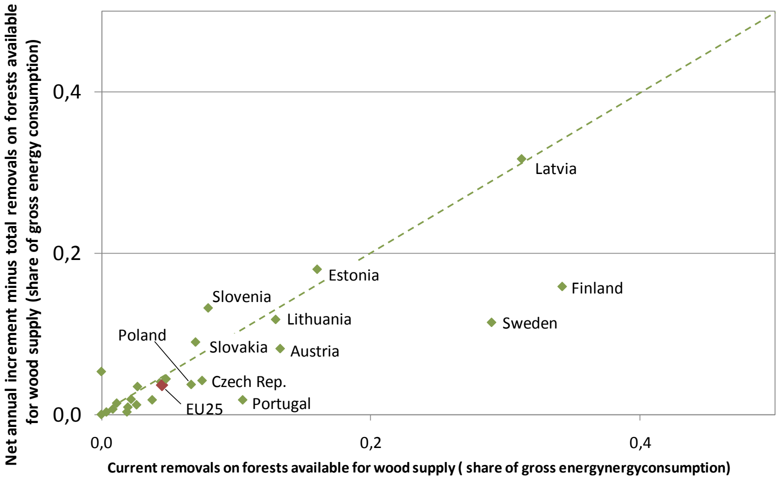

Figure 25.2. Relationships between current gross energy consumption and wood removals from forests available for wood supply (x-axis) and the balance between net annual increment and current removals in the respective countries (y-axis). The forest extraction levels and balance are converted to energy units based on an assumed energy content of 10 GJ/m^3 of wood and then divided by each country's gross energy consumption. Calculations are based on (ECE, 2000).

Sweden and Finland have the largest annual wood removals in the EU, corresponding to roughly 600 PJ and 500 PJ, respectively. As indicated in Figure 25.2, the level of extraction is also substantial relative to domestic energy use. The three Baltic States and a few other countries also have significant forest extraction relative to their own energy use. Although forest wood extraction is also substantial in France and Germany, compared to the energy use in these countries it is only a few percent. Forest extraction in Poland is about half the level in Finland, and that in Austria it is roughly one-third of the Finnish level.

The net annual increment (NAI) minus current wood removals (Figure 25.2, y-axis) is a rough indication of how much removals can increase in a given country. NAI refers to the average annual volume of increment of all trees, with no minimum diameter, minus the natural losses. Thus, it is equivalent to natural forest growth in a year (minus the natural losses). Countries that lie close to the dotted diagonal in Figure 25.2 have a non-used NAI that is roughly equal to the current removals, i.e., the total NAI is twice as large as the level of current removals. The further up a country is in the diagram, the larger is its non-used NAI compared to its gross energy consumption.

It is evident that several countries could substantially increase their removals from forests, although for many countries, potential removals are rather small (less than 10%) in relation to gross energy consumption. For the entire EU, the current level of wood removal corresponds in energy terms to about 3.2 EJ/yr or 5% of the gross energy consumption. Even if removals increased to become as large as the net annual increment, it would still be relatively modest compared to the climate neutral energy supply that will be required for the EU to contribute to the longer-term 2-degree target (Copenhagen Accord). Nevertheless, the forest resources are clearly significant in comparison with the more near-term 2020 targets for bioenergy in the EU.

It is clear that the utilisation of organic waste and residue flows in agriculture and forestry can support expansion in response to near-term targets, although (with the exception of countries that have large forest resources and significant forest industries) these biomass sources will not be sufficient to meet a strongly increased demand for bioenergy. Biomass/biofuel imports, or dedicated biomass production, in Europe will be needed.

EUROPEAN BIOMASS POTENTIALS

European biomass potentials were estimated in the framework of EU projects (Refuel and Elobio), in which Chalmers University of Technology co-operated with European groups. Figure 25.3 shows selected results for land availability assessments, which were based on food sector scenarios for 2030, considering nature protection requirements and infrastructure development (Fischer et. al., 2010). Depending on the scenario assumptions, some 44–53 million hectares of cultivated land and almost 20 million hectares of pasture land might not be needed for food production by 2030, and could (from a biophysical perspective) support biomass production for energy. This is a considerable proportion of Europe's present agricultural land area, which currently amounts to 164 million hectares of cultivated land and 76 million hectares of permanent pasture (including Ukraine). The cost-supply curves shown in Figure 25.3 were produced based on the estimated land availability and modelling of the production costs for various types of energy crops (de Wit and Faaij, 2010). A key factor determining the size of the potential is the development of agricultural land productivity, including animal production.

Note that the maps shown in Figure 25.3 correspond to a specific food sector scenario that assumes unchanged national food self-sufficiency levels up to 2030. Biophysical, economic, institutional, and other factors may result in countries that have an indicated, relatively high land availability (e.g., Ukraine), deciding to produce more food crops for export rather than producing bioenergy. Conversely, countries with indicated lower land availabilities may become the ones that establish the most bioenergy plantations in the coming decades. Even so, a clearly significant potential is estimated for Europe as a whole.

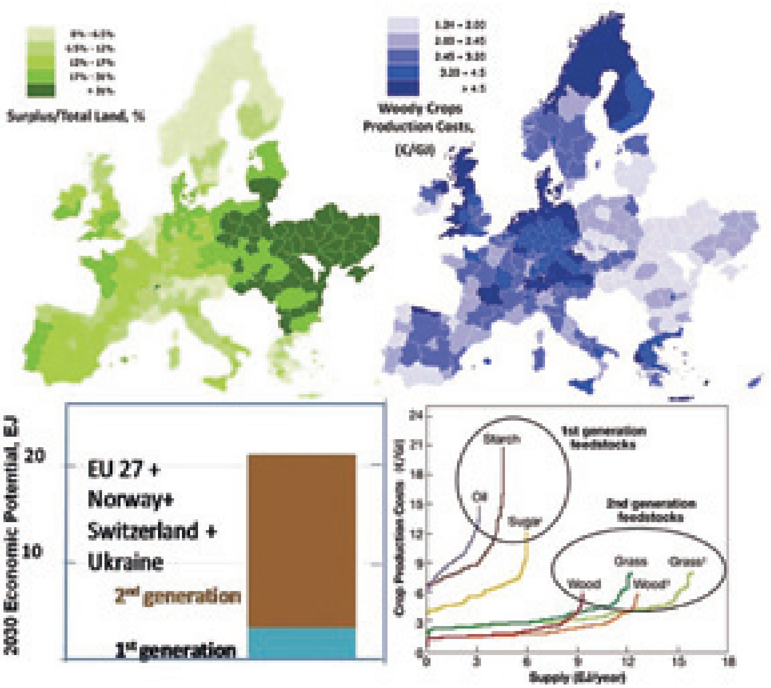

Figure 25.3. Indicative maps showing the availability of suitable land (% of total agriculture land) for bioenergy plantations, given a specific food sector scenario (upper-left panel), and estimated production costs for woody plants such as willow and poplar (upper-right panel). The lower-left panel shows the total technical bioenergy resource potential by 2030, assuming favourable development, and the lower-right panel shows the cost-supply curves based on this scenario.

For more information:

Göran Berndes
Physical Resource Theory, Chalmers

Further reading:

IEA Bioenergy. 2009, Bioenergy – a sustainable and reliable energy source: a review of status and prospects. IEA Bioenergy:ExCo:2009:06

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Realising supply potentials and prioritising bioenergy use

If climate change mitigation and import dependency reduction are top priorities, bioenergy options based on lignocellulosic resources should be promoted, regardless of whether the biomass is used for transport or for heat and power. The large-scale use of bioenergy requires the development of efficient and cost-competitive conversion technologies, as well as development of the entire production chain, including the supply infrastructure and biomass production management. In addition, policies are needed to support and stimulate the increased use of biomass for energy purposes.

Realization of the bioenergy supply potentials indicated in Chapter 25 requires far-reaching changes in present land use, and will involve the planting of many million hectares of land with bioenergy-appropriate plants. Significant changes in forest management will also be required to provide forest wood in sufficient volumes. The ways in which forest bioenergy develops and biomass plantations are established, will determine whether, and to what extent, bioenergy expansion will lead to greenhouse gas emissions or removals, through the associated changes in land use. This will significantly influence the overall climate change mitigation benefit of bioenergy expansion (further discussed in Chapter 28).

THERE ARE SEVERAL DRIVERS FOR BIOENERGY

Climate change mitigation is not the only aspect that needs to be considered when assessing the merits of bioenergy. Other important aspects include the security of energy supply, the potentials for job creation and income generation, and the consequences for biodiversity, water, and soils. The Pathways project includes assessments of bioenergy options, using several modelling tools and other assessment frameworks and considering different energy policy objectives.

Studies, that have separately evaluated the effects of substituting fossil fuels with biomass in different specific applications, have indicated that substituting biomass for fossil fuels in heat and electricity generation is generally less costly and entails greater reductions in CO_2 emissions per unit of biomass, than substituting biomass for gasoline or diesel used for transport. The major identified causes for this are the higher conversion losses experienced when biomass is processed into biofuels for transport, and also the higher energy inputs for the production and conversion of biomass into such fuels. However, it is important to note that comparisons of individual options fail to consider the systemic aspects of different biomass uses. For instance, Grahn et al. (2007) have shown that the relative cost effectiveness of biomass used for climate change mitigation in the transport or stationary energy sector, depends on how carbon emission reduction targets are implemented, in combination with the development of low-carbon transport options other than biofuels.

Hansson and Berndes (2007) investigated whether three major policy objectives, underlying the promotion of bioenergy (cost-effective climate change mitigation, employment creation, and reduced dependency on imported fuels), come to a consensus on which bioenergy options should be used. They found that these policy objectives are not in agreement on the order of priority of bioenergy options. Maximisation of climate benefits in a cost effective manner was found to conflict with maximisation of employment creation. The former perspective proposes the use of lignocellulosic biomass in the stationary sector, while the latter requires biofuels for transport based on traditional agricultural crops. Furthermore, from a security-of-supply perspective, the appeal of a given bioenergy option depends on how dependencies on oil and gas imports are weighed relative to each other. Consequently, there are tradeoffs that need to be addressed by policymakers who promote the use of bioenergy.

If climate change mitigation and import dependency reduction are the top priorities, bioenergy options based on lignocellulosic resources should be promoted regardless of whether the biomass is used for transport or for heat and power. In addition, the advantage of lignocellulosic plants over traditional agricultural crops, which have been emphasised from a well-to-wheel perspective, could be validated also from an energy system modelling perspective.

Turning to other environmental aspects, there is solid basis for concluding that increased cultivation of perennial lignocellulosic plants could be a valuable tool for mitigating some of the environmental impacts associated with intensive agriculture, such as nutrient leaching and erosion resulting in water and soil degradation. The AGS Pathways report "Multifunctional bioenergy systems" uses different applications of willow cultivation to illustrate how bioenergy systems – through well-chosen localisation, design, management and system integration – can offer extra environmental services that, in turn, create added value for the systems (Berndes and Börjesson, 2007).

BIOENERGY SYSTEMS THAT USE LIGNOCELLULOSIC RESOURCES WILL LIKELY PREDOMINATE IN THE LONGER TERM

It is generally expected that future bioenergy systems will use lignocellulosic biomass as the primary resource. Current biofuel use in the transport sector has been criticised, as the production of so-called 'first-generation' biofuels, which use conventional agricultural food and feed crops as feedstock, are perceived as having considerable risks related to their effects on agricultural commodity markets and the environment. The use of lignocellulosic resources has several advantages over present-day biofuel production using conventional agricultural food and feed crops:

- As noted in Chapter 25, lignocellulosic residues and processing by-products of the forestry and agriculture sectors represent a considerable resource. Moreover, the cost of these commodities is relatively low;
- Dedicated production of lignocellulosic plants avoids some of the environmental impacts associated with conventional agricultural crops;
- Land-use competition may be mitigated by producing lignocellulosic plants at sites that are less suitable for conventional agricultural crops.

So-called 'second-generation' biofuels, which use lignocellulosic biomass as feedstock, are proposed as an alternative for the transport sector, and may reduce some of the concerns associated with first-generation biofuels. Since the production of lignocellulosic feedstocks commonly requires less fuel, fertiliser, and other inputs, there is also scope for greater savings in greenhouse gases than when biofuels are produced from conventional crops. The importance of lignocellulosic crops has also been recognized by the European Commission (EC), which in its communication An EU strategy for Biofuels includes, as one of three main aims, *"...to prepare for the large-scale use of biofuels by improving their cost-competitiveness through the optimised cultivation of dedicated feedstocks, research into "second generation" biofuels, and support for market penetration by scaling up demonstration projects and removing non-technical barriers"* (COM, 2006). In addition, the renewable energy targets that the EC has stipulated for 2020 indicate a rapid increase in the use of lignocellulosic biomass for electricity and heat purposes.

Selected types of bioenergy plants that may become more common in the European agriculture in the future are presented in the box on the next page.

Examples of lignocellulosic bioenergy systems

Switchgrass, a perennial grass native to North America, is presently grown as forage for livestock or as a ground cover, to control erosion. It is established from seed and gives high yields with low fertiliser input. It can be cut and baled with conventional mowers and balers, either annually or semi-annually for 10 years or more before replanting is needed.

Eucalyptus, which is the dominant hardwood plantation species, is planted extensively throughout the tropics, and particularly in sub-tropical regions. Currently, it is used primarily for industrial roundwood. The photo shows one route for integrating bioenergy with food crop production. Eucalyptus is in this case inter-planted with corn in Brazil. Bioenergy plants can be inter-planted also with other crops and used in silvipastoral systems. It is suitable as wind breaks and is also planted to lower water tables. Eucalyptus is currently mostly planted in the southern part of Europe.

Willow is a coppicing plant that is planted using cuttings. It can be harvested, using modified agricultural machinery that also chips the stems, every 3-4 years for about 25 years before re-establishment is needed. It is presently commercially cultivated mainly in Sweden, where willow is cultivated on about 15 000 ha to supply biomass primarily for heating. Willow can also provide environmental services, e.g., as vegetation filters for treating nutrient-rich water, and for the removal of cadmium from cropland.

Miscanthus is a perennial grass that is established by planting pieces of the root, called rhizomes, from fields in which the crop is already established. Rhizomes can be broken up, collected, and planted using existing agricultural equipment, such as potato harvesters and planters. The crop is normally harvested from year 2 onwards, and yields continue to increase until they level off around the 5th or 6th year.

THE SUPPLY INFRASTRUCTURE IS NOT YET ESTABLISHED THROUGHOUT EUROPE

Besides the challenges of developing efficient and cost-competitive conversion technologies, the supply infrastructures for lignocellulosic biomass have not yet been fully established. In European countries that have large forestry sectors, a wood supply infrastructure is in place, and in a few countries, such as Sweden and Finland, the use of forest wood for energy represents a substantial activity that has influenced the wood supply infrastructure. However, in most European countries, the wood supply infrastructure has still to develop in response to changing demand patterns, as bioenergy becomes an increasingly important end use. This development not only concerns technology and the economics of logistical systems, but also institutional development. Regulations need to reflect the new situation, and ensure that the increased forest biomass output respects sustainability considerations, which in many instances also need to be better understood. One example is the increased utilisation of the residues from forests, including stumps, which requires regulation and compensatory measures to maintain nutrient balances. Furthermore, the increased demand for forest wood in general can be expected to stimulate measures to intensify forest management, e.g., forest fertilisation may become more common. This intensification needs to be managed in a responsible way.

In the agricultural sector, the lignocellulosic output to date has consisted mainly of fibre crops for non-energy purposes and harvest residues, such as straw. The harvest residues are currently mainly collected for animal feed and bedding, although in a few countries they are also used for energy purposes (heat and power). Willow has been grown commercially for heat and power in Sweden since the beginning of the 1990s, and the plantations now account for some 14 000 hectares, or about 0.5% of the arable land in Sweden. Thus, despite this experience of almost 20 years of cultivation, willow production remains an emerging agricultural activity with a small land claim. Very limited cultivation of lignocellulosic plants for energy exists in other European countries.

POLICIES IN PLACE MAY NOT EFFECTIVELY PAVE THE WAY FOR THE MOST DESIRABLE BIOENERGY OPTIONS

It can be questioned whether the policies put in place in Europe to date effectively pave the way for second-generation biofuels and lignocellulosic bioenergy options in general. In fact, there are indications that the biofuel targets may even be counter-productive regarding the development of lignocellulosic crops, in that farmers are less inclined to try lignocellulosic crops as long as they see good prospects for continued cultivation of conventional crops. Moreover, since many farmers have invested in conventional crop production, they see the possibility of a shift to second-generation biofuels as a threat rather than as an opportunity. Since not only first-generation feedstock cultivation, but the entire production chain, could become less profitable in the scenario of a shift to second-generation biofuels, one expects that stakeholders, who have invested in first-generation biofuel production plants (which includes farmer-owned companies), will lobby for conserving the position of first-generation biofuels in the market.

It should be noted that significant changes in farm management and supply infrastructure will be necessary to establish lignocellulosic plant production on large scale in Europe. Conversely, minor adaptations were required at the farm level to respond to the recent years' large increase in demand for first-generation biofuel feedstocks; farmers could easily integrate these biofuel crops into their food and feed crop rotation patterns. Small farms that participate in the market with relatively low investments, could benefit from earnings related to biofuel feedstock production, as well as from the animal feed value of the by-products of ethanol and biodiesel production.

Policymakers can promote the development of second-generation biofuels and efficient conversion technologies in general (also for heat and power) by, for example, introducing specific targets for desirable options, and by providing research and development support. However, these initiatives may need to be complemented by initiatives that stimulate the development of the lignocellulosic feedstock supply systems, especially that of lignocellulosic plants in agriculture. The creation of near-term markets for lignocellulosic feedstocks, and the exploitation of expansion pathways for second-generation biofuels that are lower in cost and entail low risk, are both important. Examples of how these challenges can be addressed are given in Chapter 12 and 36.

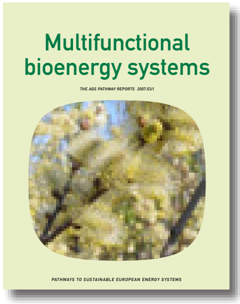
For more information:

Göran Berndes
Physical Resource Theory, Chalmers

Further reading:

Hansson, J., 2009. Perspectives on Future Bioenergy Use and Trade in a European Policy Context. Thesis for the degree of doctor of philosophy, Chalmers University of Technology. ISBN 978-91-7385-270-8.

Berndes, G., Börjesson, P., 2007. Multifunctional bioenergy systems. AGS Pathways Report 2007:EU1. ISBN 978-91-633-0270-1.



Overview of the Pathways booklet:

Multifunctional bioenergy systems

In pace with the ever-growing complexity of environmental problems, new types of measures based on a holistic perspective are needed. Focusing on only one problem at a time is impossible, as this can at worst make another environmental problem even more serious, or at best prevent taking advantage of potential synergy effects. Biomass production for energy purposes is a good example of where a holistic perspective must be adopted. The report deals with such so-called multifunctional bioenergy systems. These are bioenergy systems which – through well-chosen localisation, design, management and system integration – offer extra environmental services that, in turn, create added value for the systems.

This AGS Pathways report (2007:EU1) is available at: www.energy-pathways.org.

For further information:
Göran Berndes, Chalmers
Pål Börjesson, Lund University

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Increased bioenergy use:
competition between the energy, forestry, and food markets

An increase in the demand for bioenergy will mean increased competition with other sectors for the use of limited resources, in particular land and water, for biomass production. Shifting from first- to second-generation biofuels reduces the demand for conventional crops (e.g., cereals) as feedstock for the biofuel industry. However, increased demand for second-generation biofuel (mainly lignocellulosic) feedstocks, combined with a demand for biomass from the stationary energy sector, can push land prices upwards and increase the pressure on forest resources.

This chapter presents work within the Pathways project that also formed part of the EU-funded project Elobio (www.elobio.eu). In this project, inter-sector competition was analysed in the context of increasing bioenergy use, considering the transport and stationary energy sectors, the food sector, and the forest sector. The analyses were based on extensive literature reviews in combination with modelling.

The result show that the implementation of ambitious global biofuel targets, based on current first-generation technologies, can increase international agricultural commodity prices and food prices, with positive or negative outcomes depending on the structure of land use sectors and regional socioeconomic conditions. Furthermore, changes in land use, through the conversion of natural land to produce feedstocks for first-generation biofuels and the displacement of existing agricultural activities to other areas, may influence the reduction in greenhouse gas emissions related to the production and use of biofuels (as also discussed in Chapter 28).

LIGNOCELLULOSIC BIOMASS CAN BECOME AN IMPORTANT ENERGY SOURCE

Second-generation biofuels that use lignocellulosic biomass may decrease some of the pressure on agriculture commodities, especially if they are derived from residues and bioenergy plants produced on marginal lands. In addition, they are expected to provide a substantial contribution to reducing greenhouse gas emissions. However, since a combination of first- and second-generation biofuels is likely to be used in the future, strategies to increase agricultural productivity, especially in developing countries that currently have low yields, will be very important.

Lignocellulosic feedstocks are also in demand in other sectors, particularly in the stationary energy sector for the production of heat and power, and in the forest sector for the production of other wood-based products. While the sawmill industry depends entirely on a supply of roundwood, the pulp and paper and wood-based panel industries also use by-products, e.g., the sawdust and wood chips that are produced during the production of sawn wood. Recovered paper and board are also major sources of raw material for the paper industry. European forest-based industries also use biomass to generate energy for their own purposes and for external customers. For example, the pulp and paper sector is the largest producer and user of renewable energy sources, with 50% of its primary energy consumption coming from bioenergy, in particular from waste wood, bark, and black liquor.

NEW POLICIES IMPLY INCREASED DEMAND FOR BIOMASS

The most important EU policies behind the growth of bioenergy in Europe are the Promotion of Renewable Electricity, Biofuels and Landfill Directives, the EU Emissions Trading Scheme (EU-ETS), and parts of the Common Agricultural Policy (CAP). The recent Renewable Energy Directive (2009/28/EC) in particular has the potential to trigger step-changes in the development of bioenergy policy. As a consequence, the biomass use for energy may grow substantially in the coming decades.

As an illustration of how policies can drive biomass demand, Figure 27.1 presents the modelled development of the electricity supply system in the EU27 countries plus Norway, in a scenario that takes into account all three cornerstones of current EU energy policy for 2020 and beyond, i.e., targets for CO_2 emissions, efficiency measures, and targets for electricity generation from renewable sources (RES), which should represent 20% of total electricity generation by 2020 and 60% by 2050. The present electricity generation capacities are indicated by white lines in the lower grey field in Figure 27.1. The modelling results indicate that the present system (including investments planned for the next few years) will account for about 60% of total electricity generation by 2020. In comparison, the global estimates presented by the IEA (IEA, 2008) indicate that about 66% of total electricity generation will originate from existing power plants in 2020.

The modelling results suggest that renewable energy-based electricity generation will amount to 2300 TWh by 2050, of which approximately 450 TWh will come from hydro, 550 TWh from wind power, and 1300 TWh from biomass. Generating 1000 TWh of electricity requires about 9 EJ of biomass at 40% average conversion efficiency. Considering the current EU levels of cereal production (about 4 EJ/yr) and forest wood removal (about 3 EJ/yr) (see Chapter 25), it becomes clear that biomass use for electricity generation can increase significantly under a policy that responds to ambitious climate targets, such as the 2 degree target set out in the Copenhagen Accord (UN, 2009).

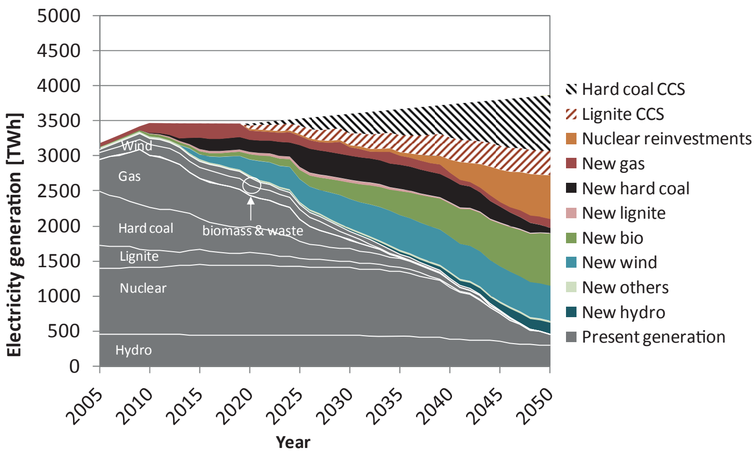

Figure 27.1. Electricity generation in EU27 countries plus Norway aggregated from Member State results, as derived from the ELIN model. The grey field in the lower part of the graph represents the contribution to electricity generation from the present system, with the fuel mix indicated by white lines. All three cornerstones of current EU energy policy for 2020 and beyond are considered, i.e., CO_2 emissions, efficiency measures, and electricity generation from RES (see Chapter 1).

STRONGER LINKS BETWEEN THE ENERGY, FORESTRY, AND FOOD MARKETS

Several supply-side options for meeting the increased demand for bioenergy are available: (i) mobilisation of forest resources (energy markets can offer more income for forest owners, and thus catalyse the harvesting of new forest areas and changes in management to increase biomass output); (ii) enhanced paper recovery and recycling, with energy use as the final option; (iii) improved land use productivity in agriculture, especially in developing countries; (iv) promotion of agricultural production of lignocellulosic plants; and (v) facilitation of international trade in biomass and biofuels.

Lignocellulosic plantations could obviously play an important role in meeting the future biomass demand in the stationary energy sector (and eventually, the demand from second-generation biofuel plants). At the same time, the possibility to cultivate lignocellulosic plants on agricultural land strengthens the links between the energy, forestry, and food markets. Policy-induced demand for second-generation biofuel feedstocks combined with biomassdemand from the stationary energy sector, could increase wood prices and also lead to increased competition for cultivable land, thereby pushing food commodity prices upwards.

Figure 27.2 illustrates this situation, in showing the magnitude of the paying capacity for biomass in the stationary energy sector (in this case, a large coal-based power plant with the possibility for biomass co-firing), in relation to wheat prices in the EU. The dashed and solid lines in Figure 27.2 show how the sellers' price for biomass develops over time, given certain developments of fossil fuel prices and CO_2 charges (carbon tax or carbon prices within a carbon trading system, see also energy market scenarios on page 269-270. The two shaded horizontal bars show – for two different cereal prices – how much a farmer needs to be paid for biomass, in order to obtain higher revenues from willow production than from cereal production. It is evident that the paying capacity for biomass increases rapidly as CO_2 charges increase, and soon reaches a level whereby farmers that produce biomass can obtain higher revenues than if they engaged in cereals production, unless cereal prices increase substantially.

Even though the demand for biomass from second-generation biofuel technologies is negligible at present, the demand volume and the paying capacity of that sector will become significant once the technologies become commercially available and attain greater importance in the biofuels market. A high 'ability to pay' is related to the economies of scale of second-generation biofuel plants, in which the feedstock cost share is small compared to that of first-generation biofuel plants, and the policy measures that support them. Moreover, possible future increases in oil prices will increase the competitiveness of these biofuels. Therefore, the situation described for stationary bioenergy (in Figure 27.2) is also relevant for biofuel production for transport.

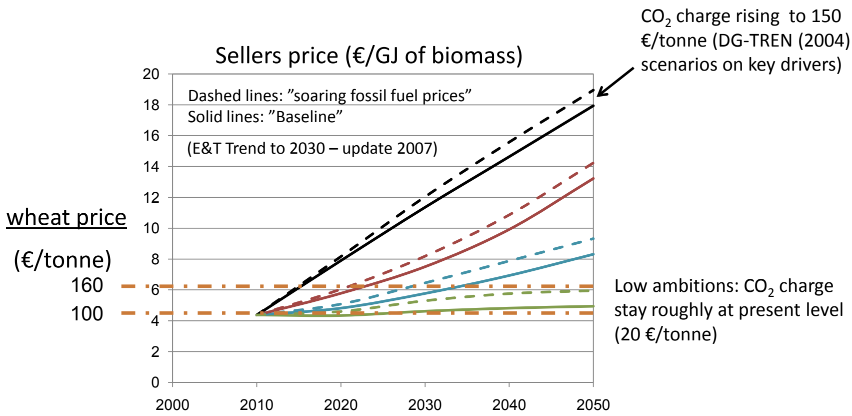

Figure 27.2. Illustration of the possible impact of a high-paying capacity for biomass in the stationary energy sector on food prices in the EU. The dashed and solid lines show how the seller's price for biomass develops over time, given certain developments for fossil fuel prices and CO_2 charges. The shaded horizontal bars show how much a farmer needs to be paid for biomass in order to be better off economically, compared to engaging in cereal production. Source: Elobio (2010).

NEW REGULATIONS FOR A NEW BIOENERGY MARKET

Currently, there is very limited cultivation of lignocellulosic plants for energy in Europe. Although farmers are unlikely to shift to lignocellulosic crops simply based on the promise of higher returns, once the other barriers have been overcome, this shift becomes more likely. The markets for biomass for the stationary energy sector, transport fuels, and the food- and forestry-based industries are becoming increasingly interdependent.

The increasing demand for biomass from the energy and transport sectors is changing the nature of the food and wood fibre markets, with important implications for the traditional land use sectors. This implies new challenges for policy makers. New rules and regulations may be needed to promote lignocellulosic crop production on marginal lands that are unsuitable for conventional food and feed crops. This could be achieved through strict measures, such as limiting the amount of land allowed to be used for lignocellulosic plant production, and through the research and development of specific plants that are better suited for production on marginal lands. In a scenario in which CO_2 charges are set at high levels and other low-carbon options do not act to stabilise energy prices, bioenergy plants may eventually have to be taxed so as to avoid the situation in which wood and food commodity prices must be increased to very high levels in order to maintain competitiveness.

The developments in wood-based energy production may have positive effects on the sawmill industry, as they will get a higher price for secondary products (slabs, chips, and sawdust), although the wood-based panel industries are likely to be affected negatively due to the increasing competition for slabs, chips, and sawdust from the sawmills as well as for roundwood. A major challenge for this industry is the fact that it has little or no secondary products to be fed into the energy markets. In contrast, forest industries can be adapted to become "biorefineries" that include both the production of fuels and the generation of energy, in addition to their traditional products. The production of biofuels, along with wood-based chemicals and other products in biorefineries, represents an effective use of a possibly scarce raw material, whereby the outputs are optimised according to market trends.

The possibility of future stronger links between the energy, agricultural, and forestry sectors can also be seen as a motivation for promoting uniform global instruments for meeting the energy and climate challenges. If strong biomass competition emerges in Europe but not in other regions, European companies will lose their competitive edge, which may lead to slower growth and even reductions of capacity and production.

For more information:

Göran Berndes

Physical Resource Theory, Chalmers

Further reading:

Elobio, 2010. Reconciling biofuels, sustainability and commodities demand: pitfalls and policy options. Elobio final project report. Available at www.elobio.eu

28

Bioenergy and land use change: implications for climate change mitigation

Replacement of fossil fuels with bioenergy is an important option for the mitigation of climate change. Bioenergy projects can result in both direct and indirect land use change (LUC), which can affect greenhouse gas balances in several ways, and have both beneficial and detrimental outcomes for the contribution of bioenergy to climate change mitigation. When land that stores high levels of carbon (notably, forests) is converted to bioenergy, the associated greenhouse gas emissions can be very high. However, the establishment of bioenergy plantations can promote the assimilation of CO_2 into soils and above-ground biomass, and this enhances the mitigation benefits. When LUC results in greenhouse gas emissions, the negative impact is usually greatest in the near-term, and the cumulative net greenhouse gas savings improve over time, as the savings from fossil fuel replacement accumulate. Thus, the overall net emissions savings may be subject to a time lag which needs to be taken into account in considering the role of bioenergy.

> This chapter gives an overview of the extensive complexity of the problem that includes bioenergy and land use change. In Berndes et. al. (2010) a more detailed description is presented.

This chapter discusses the connection between bioenergy and land use change (LUC), and examines whether there is a risk that greenhouse gas emissions associated with LUC could significantly undermine the climate change mitigation benefits of bioenergy. This chapter is partly based on work commissioned by the Swedish Energy Agency and IEA Bioenergy (Berndes et al., 2010). Figure 28.1 shows the historic contributions of fossil fuel use and LUC to greenhouse gas emissions. It is clear that fossil fuel use dominates anthropogenic emissions. About 330 Pg of fossil carbon has been emitted into the atmosphere since 1850. However, greenhouse gas emissions associated with LUC are also important contributors; roughly one-third of the accumulated anthropogenic emissions from 1850 to the present day have been caused by LUC, primarily through the conversion of forests to agricultural land required to feed a growing population.

Presently, fossil fuel burning contributes to more than 80% of annual emissions and this proportion is increasing rapidly. The present LUC emissions arise mainly from deforestation in tropical regions. Currently, less than 1% of global agricultural land is used for cultivating bioenergy plants, and LUC associated with expanded cultivation of bioenergy plants represents a small part of the overall changes in land use.

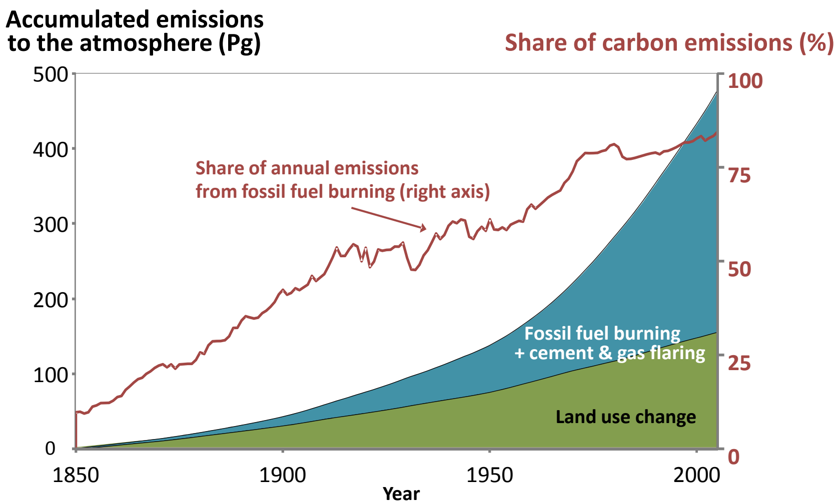

Figure 28.1. Accumulated anthropogenic carbon emissions into the atmosphere since 1850. Data source: CDIAC (2010).

SEVERAL ENERGY OPTIONS CAUSE LAND USE CHANGE

Bioenergy is not the only energy option that influences land use. Large areas of land may become submerged in hydropower projects, which in some instances also lead to large methane emissions due to the anaerobic decomposition of submerged vegetation. Surface mining of coal destroys soils and eliminates existing vegetation and, in terms of onshore oil and gas projects, also causes deforestation and other land conversion for access roads, drilling platforms, and pipelines. Prospective unconventional fossil resources include oil shale for which surface mining, processing and disposal requires extensive areas, and oil sand, which requires the removal of vegetation, as well as the topsoil and subsurface layers above the oil sand deposits.

Even so, LUC is to a greater extent linked to bioenergy owing to its close association with agriculture and forestry. Given that reducing emissions is one important driver for bioenergy, policy makers are understandably concerned that the impacts of LUC are properly taken into account when the planting of more energy crops is being contemplated or incentivised.

DIRECT AND INDIRECT LAND USE CHANGE

Direct LUC (dLUC) involves changes in land use on the site used for the bioenergy feedstock production, such as a change from food or fibre production (including changes in crop rotation patterns, conversion of pasture land, and degradation of managed forests) or the conversion of natural ecosystems. However, bioenergy projects can also induce changes in land use elsewhere (termed indirect LUC, or iLUC). For example, displaced food producers may re-establish their operations elsewhere by converting natural ecosystems to agriculture land, or the agriculture area may expand elsewhere to compensate for the losses in food/fibre production caused by the bioenergy project. A broad definition of iLUC includes changes in crop rotation patterns and/or intensification on land used for food or feed production (Figure 28.2).

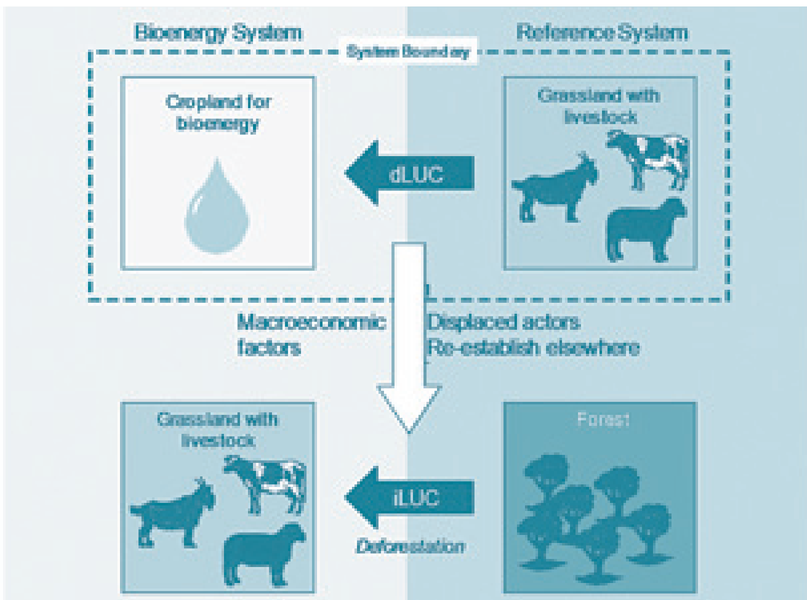

Figure 28.2. Examples of direct and indirect land use changes arising from a bioenergy project. Figure courtesy of Neil Bird, Joanneum Research, Austria. See also (European Commission, 2010).

LUC can affect greenhouse gas emissions in a number of ways, for example when: (i) biomass is burned in the field during land clearing; (ii) land management practice is changed so that the carbon stocks in soils and vegetation are changed; (iii) changes in the intensity of land use lead to changes in greenhouse gas emissions, in particular N_2O emissions due to fertiliser use; and (iv) LUC results in changes in the rates of carbon sequestration, i.e., the CO_2 assimilation of the land is lower, or higher, than in the absence of LUC. Figure 28.3 shows an example of how reforestation leads to CO_2 assimilation in soils and standing biomass. An additional benefit in this case is that the soil quality, and therefore productivity, is improved over time given appropriate plant selection and land management.

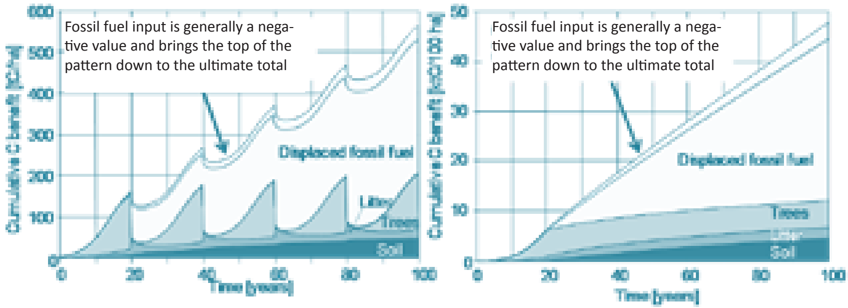

Figure 28.3. Reforestation of sparsely vegetated land having relatively low-carbon soil, with subsequent use of the harvested biomass for energy. The cumulative climate benefit is shown on the 1-hectare stand level (left panel) and on the 100-hectare landscape level, i.e., a plantation system producing a constant stream of biomass (right panel). The longer-term climate benefit is dominated by the fossil fuel displacement, although the carbon build-up in soils, litter, and trees also contributes substantially. Note that this example excludes the possible consequences of any iLUC that might arise due to reforestation. Diagrams produced using the GORCAM model. Source:http://www.joanneum.at/gorcam.htm).

Not all bioenergy systems are associated with LUC. The use of post-consumer organic waste and by-products from the agricultural and forest industries does not result in LUC if these biomass sources are waste materials, i.e., are not utilised for alternative purposes. Biomass that is burned, such as straw on fields or natural vegetation during forest clearing, is an obvious example. The use of biomass from wet conditions can also lead to additional benefits, such as reduced CH_4 emissions. If not utilised for bioenergy, some biomass sources (e.g., harvest residues left in the forest) retain organic carbon for a longer time than if they were used for energy. Such delayed greenhoouse gas emissions can be considered beneficial in relation to near-term greenhoouse gas targets and may also be relevant for longer-term accounting in regions where biomass degradation is slow (e.g., boreal forests). However, natural disturbances, such as fires and insect outbreaks, can convert forests from net sinks to net sources of greenhoouse gas, and the dead wood left in forests can be lost in fires. In forest lands that are susceptible to periodic fires, good forestry practices can lead to less-frequent, lower-intensity fires that accelerate forest growth rates and soil carbon storage. If the material removed in such practices is used for bioenergy, it can generate greenhoouse gas reductions by utilising energy from biomass that might otherwise be burnt in open air forest fires.

Bioenergy feedstocks can be produced in combination with food and fibre, avoiding land use displacement. The targeting of unused marginal and degraded lands can also mitigate LUC emissions associated with bioenergy expansion. Wisely designed, located, and managed bioenergy plantations can improve the productive use of land and provide benefits in addition to greenhouse gas savings, such as reduced erosion, reduced eutrophication, improved biodiversity, and improved socioeconomic conditions in the areas where bioenergy production expands. One promising way of reducing emissions from LUC is to increase the use of lignocellulosic feedstocks that can be grown on marginal land that is less suitable for annual crops, thereby decreasing the pressure on prime cropping land. Strategies to increase agricultural productivity, especially in developing countries, will be critical to minimising the impact of LUC. In general, stimulation of increased productivity for all forms of land use reduces the pressure for LUC.

EFFECTS OF LAND USE CHANGE ON GREENHOUSE GAS SAVINGS

LUC can affect greenhouse gas balances in several ways, having both beneficial and detrimental outcomes for the contribution of bioenergy to climate change mitigation. Some bioenergy projects cause very large LUC-related emissions, and these will not contribute positively to climate change mitigation within relevant time horizons. The clear felling and drainage of peat swamp forests to establish oil palm plantations is one such example. When peatland is drained, oxidation of the peat material results in very high CO_2 emissions, which adds to the upfront emissions of forest clearing for palm oil plantations. As a consequence, palm oil processed into biodiesel could in the worst case cause emissions dozens of times higher than the displaced emissions of fossil diesel.

When bioenergy expansion causes increases in LUC-related emissions, the negative impact is usually greatest in the near-term, and the cumulative net greenhouse gas savings improve over time as the savings from fossil fuel replacement accumulate. Therefore, the overall net emissions savings may be subject to a time lag which needs to be taken into account when considering the role of biofuels, for example, as one of the few near-term options for climate change mitigation in the transport sector (Figure 28.4).

However, biofuels can be considered a useful measure to reduce greenhouse gas emissions even if net savings are not always instantly achievable. The long-term contributions of biofuels can become especially important in a scenario in which the alternative is to produce transport fuels based on unconventional oil and coal. Furthermore, the achievement of ambitious climate targets will require climate-friendly fuels also in the aviation and shipping transport sectors, for which no alternatives to biofuels are currently available.

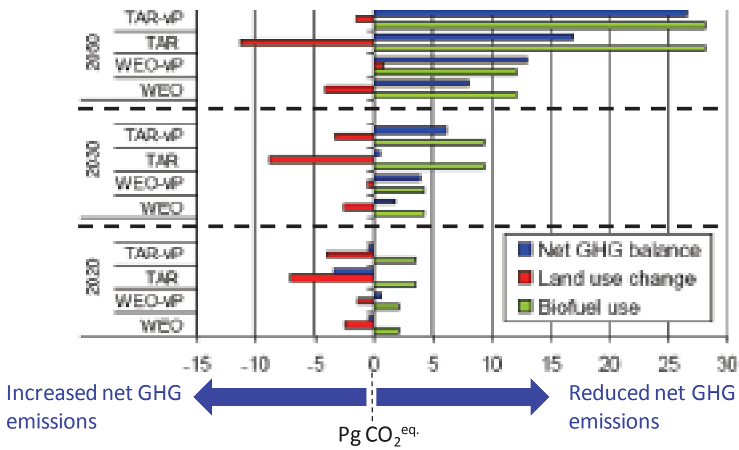

Figure 28.4. Accumulated net GHG savings for biofuel scenarios. The green 'Biofuel use' bars show GHG savings (positive) from biofuel replacement of gasoline and diesel; the red 'Land use change' bars show GHG emissions (negative) caused by LUC and iLUC; and the blue 'Net GHG balance' bars show the result of subtracting 'Land use change' emissions from 'Biofuel use' savings. Regional biofuel use up to 2030 is projected in the IEA World Energy Outlook (WEO) 2008 (IEA, 2008) reference scenario (4.2% of total in 2020, and 5.4% in 2030). Second-generation biofuels are gradually deployed after 2015 (4% of all biofuels in 2020, and 19% in 2030). The TAR scenario (Elobio, 2010) has roughly twice as high biofuel use as the WEO scenario and faster deployment of second-generation biofuels (33% of all biofuels in 2020, and 51% in 2030). The vP scenarios have higher agricultural productivity growth in developing countries, leading to lower LUC. Source: Elobio, 2010.

BIOENERGY'S CONTRIBUTION TO CLIMATE STABILISATION

Climate targets set limits on future greenhouse gas emissions. Many different emission trajectories are compatible with a given stabilisation target. Mitigation efforts over the next two to three decades will have significant impacts on opportunities to achieve lower stabilisation levels. Drastic changes in the global energy system are needed. However, the establishment of the required new energy technologies, and associated infrastructure, will in itself lead to greenhouse gas emissions, which means that a portion of the 'emission space' allowed within the greenhouse gas target will need to be 'invested' in energy system transformation. For example, electric vehicle fleets may contribute to increasing atmospheric greenhouse gas levels as long as electricity is mainly generated from fossil fuels. However, the promotion of electric vehicles is justified because they will provide efficient transport services that result in low greenhouse gas emissions once electricity production becomes less reliant on fossil fuels.

Similarly, some modest level of LUC emissions associated with bioenergy expansion may be an acceptable temporary consequence of the establishment of an industry that is capable of providing long-term renewable and climate-friendly energy services for the world. The greenhouse gas emissions associated with bioenergy will decrease over time, as above-ground biomass and soil carbon attain new equilibrium levels, conversion technologies improve and use renewable sources for process fuel, and feedstock production systems become less greenhouse gas-intensive.

It is important to note that climate change mitigation is just one of many rationales for ecosystem protection. Measures to reduce emissions due to LUC may encourage LUC on low-carbon stock lands, such as natural grasslands. While this may have a low impact in terms of climate change mitigation, it may impact negatively on biodiversity and water tables. Furthermore, pricing LUC carbon emissions may not suffice to make deforestation for bioenergy production unprofitable (Persson and Azar, 2010), since a higher carbon price will not only increase the cost of forest clearing, but also the revenues from bioenergy production. Land owners may therefore see a net profit from converting relatively high-carbon stock land to bioenergy plantations, even if this leads to additional carbon payment costs due to initial LUC. Thus, stronger protection measures may be needed to meet the objective of tropical forest preservation. Another conclusion is that forest conversion to highly productive bioenergy plantations may in some places represent a cost effective strategy for climate change mitigation, i.e., from a strict climate and cost efficiency perspective, some level of up-front LUC emissions may be acceptable noting the climate benefits of subsequent continued biofuel production and fossil fuel displacement. Clearly, the balance between bioenergy expansion, and its LUC impacts on biodiversity, water and soil conservation, is delicate.

Policy measures should be based on a holistic perspective that recognises the bioenergy's strong interconnectedness with food and fibre, and the multiple drivers and impacts of LUC. Options for addressing bioenergy-driven LUC may, depending on their implementation, not be able to completely avoid indirect greenhouse gas emissions, due to the interconnectedness of the agricultural and forestry systems. In the longer term, a global greenhouse gas emissions cap, that regulates both fossil and biospheric carbon emissions, could be an option that provides the necessary flexibility. Countries may then decide to use a certain share of their allowed emission space to develop a bioenergy industry, so as to secure a long-term domestic energy supply or to generate export revenues.

For more information:

Göran Berndes
Physical Resource Theory, Chalmers

Further reading:

Berndes, G., Bird, N., Cowie, A. , 2010, Bioenergy, land use change and climate change mitigation. Report for policy advisors and policy makers. IEA Bioenergy and Swedish Energy Agency.

Berndes, G. and Börjesson, P. , 2007, Multifunctional bioenergy systems. The AGS Pathways Report 2007:EU1.

IEA Bioenergy, 2009a. Bioenergy – a sustainable and reliable energy source: a review of status and prospects. IEA Bioenergy:ExCo:2009:06.

Overview of the Pathways booklet:

The complexity of the climate system

The Earth's climate system is a complex, interconnected system formed by the atmosphere, the oceans and other bodies of water, land surface, snow and ice cover together with all living organisms, and linked by flows of energy and matter.

The carbon and nitrogen cycles are interwoven and influence the amount of CO_2, CH_4 and N_2O in the atmosphere, thus playing a part in climate change. There are however still many open questions on how these cycles interact with each other and what the implications of these interactions might be.

Greenhouse gases in the atmosphere

Changes in the Earth's climate are influenced mainly by changes in the atmospheric composition of gases and particles, but also by changes in solar radiation and surface albedo. The most important component to influence the atmosphere is CO_2, which stands for 70 % of the global warming potential in the atmosphere. Other gases of great importance are long-lived gases like CH_4 (20 %), N_2O (5 %) and fluor-containing gases like HFC, PFC and SF6 (5 %). All act on a global scale.

Other more short-lived components in the atmosphere are water vapour (obvious climate effect on a daily basis), tropospheric ozone, and particles. The dispersion of these short-lived components is more regional, which also is true for their climate effect.

The uncertainity in radiative forcing is ±50 %

The present level of scientific understanding is high regarding the radiative forcing of CO_2 and the other long-lived greenhouse gases. However, the total effect of particles and aerosols as well as changes in surface albedo and solar irradiance is less well known. The total uncertainty in radiative forcing caused by anthropogenic impact is more than ±50 %.

Sources and sinks

Major sources of non-CO_2 greenhouse gas emissions are energy supply and use, agriculture, industrial processes and waste management. The emissions and the influence by different processes on the emissions to the atmosphere are for some sources and components (emissions of methane and nitrous oxide from forests, peatland etc.) still not known in detail. The magnitude of emission and influence on emissions via land-use changes are consequently connected with considerable uncertainties.

The main sink for N_2O is decomposition by sunlight in the stratosphere which is linked to the depletion of stratospheric ozone.

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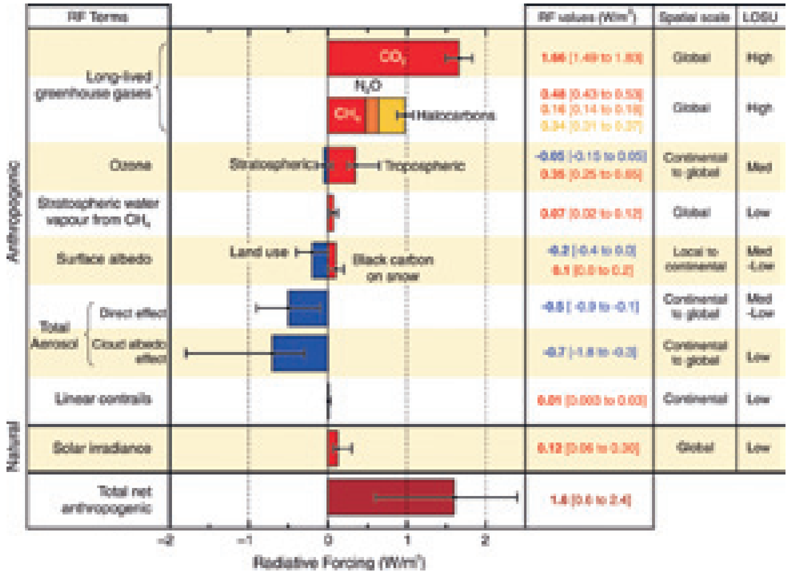

The present level of scientific understanding is high regarding the radiative forcing of CO_2 and the other long-lived greenhouse gases. However, the total effect of particles and aerosols as well as changes in surface albedo and solar irradiance is less well known. The total uncertainty in radiative forcing caused by anthropogenic impact is more than ±50 %. Source: IPCC (2007) : Climate Change - synthesis report.

Emission trends

There is a clear link between the increase of anthropogenic emissions of greenhouse gases and the observed increase of global average temperature.

The estimates of total emissions of CO_2 are significantly better known than the emissions of CH_4 and N_2O.

Abatement measures and mitigation potentials

Mitigation of greenhouse gases must consider not only CO_2 but also the other long-lived greenhouse gases. A so called multi-gas strategy has been found to achieving the same climate goal but at considerably lower costs than a CO_2-only strategy.

On a global level the energy and agriculture sectors offer the greatest potential for cost-effective mitigation of non-CO_2. There is also a major potential in the waste and industrial processes sectors. Methane mitigation shows the largest potential.

The AGS Pathways report (2010:EU2) is available at: www.energy-pathways.org.

For further information:
Gun Löfblad and
Ebba Löfblad, Profu

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Energy from waste:
potential contribution to EU targets

The results show that energy from renewable waste fractions has the potential to contribute significantly to the goal of increased use of renewable energy and to the commitment of reduced emissions of greenhouse gases in the EU. Renewable waste streams can contribute with 14-25% of the total reduction target for greenhouse gases up to 2020, depending on scenario assumptions. The corresponding contribution to the target of increased share of energy from renewable sources is 4-14%.

ONGOING CHANGES IN THE WASTE MANAGEMENT SYSTEM

European waste management is forced to undergo extensive changes in order to reduce its environmental impact in accordance with current EU directives. The impacts are likely to be decreased quantities of waste to landfilling and increased re-use, recycling, and recovery of waste. Recovery measures include energy recovery, and the aim of this chapter is to quantify the potential for energy recovery from renewable waste fractions. This energy can contribute to achieving the European targets for renewable energy and reduced greenhouse gases until year 2020.

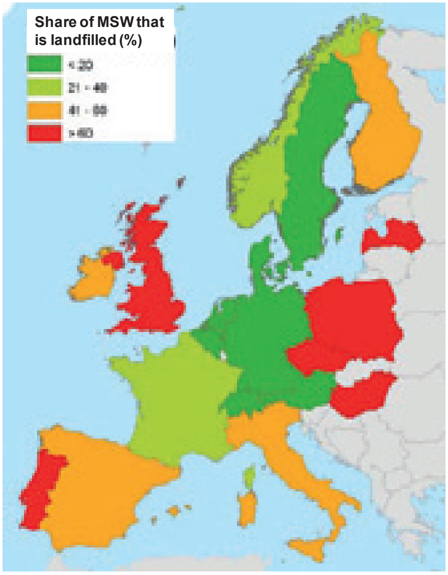


Figure 29.1. Share of municipal solid waste (MSW) landfilled in 2005. MSW mainly originates from households.

The current European waste management system is largely dependent upon the landfilling of waste (Figures 29.1 and 29.2). Landfilling is the waste handling alternative with the lowest cost, both in terms of investment and operating costs.

However, the environmental impact from landfilling is significant, as there are emissions from the landfill sites to the air and water and the resources (materials and energy) of the waste streams are not utilised. Large amounts of methane are emitted when the organic waste fractions decompose in the landfill.

"DOUBLE EMISSION-REDUCTION EFFECT"

One way to reduce the environmental impact of the European waste management system is to decrease landfilling and instead increase incineration with energy recovery of renewable organic waste streams. Thus, emissions of greenhouse gases are reduced. This reduction takes place on two levels in the waste management and energy system:

1. through reduced usage of alternative fuels for heat and electricity production, leading to reduced emissions of CO_2; and
2. through reductions in the amount of waste sent to landfilling, resulting in lower emissions of methane from the landfill sites.

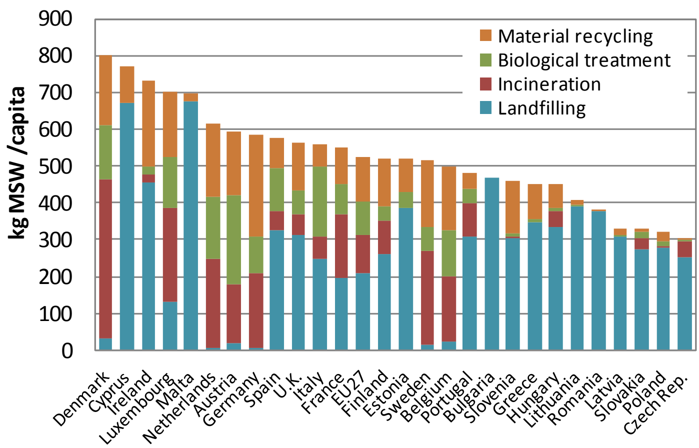


Figure 29.2. Quantities and treatment methods of municipal solid waste (kg/capita) in 2008 for the EU27 countries. Source: Eurostat (2010)

This "double emission-reduction effect" makes renewable waste incineration a competitive alternative for reaching greenhouse gas reduction targets. The reduction effect is included in the "indirect emissions" bar in Figure 29.3, which illustrates an example of the emission savings that can be gained from waste incineration with energy recovery. The largest reduction in greenhouse gases is achieved by avoiding the landfilling of waste, thereby eliminating methane emissions from the landfills.

The example is taken from a case study of the city of Malmö, Sweden, and it shows the reduction of emissions of CO_2-equivalents when mixed waste incineration is increased (Profu, 2009). The direct emissions come from the incineration of mixed waste containing various materials, e.g., plastic of fossil origin. The direct and indirect emissions comprise the "resulting total emissions" in Figure 29.3.

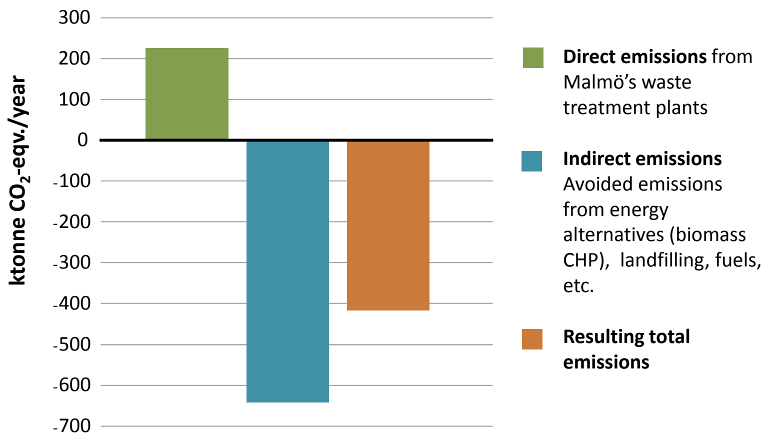


Figure 29.3. Example of resulting changes in greenhouse gas emissions from increasing mixed MSW incineration. Case study of Malmö (Profu, 2009).

THE ROLE OF WASTE IN A SUSTAINABLE ENERGY SYSTEM

There is a wide range of views on waste in a sustainable society, as well as in a sustainable energy system. On the one hand, there are voices that demand strong policy measures against consumption and thus, waste generation. One example is Zero Waste, which is an idea that encourages the redesign of resources and products so that all products are reused. Zero Waste regards waste as a resource and not as a material that is disposed of or incinerated (Glavič and Lukman, 2007). Cradle-to-cradle is another concept that looks at materials as "nutrients" that circulate in closed-loop systems (Glavič and Lukman, 2007).

On the other hand, there is the belief that consumption is not a problem to be solved, but instead is the solution needed to attain a sustainable society (Fryklund, 2007 and 2010). According to Fryklund, waste is a part, and needs to be part, of a society. Fryklund points out that in Sweden the environmental impact of Swedish waste management hace decreased, while at the same time economic growth and consumption have been allowed to increase.

When waste cannot be prevented, the waste is to be re-used, recycled or recovered (e.g., through energy recovery) or disposed of according to the Waste Framework Directive (2008/98/EC). Recovery measures include efficient energy recovery, such as the recovery rates shown by waste-fuelled Swedish plants. Thus, efficient waste incineration is one of the treatment options preferred over landfilling. However, with low energy efficiency, waste incineration is classified as a disposal measure together with landfilling.

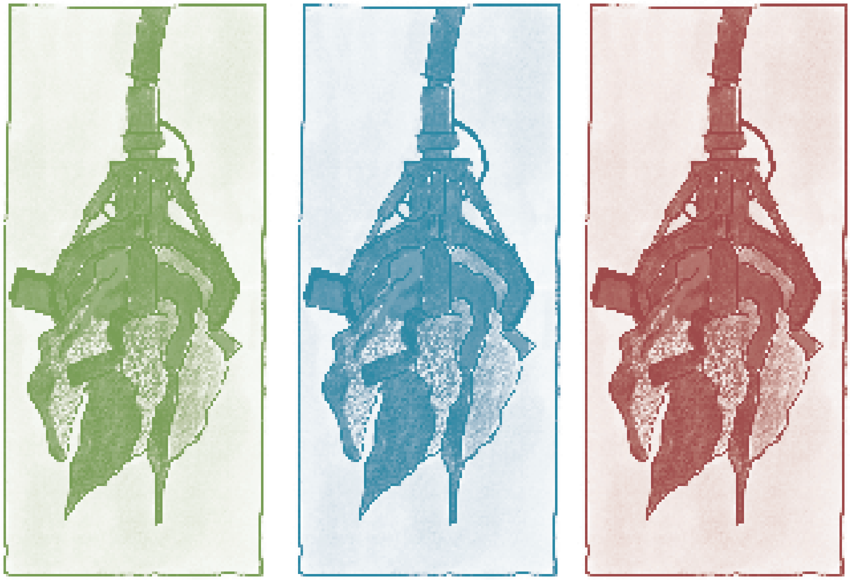
Independently of these views and according to the Directive on the Promotion of the Use of Energy from Renewable Sources (2009/28/EC), waste from agriculture, forestry, and related industries, as well as the biodegradable fraction of industrial and municipal waste falls under the category of biomass, and is thus seen as a renewable energy source. Therefore, energy-efficient waste incineration can be regarded as one part of a sustainable future energy system and a component of a sustainable society.

TWO PERSPECTIVES STUDIED

The future potential of energy recovery from waste is viewed from two perspectives:

1. The *Total potential perspective* estimates the full potential of recovering energy from the renewable waste quantities in year 2020. The applicable energy technologies are combined heat and power plants (CHP), heat-only plants, and condensing plants for electricity production only. This change in waste management systems presupposes large investments in both incineration plants and district heating systems.
2. The *Reasonable growth perspective* refers to the reasonable growth of waste-to-energy capacity in Europe, based on the historical growth rate. Between 1995 and 2005, the waste-to-energy capacity increased of 13 Mtonnes in total, corresponding to a growth rate of 1.3 Mtonnes/year. The same annual growth rate is assumed to continue from 2006 to 2020.

The starting point for both perspectives is the current estimated energy recovery from the renewable waste stream of 52 TWh in Europe (year 2006). From this, future waste quantities and potential energy recovery are estimated. The details and the methodology used are further described in Chapters 27 and 28 in the *Methods and Models* book. It is stressed that the potential energy recovery is calculated after material recycling and biological treatment. Therefore, the energy recovery described in this chapter does not undermine the possibilities to reach EU targets on material recycling.



CONTRIBUTIONS TO REDUCTION OF EMISSIONS OF GREEN-HOUSE GASES

Assuming that all new plants will be built with the best technologies and efficiencies, the contribution to the reduction target for greenhouse gas emissions up to year 2020 would be 25% (*Total potential perspective)* (Figure 29.4, 'high'). With the historical growth rate (*Reasonable growth perspective*), the contribution to the total reduction target for greenhouse gases would be 14% (Figure 29.4, 'low'). In these results, six percentage points come from replacing fossil fuels and eight percentage points come from avoiding landfilling.

RENEWABLE ENERGY CONTRIBUTION

Figure 29.5 shows the potential for the renewable waste-to-energy contribution to the target of 20% renewable energy by 2020. The contribution to the target is 4-15% depending on the perspective studied.

These results differ from the results of a previous study conducted by the EEA (2006), in that the potential energy from waste in the highest scenario presented in this chapter is about 20% lower than that reported by the EEA. This discrepancy reflects the fact that the EEA study included sludge and agricultural waste, which are not considered here. Other differences between the studies are that the study presented in this chapter includes more wood waste, which the EEA study placed in another category, as well as paper and cardboard, which the EEA study did not consider for energy purposes.

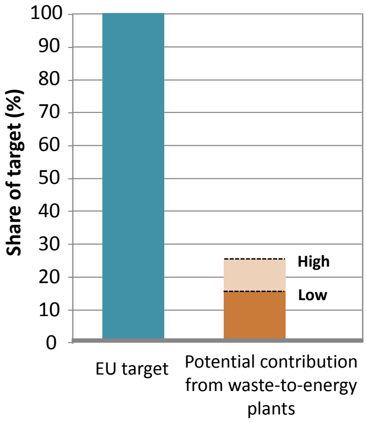


Figure 29.4. Potential contributions from waste-to-energy plants to the target of reduction of greenhouse gas emissions until 2020.

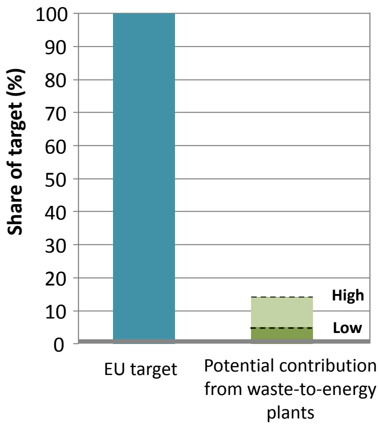


Figure 29.5. Potential contributions from waste-to-energy plants to the target of renewable energy until 2020.

For more information:

Jenny Sahlin
Profu

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Pathways for European waste management

European waste management needs to undergo extensive changes in order to reduce its environmental impact. In this chapter, three pathways for the necessary changes in waste management are identified, representing movement from landfilling to alternative waste treatment methods. The pathways differ in the extent of policy measures introduced and stimulation of market mechanisms. As a model, the last 20 years of development of the Swedish national waste management system is used, as this has evolved from a system that was heavily dependent upon landfilling to the current system, which includes alternative waste handling methods and has a lower environmental impact (Swedish Waste Management, 2010).

A reduction in environmental impact by European waste management is a requirement of the *Waste Framework Directive* (2008/98/EC) and the *Directive on the landfill of waste* (1999/31/EC). Waste management systems need to undergo extensive changes in order to meet these requirements, as the directives give priority to waste prevention and minimisation, combined with a shift in waste-handling methods. The prescribed changes are essential to decrease the landfilling of waste and to encourage the re-use, recycling, and recovery of waste (Figure 30.1).

Waste recovery includes recovering the energy of the waste, and energy that can be used for heating, electricity or transportation fuel purposes. The aim is to identify pathways in waste management that will facilitate the shift from landfilling to alternative waste treatment methods.

Biological treatment involves anaerobic digestion and composting. Currently, it is primarily anaerobic digestion that is undergoing significant expansion. The process is based on microorganisms that break down biodegradable compounds in the absence of oxygen (an anaerobic atmosphere). The process results in a biogas and a digested end-product, which can potentially be used as fertilizer. The biogas can be used for energy purposes, as heat and electricity, or upgraded to vehicle fuel.

The compost from the composting process is rich in nutrients, and can be used in several countries as a soil conditioner for conditioning the humus layers and preventing soil erosion.

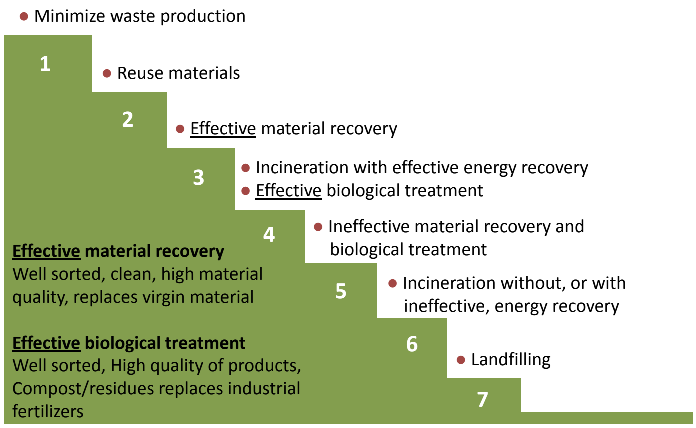

Figure 30.1. Hierarchy of waste treatment alternatives (Profu, 2009).

SCENARIO ANALYSIS OF WASTE DEVELOPMENT

The method used involved data collection in combination with scenario analysis. Data on current waste management systems was collected from the Eurostat database (Eurostat, 2010). First, scenarios for the growth of future waste quantities were set up. Second, the scenarios were further explored and pathways for the development of the waste management system were identified. Results were generated for three differing pathways (scenarios) for the development of the future European waste management system. These pathways are: (1) a policy-driven scenario; (2) a scenario driven by market mechanisms to stimulate energy recovery from waste; and (3) a scenario with a less marked decrease in landfilling owing to less policy measures, as well as weak market conditions for the alternatives to landfilling. More about the methodology can be found in the *Methods and Models* book.

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SCENARIO 1: POLICY MEASURES

The resulting pathway is shown in Figure 30.2. A 92% decrease in the landfilling of waste is evident, which matches the decline in landfilling experienced in Sweden over the last 20 years. Concomitantly, large increases in material recycling and biological treatment occur. At the same time, it is assumed that measures are introduced to reduce the waste growth rate. In Figure 30.2, the growth rate of waste is reduced from the historical 2% to 1% per year. Energy from waste incineration is allowed to increase according to the current growth rate in Europe.

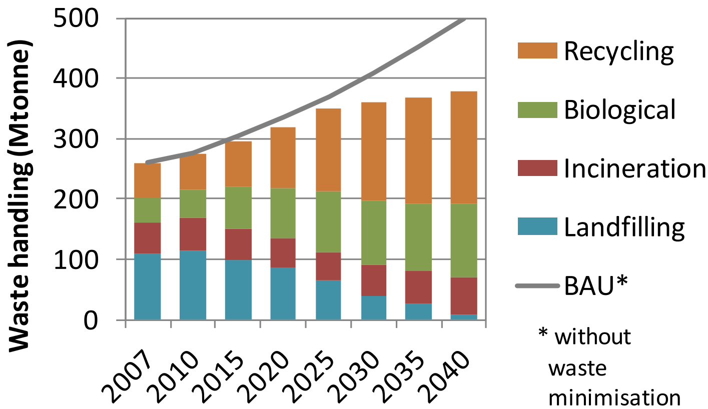


Figure 30.2 The policy-driven pathway, with assumes policy measures aimed at decreasing waste quantities, decreasing landfilling, and increasing material recycling and biological treatments.

The pathway is assumed to be realized through the introduction of strong policy measures. The main measures introduced for the Swedish waste management system during the last 20 years were used as a model for the future European waste management system (Swedish Waste Management, 2010) in this scenario. Thus, it is assumed that the same or similar measures will be introduced, and that they will have the same effects as those experienced in Sweden. The policy measures that have driven the formation of the Swedish waste management system are:

1. **Producer responsibility,** which compels the producers of packaging of products to take responsibility for their environmental impact. Producers are obligated to pay a proportion of the cost of the recovery and recycling of their packaging or products. One of the aims of this measure is to facilitate and increase material recycling. In Sweden, producer responsibility was

introduced in 1993 and has been increased over time to include additional products. In addition, in the EU, this measure is already in place.

2. **A ban on the landfilling of organic waste** was introduced in Sweden in 2002. This strong measure has not yet been introduced across the EU. Instead, all member states must reduce the amount of biodegradable municipal waste going to landfill to 35% of the 1995 level by 2020 (European Community, 1999);

In addition, in the forthcoming Swedish waste management plan, the focus will be on:

3. Measures to stimulating **waste prevention or minimization**, thereby preventing further growth in waste volumes. Such measures are to be introduced both in Sweden (Swedish Environmental Protection Agency, 2010) and the EU (European Community, 2008). Examples of such measures are awareness campaigns and improved collection systems.

SCENARIO 2: STIMULATING MARKET MECHANISMS

Figure 30.3 shows the pathway driven by market mechanisms, in which landfilling is reduced by 70%. The markets for energy from waste and for recycled materials are stimulated, and both increase by more than 200%.

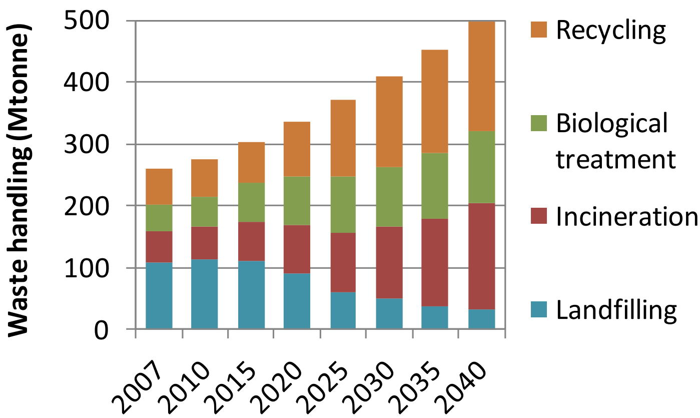


Figure 30.3 The pathway driven by market mechanisms that stimulate energy production from waste and the use of recycled materials.

The growth of alternative markets leads to a reduction in landfilling as a waste-handling method. Market-based stimulation measures that are already in place or that are being discussed in the EU include:

1. Measures for increased energy production from waste, which could be included in **support schemes**, such as investment aid, electricity certificates or feed-in tariffs, as mentioned in the *Directive on the Promotion of the Use of Energy from Renewable Sources* (2009/28/EC), with the aim of stimulating energy production from non-fossil sources. In Germany, this measure is already in place, and is stimulating energy production from renewable waste fractions.
2. Measures through which the markets for recycled materials are stimulated, i.e., through the introduction of **recycling certificates**, as discussed in Sweden (Bisaillon et al., 2009).

The energy recovered in this scenario is assumed to be used for heating purposes in current, expanded, and new district heating systems, as well as in the form of electricity, which currently is a focus for research and development. The large potential of energy from waste and its contribution to reducing greenhouse gases has been explored by several groups (see Chapter 29; CEWEP and Ffact, 2008). A large increase in waste incineration capacity is in the planning process, for example in Poland and Finland, both of which countries are still heavily dependent upon landfilling of waste.

In Poland, the planning process has been initiated to increase the number of waste-to-energy plants from the existing one in Warsaw, to eventually have nine plants (Pajak, 2010). Currently, all eight planned plants are aiming for investment support from the EU (ibid.). However, the national decision process is pending and obstacles are reported.

In Finland, there are three existing waste-to-energy plants, of which two have recently begun operating. In addition, one plant is under construction, two are approved, and six plants are currently being planned (Ecoprog, 2010).

In contrast to the above countries, Great Britain has had an official strategy of not expanding waste-to-energy systems, preferring instead to intensify material recycling and biological treatments. However, the official strategy is changing, and several new waste incineration plants are being built (Defra, 2010; Fleck, 2010). Several countries, including Sweden, Denmark, Switzerland, and The Netherlands, have experienced a large increase in energy from waste, alongside growth in material recycling, which has substituted for landfilling. This pattern of development could eventually be adopted by the whole EU.

However, with no policy measures for waste prevention or minimisation in place, waste quantities increase and landfilling is not reduced as much as in Scenario 1 (Figure 30.2), either in absolute or relative levels.

SCENARIO 3: LESS MARKED DECREASE IN LANDFILLING

Figure 30.4 shows a pathway with a less marked decrease in landfilling than in the earlier scenarios. With fewer policy measures in place or weak market conditions, a situation in which there is a continuing and relatively high proportion of landfilling of waste prevails. This is true even if waste growth rate decreases as result of waste minimization measures. Furthermore, although the increase in energy from waste is less significant than if the market is stimulated, it still corresponds to a reasonable growth of waste-to-energy capacity in Europe, based on the historical growth rate (see Chapter 29).

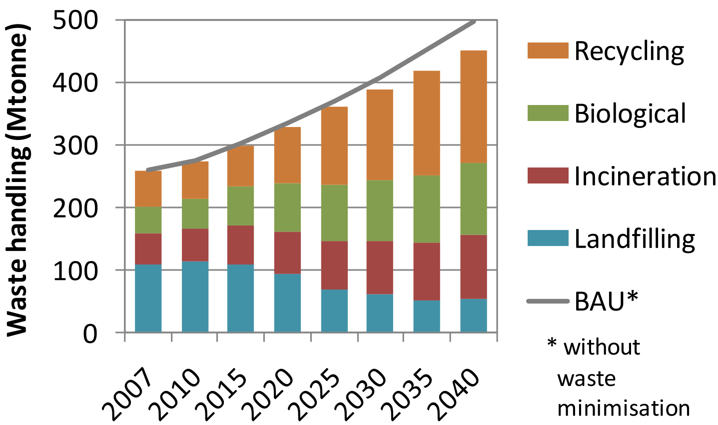
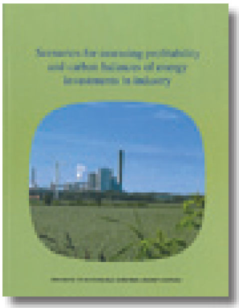


Figure 30.4. A pathway with a less marked decrease in landfilling, which is based on fewer policy measures and weak market conditions for alternatives to landfilling.

For more information:

Jenny Sahlin
Profu



Overview of the Pathways booklet:

Scenarios for assessing profitability and carbon balances of energy investments in industry

The industrial sector can be a major contributor to increased energy efficiency and reduced CO_2 emissions, provided that appropriate energy-saving investments are made. The profitabilities and potential for net reductions in CO_2 emissions of such investments must be assessed by quantifying their implications within a future energy market context, e.g., using different energy market scenarios that include CO_2 emissions and energy prices for different energy carriers. By assessing the levels of profitability for different cornerstones of the energy market, robust investment options may be identified.

Construction of the scenarios

The energy market parameters within different scenarios must be consistent, that is, different energy market parameters must be clearly related to each other (e.g., via key energy conversion technology characteristics and substitution principles). For constructing consistent scenarios, a calculation tool, the Energy Price and Carbon Balance Scenarios (ENPAC) tool, was developed by the authors. The ENPAC tool

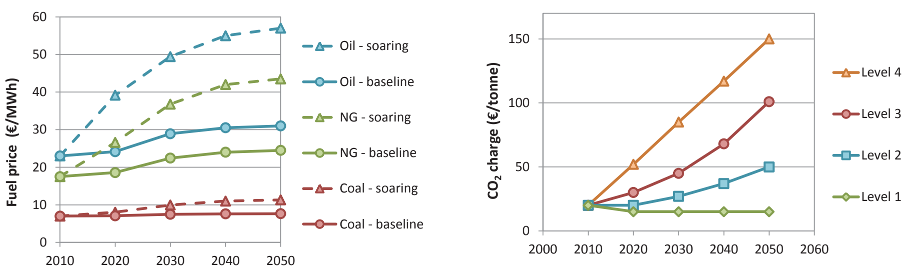


Figure A. Input data for ENPAC: high and low fossil fuel prices (left), and four levels of CO_2 emission charges (right).

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calculates energy prices for a large-volume customer based on forecasted fossil fuel prices on the world market, relevant policy instruments, and key characteristics of energy conversion technologies. Moreover, CO_2 emissions related to marginal use of the energy streams associated with industrial plant operations can also be determined.

Input data and resulting energy market parameters

Using the ENPAC tool, eight energy market scenarios, covering the period from 2010 to 2050, have been developed for the EU energy market. The eight scenarios are the result of combining two levels of fossil fuel prices and four levels of CO_2 emissions charges (Figure A). For the year 2010, only one set of input data is used, providing the starting point for all the scenarios. An example of the results is presented in Figure B; the market price of low-grade wood fuel is shown, with the assumption that coal power plants with support for renewable electricity are the marginal user. As shown in Figure B, the carbon emission cost has a significant impact on the wood fuel price, while the difference in world market fuel prices has a less serious consequence.

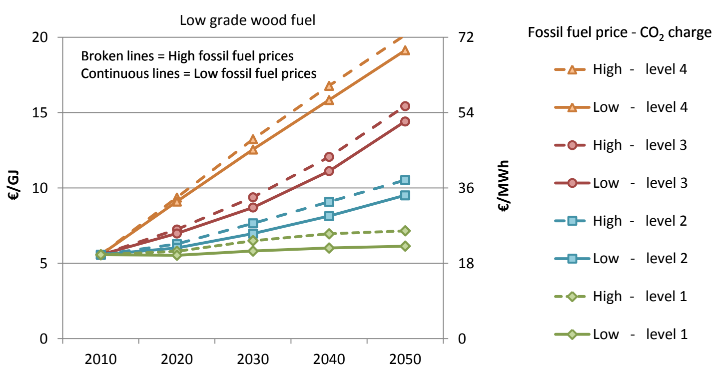


Figure B. Market prices of low-grade wood fuel if coal power plants with support for renewable electricity are the marginal user.

The AGS Pathways report (2010:EU1) is available at: www.energy-pathways.org.

For further information:
Erik Axelsson, Profu and
Simon Harvey, Chalmers

31

Regional and local energy planning: linking short-term actions to long-term vision

Actions undertaken at the local or regional level are crucial for meeting the global and/or EU goals for sustainable development. PATH-TO-RES is an EU/IEE-funded project that was initiated at Chalmers University of Technology in 2007 (Chalmers, 2010). The main aim has been to assess and develop a step-by-step methodology that can be used to evaluate and define pathways to renewable and efficient energy systems in the local setting, i.e., a supporting tool for local energy planning. The methodology was tested in six case study regions within the EU. The most important outcome of the work is a step-by-step methodology that can be used for linking near-term actions with long-term visions.

In order to meet global and/or EU goals for sustainable development, actions that are undertaken in the local community are crucial. Although methodologies for local energy planning exist, many of them are not suitable for considering the long-term (i.e., 30-50 years from now) transformation of local energy systems. This is an important topic, since local energy infrastructures are long-lived and are not amenable to rapid changes. Therefore, there is a need for a methodology that enables the definition of both short-term action plans and long-term strategies and visions, and that facilitates the linking of these two aspects. The work is based on the concept of "think global, act local".

The basic hypothesis behind this work is that seven specific steps must be assessed in order to formulate a roadmap for transforming local energy systems to sustainable systems. This hypothesis has been tested in the six case studies in Göteborg (Sweden), Valencia (Spain), Dunkerque (France), Gdansk (Poland), and Arnhem and Lochem (The Netherlands).

A STRUCTURED DESCRIPTION OF THE ENERGY SYSTEM

A strong emphasis has been placed on describing energy systems in which the structure (i.e., components, flows, and connections) and energy balance were established according to a common principle. A schematic model, called a Reference Energy System (RES) diagram, was used to describe the energy systems. The principle design of a RES diagram is shown in Figure 31.1. For each case study, RES diagrams for the short-term, mid-term (up to 2020), and long-term (up to year 2050) were established. Related to this, a number of steps (or activities) were designated as check-points, to ensure that one or more pathways could be formulated. The resulting pathways describe how the local energy system can be transformed to comply with goals and targets. Based on a pathway, valuable judgements can be made as to possibilities, challenges, and potential long-term lock-in effects.

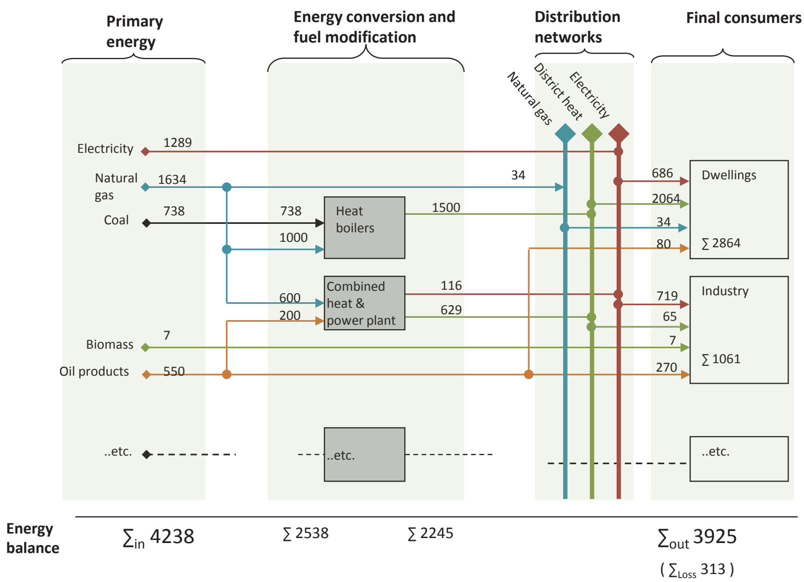


Figure 31.1. Basic design of an RES diagram with indicative structure and data.

THE SEVEN STEPS

With few adjustments, the basic hypothesis with the seven steps proved to be relevant, based on the six case studies and in relation to which the assessment has been iteratively developed. The seven steps in the assessment are as follows:

1. Project initiation (clarify purpose and create commitment among decision makers)
2. Establish a detailed description of the present system
3. Assess local, EU, and global goals for sustainable development

4. Identify and assess key technologies that can bridge to a future sustainable system
5. Identify key actors in the region
6. Formulate and analyse pathways towards a more sustainable energy system
7. Establish a roadmap (with respect to technologies, markets, and institutions)

The six regions/municipalities included show considerable variability in terms of population size, land area, and characteristics of the existing energy systems. Nevertheless, the results indicate that the seven-step assessment tool is applicable to each of the six case studies, despite their considerable differences and unique features (Sköldberg, 2010). This confirms the usefulness of the methodology.

DESCRIPTION OF THE PRESENT SYSTEM PROVIDES IMPORTANT INSIGHTS

For all the case studies, it turned out to be more difficult to describe the present energy system than was initially anticipated. Establishment of the RES diagrams provided, for all the participants, a valuable understanding of the present energy systems and the possibilities for transforming them so as to meet local and/or global goals. The importance of considering the present system lies in the very long lifespan of the energy system infrastructure, which includes buildings, district heating distribution, and energy conversion equipment. This implies that development over long periods of time is highly influenced by the present system. The majority of the buildings that will be heated in the year 2050 already exist.

The case studies differed with respect to the access to data describing the present energy system and in some cases, the availability of existing goals and plans. For most of the pathways developed in the case studies, the "EU202020" goals, as well as the IPCC goals for 2050 are considered. For some of the cases, local plans and policies already exist, whereas in other cases few local goals and plans related to these targets exist.

PATHWAYS COMBINE SHORT-TERM ACTIONS WITH LONG-TERM VISIONS

The pathway descriptions facilitated assessments of the extent to which existing local policies and plans contribute to a sustainable development, and in the absence of relevant plans, the extent to which policies or consideration of global goals could be identified. Different time horizons have been described and analysed. The concept applied in the case studies is illustrated in Figure 31.2. For all the case studies, pathways for the short-term (2012-2015), mid-term (2020), and long-term time (2050) have been created. It was considered important in the methodology to incorporate all three perspectives, to create an effective planning process that is both action-oriented and guided by clear long-term visions. Indicators have been used to present in quantitative terms how the energy system develops. A number of indicators have been suggested in the PATH-TO-RES methodology. For all the case studies, such indicators have been prepared, and they have proven to be useful for describing energy system development and the emissions associated with each pathway.

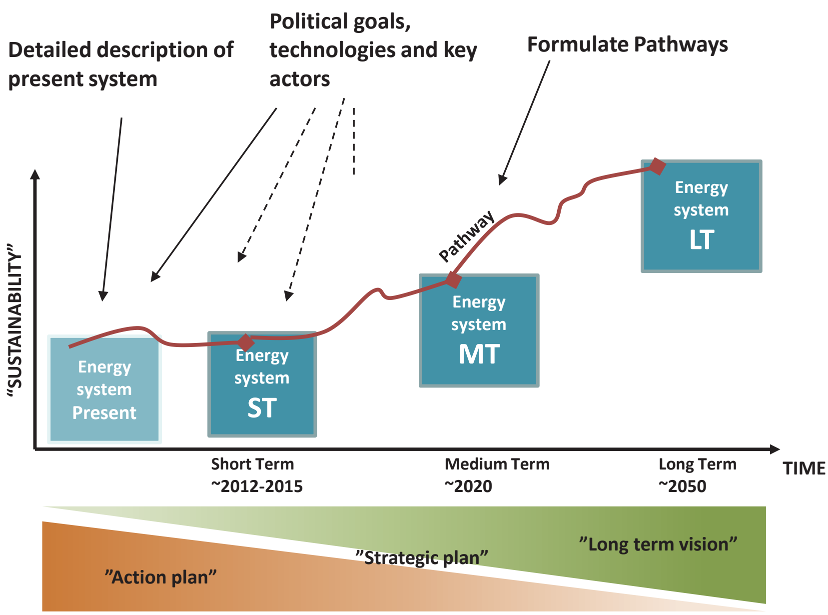


Figure 31.2. Basic description of a pathway and how it interacts with plans and strategies for different time horizons.

EARLY COMMITMENT FROM KEY ACTORS IS CRUCIAL

The commitment of local key actors and decision-makers varies, and in some of the studied cases it has been difficult to stimulate the interest of these persons in local workshops and in the development of the roadmaps (through which the assessment is applied in each case study). An important outcome of this work is that early commitment from key actors and clarification of the purpose of the planning effort are crucial for ensuring that any document, such as a roadmap or energy plan, is accepted in the community and that the plan becomes operative. To attract interest, it is important to focus on short-term development and actions. A long-term focus, e.g., beyond 2030, may be regarded as being too abstract. It is also difficult to connect the long-term goals to ongoing activities.

A ROADMAP IS A COMBINATION OF A PREFERRED PATHWAY AND HOW IT COULD BE TRANSFORMED TO REAL ACTIONS

When different pathways are identified and analysed, it is time to establish a roadmap. The roadmap is the preferred pathway, together with the process of how to transform this into real actions, and visions that act as guidelines for these processes. In the construction of the roadmap, conflicts of interests and controversial questions can be highlighted and discussed, which is valuable for the continuous processes of local and regional energy planning. It is important to see the roadmap as "an instrument for change" in a sustainable direction. The roadmap report per se is not the main goal of the planning effort, rather the most important outcome is the subsequent development of the energy system in the desired direction. The planning process is merely the means for achieving the desired development.

It is important to be aware of the possibility to influence development in different sectors. The municipality has direct control over its own buildings and its own vehicles. In other areas, the possibilities to influence are less direct, e.g., by means of physical planning. In some areas, the municipality may act, e.g., through specifying certain qualities when equipment or services are bought, whereas in other areas, the only way that the municipality can influence development is through information. Consequently, different strategies ("control", "act", and "information") must be considered.

For the very long-term, there should be a greater focus on visions and strategies. For development planned 40 years from now, it is not meaningful to specify a typical action plan. Too many things can change and what is specified today may be totally irrelevant in 40 years time. The desired development for this period could instead be expressed in terms of visions and general strategies, which could subsequently be transformed into "action-like" plans (Figure 31.2).

THE ACTION PLAN

The seven steps of the assessment do not necessarily have to be performed in a strict order, and for a municipality that already has an operating process for energy planning it is not certain that all the steps have to be considered with the same weight. An integrated part of the seven-step check list is that the roadmap should contain an action plan with specific measures, roles and responsibilities, in order to function as a tool for change. Important items related to the action plan are that:

- It is specified how the specific measure should be implemented, who is responsible, when it should be completed, and how it should be evaluated
- There are different possibilities to influence the development in different sectors ("control", "act" or "information")

- The key actors assigned responsibilities within the action plan should be included in the planning process
- All parts of the action plan should be followed up and evaluated
- The plan should be converted into decisions on actions, goals, directions, and ambitions
- Measures from the action plan should be included in the budget process of the municipality

From the case studies, it is evident that most of the suggested pathways have the EU202020 goal as a common point of reference. However, the purpose of the methodology is to break down the chosen goals into more specific measures. This makes it possible to describe a pathway that complies with the chosen goals. Thus, the methodology itself does not specify which goals should be applied to a particular pathway. Importantly, the methodology can be applied to a policy-oriented pathway, as well as to a more market-oriented pathway.

Our overall conclusion is that the PATH-TO-RES project and the seven-step checklist have both been successful. The identified problems, together with suggested methods to overcome these problems, are examples of how the initial hypothesis has been tested and how the methodology has been gradually improved.

For more information:

Håkan Sköldberg and **John Johnsson**
Profu
Jonas Lodén, Energy Technology, Chalmers

Further reading:

Chalmers, 2010, Seven steps towards sustainable local energy systems, Project brochure for the PATH-TO-RES project, Energy Technology, Chalmers University of Technology.

Lodén, J., Broin, E. and Johnsson, F., Towards Energy Efficient Housing – the importance of local energy planning Presented at International Forum on Energy Efficiency in Housing, 23-25 November 2009, Vienna, Austria

Sköldberg, H., Johnsson, J., Lodén, J., 2010, Detailed description of the 7 steps – how it was assessed and developed, Gothenburg.

32

Development of the district heating in EU27

The development of district heating (DH) in the EU27 countries was assessed for eight specified countries and one region covering the remaining countries ('8+1 regions'). Based on plans, intentions, potentials, and opportunities, the development of market share and production mix was established for the 8+1 countries. The analysis shows that the market share for DH could double in the EU up to 2050, while at the same time DH production could become essentially carbon-free.

COUNTRY-WISE BOTTOM-UP ANALYSIS

To assess the development of the DH sector within EU27, a country-wise bottom-up approach was applied, in which the eight EU countries with the greatest potential for increased DH and that currently have the highest share of DH (Finland, France, Germany, Italy, Poland, Spain, Sweden, and UK) were treated as separate entities and the remaining countries were treated as one unit ('8+1 regions').

Initially, a low potential and a high potential for DH in the 8+1 regions were established. These potentials were based on the results presented in Chapter 33 and 44. With the potentials for DH in hand, country-specific analyses of the heat market were performed, to establish developments of DH that were in line with the Policy and Market Pathways, respectively. In these analyses, national plans, intentions, and possibilities were also included. A more thorough description of the approach applied can be found in Chapter 26 in the *Method and Models* book.

District heating - an important energy infrastructure

The development of the European district heating (DH) sector is of crucial importance to the pathways to a sustainable European energy system. DH allows for efficient use of energy resources and facilitates the use of renewable energy resources. Therefore, DH can be a vital part of a sustainable energy system. DH has strong growth potential in many European countries and can be considered as an important energy infrastructure component in a sustainable energy system.

POTENTIAL FOR DISTRICT HEATING EXPANSION

There is considerable potential for the expansion of DH in many European countries (Figure 32.1). France and Germany have the greatest expansion potential, while Italy and the UK also have promise in this area. However, in Finland, Poland, and Sweden, DH is more or less fully developed and the potential for further expansion is limited.

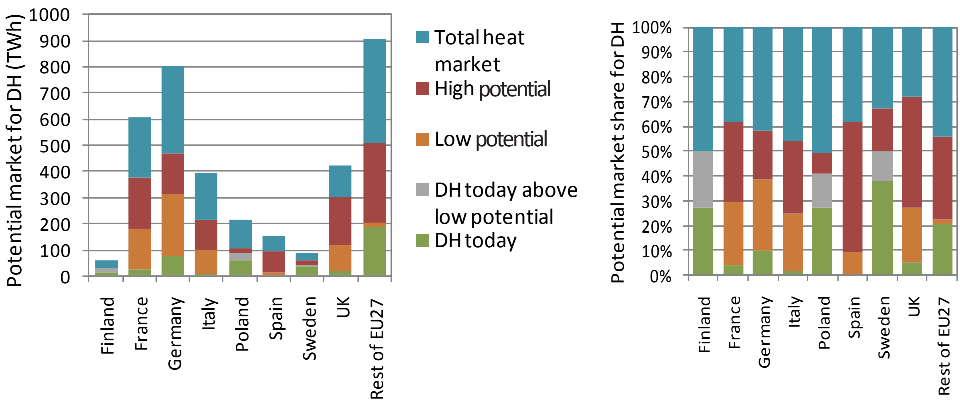


Figure 32.1. Potential market share for DH in absolute terms (left) and share (right).

Based on the potential for expansion, assumptions regarding the possible growth rate, and energy savings on the demand side, the development of the market share of DH was established for the 8+1 regions (Figure 32.2). The market share of DH is expected to double by the end of the studied period. The Market scenario shows a higher market share for DH at the end of the period, although this is not as high as one might expect in this supply-side-oriented pathway. The explanation for this is that in the Market scenario, DH competes with heat pumps in areas of low and medium heat density to a greater extent than in the Policy scenario. However, the expansion in terms of delivered heat is much higher in the Market scenario.

Defining the pathways from sector specific scenarios

Two different European Energy Pathways are defined in this project: the Policy Pathway and the Market Pathway. The Policy Pathway relies more on targeted policies that promote energy efficiency and renewable energy; the measures in this pathway are primarily demand-side-oriented. In contrast, in the Market Pathway, the measures are more supply-side-oriented and the cost to emit CO_2 is the predominant policy measure. These two Pathways are based on the results from the sector-specific scenarios and analyses described in Chapters 1-46 of this book.

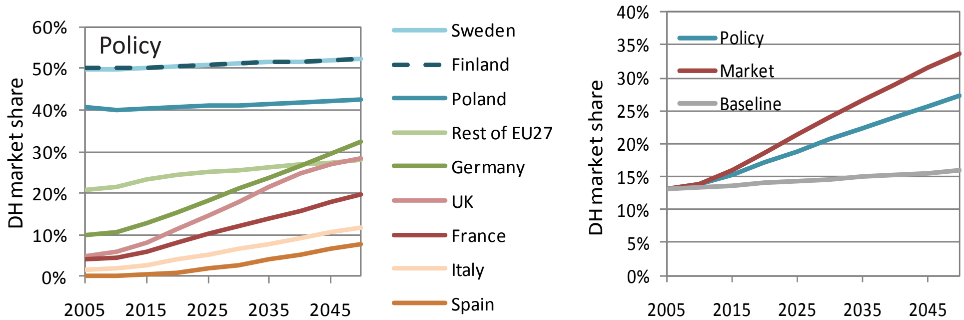


Figure 32.2. Development patterns for the market share of DH in the 8+1 regions according to the Policy scenario (left), and in the EU27 in the three analysed scenarios (right).

DEVELOPMENT TOWARDS SUSTAINABLE DISTRICT HEATING

The increasing demand for DH and decommissioning of old production units will have to be met by commissioning of new production units. The character of the new units will determine the development of DH production. The development in each region is set according to a analysis of the heat market development and is synchronised with the results from other fields in the Pathways project, e.g., the electricity market and waste management. The results at the EU level for the two scenarios (Policy and Market) are presented in Figure 32.3. The development of a renewable and a more sustainable DH production is apparent in both scenarios. The development of DH production presented in Figure 32.3 is the sum of the country-wise assessment. The developments in the individual regions can take different paths, as illustrated in Figure 32.4.

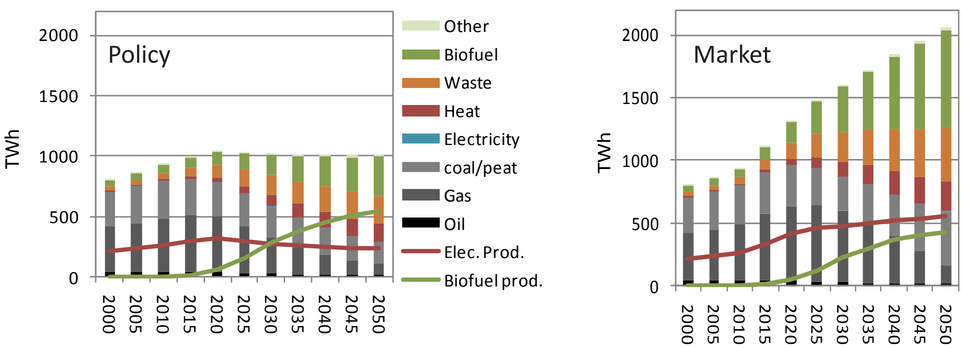


Figure 32.3. Energy supply for the DH sector in the EU27 and the production of electricity and biofuels therein, in the Policy (left) and Market (right) scenarios. Fuel for biofuel production is not included in the energy supply values.

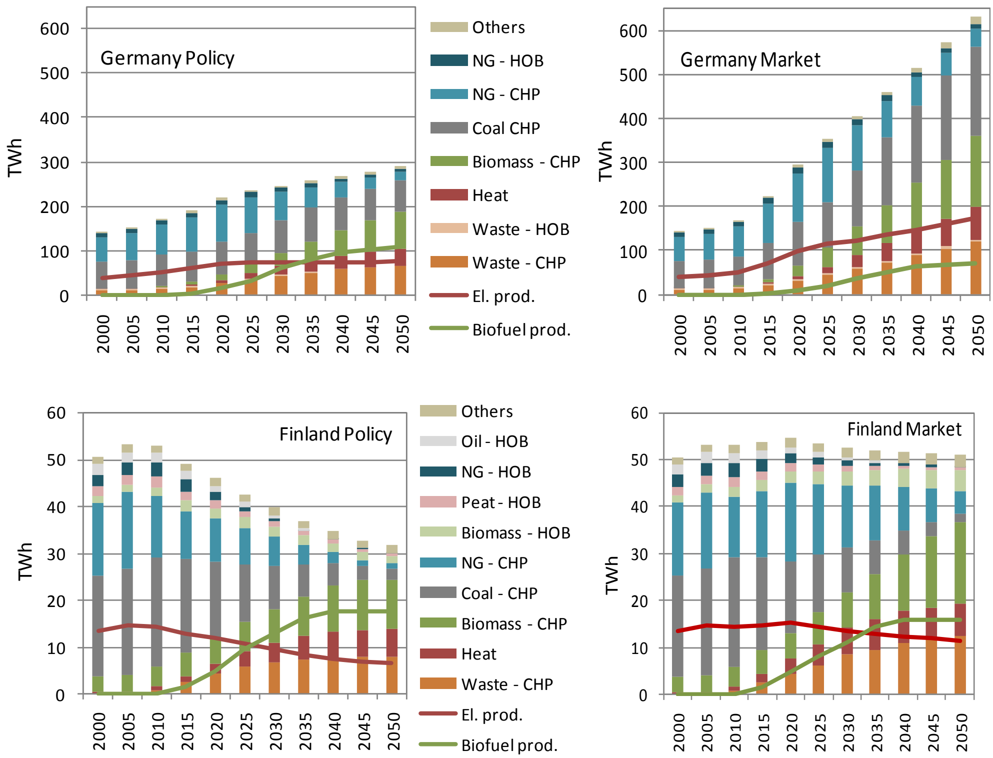


Figure 32.4. Energy supply for the DH sector and the production of electricity and biofuel therein, in Germany (upper) and Finland (lower) in the Policy (left) and Market (right) scenarios. Fuel for biofuel production is not included in the inputs.

As a result of the decreasing use of fossil fuels in DH production, CO_2 emissions will decrease (Figure 32.5). Moreover, carbon capture and storage (CCS) will be introduced into DH production, adding to the reduction in CO_2 emissions. As can be seen in Figure 32.5, the production of DH could be more or less carbon-free by the end of the period. In the Market scenario, decarbonisation is to a greater extent dependent upon CCS, as compared with the Policy scenario.

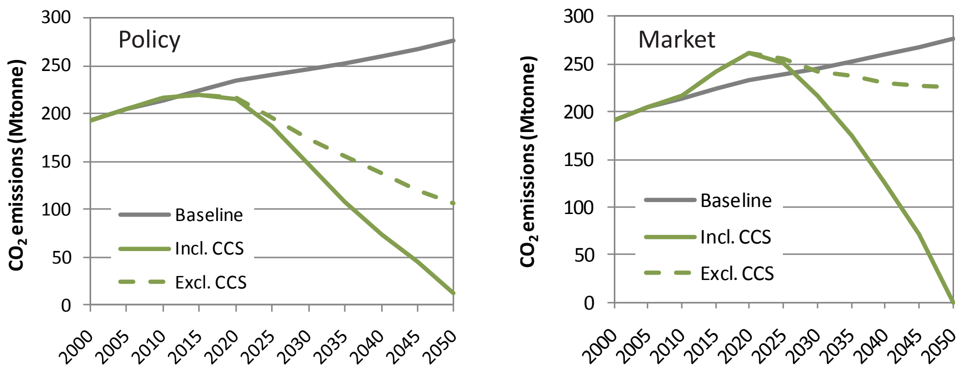
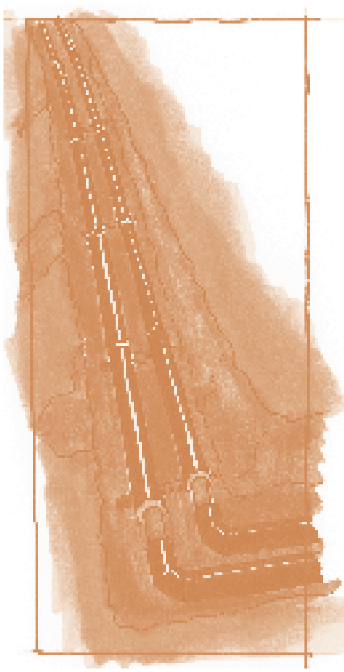


Figure 32.5. CO_2 emissions from DH production in the EU27 countries (including emissions for electricity production in CHP) in the Policy (left) and Market (right) scenarios.



CONCLUDING REMARKS

The following can be concluded regarding the potential development for district heating:

- The market share for DH may increase twofold in the Policy scenario and to an even greater degree in the Market Scenario

- A twofold increase in market share will result in only a slight increase in the absolute level of DH production in the Policy scenario, due to the demand-side energy savings.

- In the Market scenario, the increase in DH production will be in accordance with the increased market share.

- The development of DH (both regarding size and shape) differs significantly between the different countries, due to the differences in prerequisites for DH.

- By introducing renewable technologies and CCS, the DH sector can become more or less decarbonised, in both the Policy and Market scenarios.

- It is clear that DH has the potential to be a vital part of a sustainable energy system.

For more information:

John Johnsson and **Erik Axelsson**
Profu

Further reading:

Axelsson, E., Rydén, B., and Colpier, U., 2010, "EMER model results: Two Pathways to Sustainable European Energy System", Pathways Internal report 1/2010. See also www.energy-pathways.org.

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Competitiveness of European district heating systems

District heating is a well known technology that is present in many European countries today, but at heat market shares far below its competitive potential. According to the findings in the Pathway project, heat market shares of 60% are attainable for district heating systems in large and high heat density European cities at competitive network investment cost levels. In studying 83 cities (1703 city districts) in France, Germany, Belgium, and the Netherlands, it was found that the present district heating heat market share is only 21% of the total heat market, indicating potential for a three-fold expansion of district heating within these city districts in the coming future.

The future role and competitiveness of European district heating systems is depending on a dynamic mixture of boundary conditions and counteracting factors, where the future competition on the heat market, the current use of district heating, and the shaping of future cities are critical factors. While the future possibility of lowered residential and service sector heat demands, due to climatic processes and/or energy efficiency measures, pose a potential risk of lowering the feasibility of district heating systems, the key abilities of district heating networks to receive and distribute excess heat act as a central counteracting factor. Increased dutilisation of abundant sources of European excess heat suggests the establishment of many new district heating systems in the future. Since the major additional cost for a district heating system, compared to a local heat generation alternative, is the unavoidable cost of heat distribution, an in-depth analysis of the heat distribution aspect of district heating was performed, in which the demand-side parameters that influence the capital cost of distribution were analysed.

General information about the included cities and specific information on the current district heating heat market shares in these cities by country are presented in Table 33.1. For more detailed information regarding the methodology, see Chapter 25 in the *Methods and Models* book.

Table 33.1. General information on the studied cities and aggregated district heat market shares in the studied cities sorted by country.

Country	Number of cities	Number of city districts	Estimated present heat market share for district heat in the studied cities	Cities included
Belgium	4	84	0%	Brussels, Antwerp, Gent, Charleroi
Germany	38	632	29%	Berlin, Hamburg, Munich, Köln, Frankfurt am Main, Essen, Leipzig, Dresden, Dortmund, Düsseldorf, Bremen, Hannover, Nurnberg, Bochum, Wuppertal, Bielefeld, Halle an der Saale, Magdeburg, Wiesbaden, Got-tingen, Mulheim an der Ruhr, Darmstadt, Trier, Freiburg im Breisgau, Regensburg, Frankfurt (Oder), Weimar, Schwerin, Erfurt, Augsburg, Bonn, Karlsruhe, Monchengladbach, Mainz, Kiel, Saarbrucken, Potsdam, Koblenz
France	31	826	11%	Paris, Lyon, Toulouse, Strasbourg, Bordeaux, Nantes, Lille, Montpellier, Saint-Etienne, Le Havre, Rennes, Amiens, Rouen, Nancy, Metz, Reims, Orleans, Dijon, Poitiers, Clermont-Ferrand, Caen, Limoges, Besancon, Grenoble, Ajaccio, Saint Denis, Pointe-a-Pitre, Fort-de-France, Cayenne, Marseille, Nice
Netherlands	10	161	21%	Gravenhage, Amsterdam, Rotterdam, Utrecht, Eindhoven, Tilburg, Groningen, Enschede, Arnhem, Heerlen
Total	**83**	**1703**	**21%**	

Reformulation of the linear heat density to project future distribution cost

The methodology in this study initially involved a theoretical reformulation of the traditional expression for linear heat density. On the basis of this vital prerequisite, the methodology was expanded to data collection and treatment, the creation of an Excel-based model tool (the Distribution Capital Cost Model), data input, model calculations, and the production and evaluation of results. Model input data were primarily gathered from national and European sources of statistics on energy use, city populations, city areas, and residential living areas. When these data combined with statistically derived values for construction costs and average grid pipe diameters (based on Swedish experiences), along with an assumed annuity (3%, 30 years), model projections of future district heat distribution capital costs could be made.

POSSIBILITY FOR A THREE-FOLD DISTRICT HEATING EXPANSION

The primary study result indicator was chosen as the combination of marginal distribution capital costs, C_d, and the corresponding heat market shares, which were consecutively sorted from the lowest to the highest marginal distribution capital cost. In reality, the actual distribution capital cost may be lower than that indicated by the marginal distribution capital cost, as observed typically for high heat density inner city areas.

The current situation

The current distribution capital cost levels and the corresponding potential district heating heat market shares in the studied city districts are presented in Figure 33.1. To emphasise the distinction between marginal and average distribution capital cost, the red curve in Figure 33.1 represents the average distribution capital cost ($C_{d, a}$), while the black curve represents the marginal distribution capital cost, ($C_{d,}$).

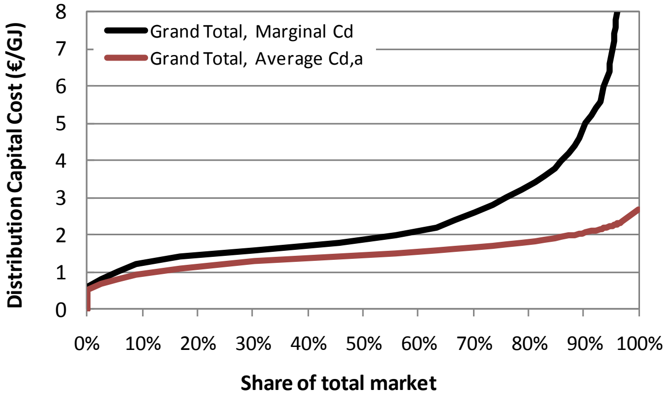


Figure 33.1. Current distribution capital cost levels and the corresponding district heating heat market shares in the studied city districts.

In Figure 33.1, it is evident that the grand total curve for the marginal distribution capital cost levels out to create a plateau for heat market shares in the interval of 10% to 60%, where market expansion can occur with only a slight increase in marginal distribution capital costs. Under current conditions, a heat market share of 60% can be reached with a marginal distribution capital cost

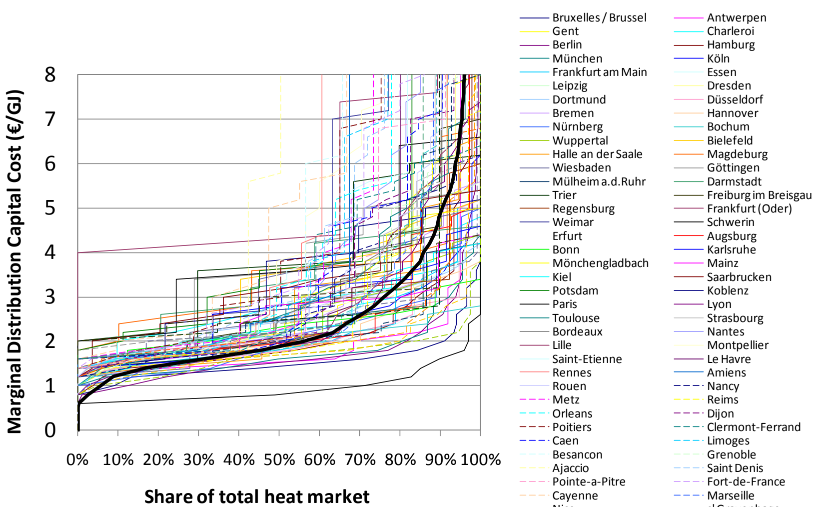


Figure 33.2. Current marginal distribution capital cost levels and the corresponding district heating heat market shares in the 83 studied cities.

of only 2.1 €/GJ, which corresponds to an average distribution capital cost of 1.6 €/GJ. Therefore, a heat market share of 60% could be considered as an indicative threshold market share in European urban areas, where district heating is directly feasible under current heat market conditions.

To illustrate the full distribution of the results, the heat market share curves for each of the 83 cities are presented in Figure 33.2.

The investigated city districts were divided into three main categories of area characteristics based on the plot ratio (e) (for more information on plot ratio, see Chapter 25 in the *Method and Model* book). The average distribution capital cost levels for the studied city districts by area characteristics are presented in Table 33.2. Above the indicative feasibility threshold, corresponding to a marginal distribution cost of 2.1 €/GJ, the model calculations suggested a total investment volume of 17.6 G€ in order to annually distribute 578 PJ of heat.

Table 33.2. City districts by area characteristics with average distribution capital costs, total heat demands, and corresponding levels of required investment.

Area characteristics	Number of city districts	Average distribution capital cost, $C_{d,a}$ [€/GJ]	Model-estimed heat demands, Q_s [PJ/a]	Required investments in heat distribution networks, I [G€]
Inner city areas	317	1.2	182 (19 %)	4.3
Outer city areas	296	1.6	160 (17 %)	5.1
Park areas, feasible	355	1.8	236 (25 %)	8.2
Total, directly feasible	**968**	**1.6**	**578 (61 %)**	**17.6**
Park areas, less feasible	735	4.5	373 (39 %)	32.9
Total	**1703**	**2.7**	**951 (100 %)**	**50.5**

In general, district heating heat market shares >60% appear unlikely, since this market segment primarily consists of low heat density areas (park areas, less feasible). An indicative threshold plot ratio value of 0.15-0.20 was identified for directly feasible district heating in the studied cities, corresponding to a marginal distribution capital cost of 2.1 €/GJ.

Two comparisons have been carried out to add further perspective on the estimated distribution capital cost levels. The first of these comparisons referred to the total district heat price levels in the studied countries. An interval of 13-17 €/GJ (excluding VAT) was defined for 2007, which is similar to the current cost of an alternative local heat supply. Thus, an average distribution capital cost of 1.6 €/GJ would represent about 10% of the full price level.

The second comparison referred to a hypothetical CO_2 emission cost scenario. If natural gas, which is used for space heating in European buildings, was part of the emission trading system (ETS), an emission price of 20 €/tonne CO_2 would correspond to an additional heat cost of 1.3 €/GJ, and an emission price of 40 €/tonne CO_2 would be equivalent to an additional heat cost of 2.6 €/GJ. Thus, the investment cost for establishing viable district heating networks in dense and semi-dense European cities is of the same magnitude as the emission prohibition costs that eventually could be added to the major local heating fuel alternative.

Based on these comparisons, it was concluded that the distribution capital cost will have to increase considerably in order to reduce the competitiveness of district heating in the future. Furthermore, the magnitude of the distribution capital cost is not currently an obstacle to expanding district heating in the studied cities, since this cost is a small proportion of the total cost level and is comparable with current CO_2 prices, if applied for heating. Since there were only small differences among the four studied countries, all of which are located in the same geographical region, these results were considered as being generally applicable to all four countries (Figure 33.3).

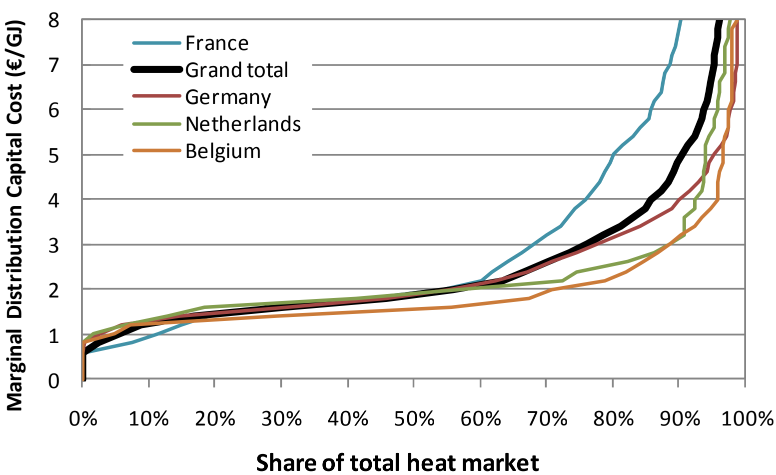


Figure 33.3. Current marginal distribution capital cost levels and the corresponding district heating heat market shares in the studied countries.

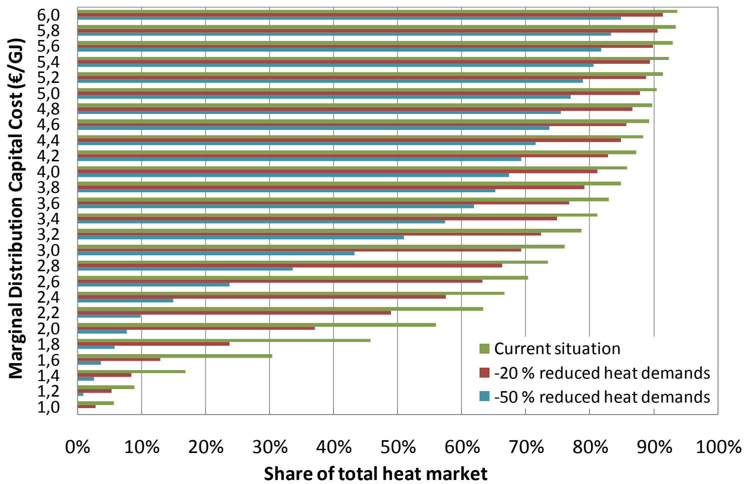


Figure 33.4. Marginal distribution capital cost levels and the corresponding district heating heat market shares in the studied city districts for 20% and 50% reductions in heat demand levels.

Heat demand reductions

In Figure 33.4 the increase in marginal distributional capital costs due to a decrease in heat demand is shown.

Within the identified heat market expansion interval of 10% to 60% an enhanced sensitivity for heat demand reductions can be observed. Nevertheless, the additional cost associated with market share persistence is relatively low in this heat market segment. The additional cost for maintaining a given heat market share is not proportional to the magnitude of the decrease in heat demand per se, but is dependent upon the present district heating heat market share. At a district heat market share of 60%, heat demand reductions of 20% would render an increase of distribution capital cost levels of anticipated 20%, while reductions of 50% would induce a 70% cost increase. Thus, reduced heat demands were anticipated to increase the current marginal overall district heat cost levels by 2% and 7%, respectively, since the distribution capital cost constitutes about 10% of the current total price level.

DISTRICT HEATING COMPETITIVE EVEN WITH REDUCED HEAT DEMAND

In summary, reduced heat demands will give pressures for somewhat higher customer prices and somewhat lower payability for recycling heat into district heating systems. However, reduced heat demands in heat dense areas are not considered to be a general obstacle to district heating in the future.

The future role and competitiveness of district heating in Europe relies on a dynamic mixture of boundary conditions and counteracting factors, and the determination by modelling of distribution capital costs and altered heat demands alone should be considered as merely indicative. The critical determining factors are: 1) future competition in the heat market; 2) the current use of district heating; and 3) the layout and configuration of future cities.

In short, with respect to district heating, the level of competition in the heat markets of the future will always depend on the combination of distribution cost levels and the cost difference between the district heat supply and any alternative local heat supply. If natural gas and fuel oil used for heating become part of the emission trading system (ETS), consumer costs for heating would be further increased. This cost increase would have the same magnitude as the current district heat distribution capital cost levels.

Related to the current use of district heating, future market share increases can be facilitated by expansions of already existing network systems and by utilisation of already existing organisations and business models. Furthermore, the key abilities of district heating networks to receive and distribute excess heat represent a central counteracting factor. Extended utilisation of abundant European excess heat would presuppose the establishment of many new district heating systems in the future.

Finally, if population densities in European cities increase in the future, the competitiveness of district heating systems will be continually improved, since densely populated cities are more suited to district heating (and cooling) than sparsely populated cities.

For more information:

Urban Persson and **Sven Werner**
Halmstad University

Further reading

Persson, U., Werner, S., 2011, Heat Distribution and the Future Competitiveness of District Heating. Applied Energy; 88:568-76.

34

Proactive strategies for sustainable development in energy companies

The stationary energy sector is a critical player in the mitigation of global warming. There is a pressing need for companies in this sector to take a strategic approach to environmental sustainability and to integrate sustainable practices into their businesses. Using a case study approach (see Chapter 6 in the Methods and Models book) the study presented in this chapter has explored proactive strategies for environmental sustainability of municipal energy companies, with the aim of elucidating these strategies and the key mechanisms that facilitate their implementation. As this chapter illustrates the strong environmental commitment of companies triggers a multitude of activities and practices that are oriented towards conducting business more sustainably.

Although companies are subject to essentially the same institutional setting and environmental regulations, corporate responses to the challenge of mitigating their impacts on the climate vary significantly. Therefore, it is important to investigate the internal factors that account for these differences. To gain a deeper understanding of the strategies needed for environmental sustainability and how they can be implemented, three municipal energy companies with proactive approaches to the environment were studied. These companies are named, LargeCo, MediumCo, and SmallCo. In the first section, the key mechanisms that facilitate the effective implementation of environmental strategies in the case companies are introduced. The second section contains highlights from the case studies viewed through the lens of these mechanisms. The third section briefly describes the framework of the analysis. Finally, conclusions are drawn as to the usefulness of the mechanisms for understanding the key components for implementing environmentally sustainable strategies in the stationary energy sector.

KEY MECHANISMS IN THE PATHWAYS FOR TRANSITION TOWARDS SUSTAINABLE BUSINESS

Analysis of the case study material involved searching for patterns that foster the effective implementation of proactive strategies for environmental sustainability in the three case companies. Thus, five mechanisms were identified as recurring themes in the empirical data (Fig. 34.1).

Figure 34.1. Key mechanisms fostering a proactive strategy for environmental sustainability.

Organisational Integration sheds light on the structures and processes that promote the integration of sustainable principles into the technical and management systems of the companies. Communication and learning are essential for the transition towards environmental sustainability. By maintaining a dialogue with stakeholders and engaging in a continuous learning process, companies can execute the required changes. Innovations are vital to strengthen the sustainability of products and processes. Emission-reducing innovations create incremental improvements, while adopting clean technologies allows for more radical changes to the production system. Furthermore, co-operation with actors that control important resources is a useful means to achieving environmentally sound solutions. Lastly, local embeddedness reflects the companies' abilities to concentrate value creation from the energy business at the local level by embedding their activities in the local context. Taken together, the five mechanisms highlight dynamic ways of working towards the implementation of environ-mentally sound strategies, thereby contributing to the sustainable development of the energy system.

CASE STUDY HIGHLIGHTS THROUGH THE LENS OF THE FIVE MECHANISMS

Organisational integration

The studied companies are characterised by strong capabilities to integrate sustainable business practices into energy systems and management processes. On the technical side, *fuel switching* is used widely, e.g., bio-oils replace fossil fuel oils. In MediumCo, this relates to part of the base-load, while in LargeCo, bio-oil was introduced as a starting fuel in biomass-fired plants and in top-load facilities. For SmallCo, fuel flexibility was an important consideration when its new biomass-based cogeneration plant was being planned. An additional priority for the technical systems is *resource efficiency*, i.e., opting for the lowest possible resource consumption and emissions per unit of energy delivered. This involves maximal use of low-quality energy, for instance waste heat, to produce district heat. For LargeCo, resource efficiency is not just a technical issue, but is also a part of the company philosophy. Further savings can be made by avoiding frequent start-ups and shut-downs of plants and by preventing top-load production. Further efficiency improvements can be made by linking separate district heating systems.

Regarding management processes, the *environmental management system* is the key driving force for improvements. In particular, establishing routines for every production process is important for controlling the environmental impact, whereas improving routines systematically is vital for developing further the environmental management system. In this system, all companies revise their environmental goals annually. In recent years, MediumCo has integrated environmental goals into its business plans, avoiding the situation in which business and the environment are treated as separate issues. Environmental measures have been further integrated into management systems, such as the performance management tool Balanced Scorecard, on which the staff incentive system is built. Moreover, MediumCo has set the ambitious goal of becoming climate-neutral, signalling its development path clearly. Central to achieving a high environmental standard are a well-established environmental organisation and the timely adoption of ISO 14001 norms. Efficient environmental management is a socially complex process that leads to continuous improvements in a path-dependent way.

Communication and learning

Communication and learning facilitate the process of change towards environmental sustainability, both internally and with external stakeholders. At the two larger companies, the environmental coordinators meet regularly to discuss emerging environmental issues and to exchange experiences. MediumCo uses the meetings to ensure that the centrally planned environmental work is spread across the entire group. Environmental managers at all the companies view external network meetings with colleagues as a valuable forum for exchanging ideas on how to improve environmental work.

Environmental training creates commitment and facilitates the implementation of environmental goals. Empowering employees to take responsibility for the environment often results in bottom-up initiatives for environmental improvements. The companies also provide environmental training to the Board of Directors, which enhances their understanding of the company's impact on the environment and how it can be mitigated.

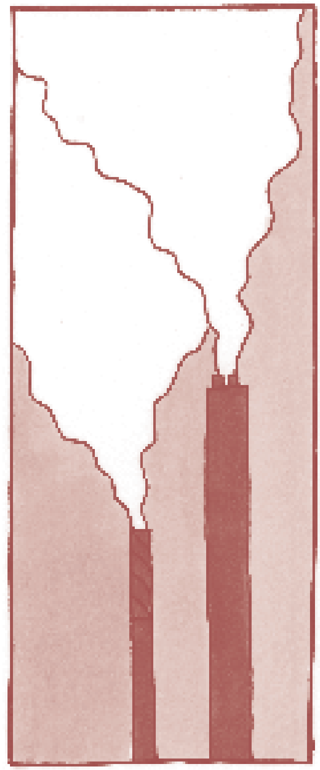
Creating a *green organisational culture* is important to the companies. LargeCo emphasises that its environmental work should be integrated into daily activities and not be considered a separate program. SmallCo sees management leadership on these issues as important for creating commitment at lower levels in the organisation. In all the companies, the environmental manager plays a crucial role in creating a greener mind-set. At the operational level, she/he is the "spider in the web", engaging, encouraging, and spurring employees to commit to environmental improvements. An open communication climate also facilitates employee involvement. Many interviewees mentioned that they felt free to raise new ideas with management.

A *continuous dialogue* with customers ensures that product development is in line with customer needs. New energy services and the development of climate-neutral district heating are prominent examples of this engagement. At LargeCo, regular discussions on efficient energy use take place with the major commercial customers and municipality-owned housing companies in order to "synchronise world views".

Communicating the environmental strategy externally, be it to owners, the local community or other affected parties, appears to be essential to smooth implementation of new investment projects. Emphasising the significance of clean technology investments and creating a dialogue with stakeholders can build acceptance for such projects and speed up the implementation process. Moreover, communicating a vision of sustainability for corporate development to employees and stakeholders is central to the implementation of a proactive environmental strategy.

Innovation

Innovations at strategic and operational levels are crucial to competitiveness and to improving the environmental qualities of products and processes. Timely identification of opportunities and threats is vital to directing the innovation process. SmallCo focuses on *product innovations* that emphasise product quality. New sustainable products, such as "Good Environmental Choice" district heating, reflect the company's efforts to offer environmentally friendly alternatives and to assist customers in their environmental endeavours. Product innovation at LargeCo relates mostly to energy services. Several products with varying degrees of involvement are offered, helping customers to save energy. Furthermore,LargeCo is developing a 'green' service for residential property owners, which comprises systematic pathways to develop residential property in an environmentally sound way.



Demand-side management is another key area for innovations. At MediumCo this involves launching a free statistics service that allows customers to check their energy consumption on a continuous basis. LargeCo manages demand in the district heating business through changes in their pricing model, which enables customers to save money by using energy in a more efficient manner. The companies agree that demand-side management is necessary to maintain good customer relationships.

Another aspect of innovation is *the phase-in of green products*. MediumCo took the initial step of providing 'green electricity' automatically to customers who did not make an active choice of tariff. For the fuel gas business, the company intends to gradually introduce biogas into the distributed fuel gas and increase the renewable share of the provided energy.

LargeCo emphasises that it wants to be at the cutting edge when it comes to environmental strategies, introducing new technologies and shaping the energy system of the future. *The phase-in of green technology* is an essential part of LargeCo's targets for biogas. The flagship project is a biogas gasification project involving the large-scale production of biogas through the gasification of biomass and wood waste. Furthermore, with regard to policy tools, LargeCo wants to gain early experience. Within the framework of the Kyoto flexible mechanisms, it participates in a CDM project through one of the first Carbon Funds.

Co-operation

Co-operation with other actors improves the sustainability of the production mix and reduces emissions. An interesting example of this is the outsourcing of district heat production to local farms, which allows for the beneficial use of waste products from farming while contributing to greener production. Waste heat utilisation and joining together neighbouring district heating systems are other well-known forms of co-operation that ensure efficient resource use.

Co-operation is also an important tool for business expansion and the dissemination of clean technologies at the case companies. *Strategic co-operation* can extend available competences and production resources. In terms of developing the biogas business, co-operation is important to secure access to renewable energy sources. The use of new substrates, for example manure, for fermentation to biogas, requires good co-operation with farmers.

Energy companies can also be valuable collaborative partners in smaller ventures, to which they can bring experience and resources. Furthermore, finding new forms of co-operation can give positive results. For example, wind farm expansion has been favoured by an innovative business model that builds on co-operation with land owners and nearby residents.

Close co-operation between SmallCo and an environmental organisation has opened up new areas of product development, enabling the company be one of the first companies in Sweden to offer environmentally certified district heat. Co-operation with the local municipality is also seen as important, especially in the areas of land use planning, district heating expansion, and energy planning.

Co-operative ventures involve, for example, building a biogas gasification test installation together with the local university of technology, which forms the basis for a large new investment project at LargeCo. The company also engages in knowledge sharing with other energy companies regarding product development. Co-operation evolves into a mechanism to establish standards within a community of practice, thereby strengthening both the participating companies' and LargeCo's development opportunities.

Local embeddedness

Energy companies can concentrate value at the local level by embedding their activities in different ways in the local setting. One of these ways is the building of an *infrastructure for sustainable products*. MediumCo continuously extends its network of fuel gas filling stations. Similarly, LargeCo has a strong commitment to building up (bio)gas-based solutions for industry and the transportation sector. Clearly, its efforts to build up the regional gas infrastructure represent an important step in this strategy.

When it comes to *regional development*, LargeCo's commitment to a gas-based society stands out. LargeCo participates in a regional cluster for biogas development, where its contribution to the value chain is the production and distribution of biogas. Regional development for MediumCo relates to the company's strategy to seek co-operation with local players. For instance, MediumCo believes that *locally-produced fuels* are advantageous because: 1) they support local agriculture and industries; 2) purchasing local renewable fuels increases the security of supply and improves control of the environmental consequences of production; and 3) locally produced fuels cause less pollution owing to reduced transportation.

Corporate governance is also an important aspect of local embeddedness. The relationship between the management and the owner, i.e., the municipality, is frequently described as being 'based on trust'. Close ties with the owner also favour clean technology investments. For SmallCo, the municipality was willing to stand as a guarantor for loans, which compensated for the disadvantages of scale that smaller companies face when planning for increased production capacity. Political support is seen as crucial for new investments, facilitating for instance the obtaining of location permits for new plants.

In the case companies, the owners focus on long-term sustainable returns. They see the company as a means to produce *social welfare* at a local level. Undoubtedly, the energy company is the municipality's strongest tool for improving the local environment. Thus, owners and their political goals are driving forces for the change-over to a sustainable energy system. A shared understanding of the future development pathway for both the company and the region is therefore crucial for taking strong action.

FRAMEWORK OF THE ANALYSIS

Corporate strategies for environmental sustainability can be considered in terms of four conceptual areas, Emission Reduction, Product Stewardship, Clean Technology, and Sustainability Vision, as outlined in the framework of analysis (see Figure 6.1 in Chapter 6 in the *Methods and Models* book). In the following section, the utility of the mechanisms for understanding what an environmentally sustainable strategy involves in these four areas is discussed.

THE USEFULNESS OF THE MECHANISMS FOR UNDERSTANDING ENVIRONMENTALLY SUSTAINABLE STRATEGIES

The integration of environmental measures into the organization with the help of environmental and other management systems, fuel switching, and a focus on local resources and efficiency measures allows the case companies to work systematically towards Emission Reductions. This integrated approach has not only reaped dividends in terms of the carbon intensity of production, but has also increased product innovation, as in the case of environmentally certified district heating. Product Stewardship has also been promoted by a close dialogue with customers and co-operation with environmental organisations. Clean technology investments are crucial for repositioning the firm and developing the sustainable competencies needed to prosper in a carbon-restrained economy. However, the change-over to clean technologies does not rely exclusively on technical innovations, as in the case of biogas gasification. The adoption of well-established clean technologies can also be speeded up by innovative business models, co-operative ventures, and the embedding of a vision for sustainable development with company stakeholders. A Sustainability Vision can work as a driver for change, e.g., the vision to become a climate-neutral energy company. Communicating this vision and offering learning opportunities for employees and stakeholders facilitate the implementation of a proactive strategy for environmental sustainability. A common vision between owners and the energy company on how the region should develop energy-wise ensures that resources are directed towards investments that can create social welfare. In embracing the above mechanisms, proactive municipal energy companies are well-positioned to develop energy solutions that facilitate the transition to a sustainable society. By taking a strategic approach to sustainability, companies can build up important resources and competencies that allow for new opportunities to be exploited. At the same time, by virtue of their being embedded in the local context, companies can contribute to strong development of the local economy and environment.

For more information:

Gabriela Schaad and **Anders Sandoff**
School of Business, Economics and Law,
University of Gothenburg

Further reading:

Schaad, G., 2010, Corporate strategies to mitigate climate change. Thesis for the degree of licentiate. School of Business, Economics and Law, University of Gothenburg.

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An overview of the carbon strategies of ten of Europe's largest energy companies

The principal source of global greenhouse gas emissions is the burning of fossil fuels for energy generation (Wagner, 2008). In the European Union, about 36% of greenhouse gas emissions are attributable to the generation of electricity and heat (EEA, 2009). A focus on the actual emitters of greenhouse gases is essential for assessing the real prospects of achieving a transition to more sustainable energy production. This chapter gives a brief account of the 'carbon strategies' of ten of Europe's largest energy companies, based on their responses to the 2009 Carbon Disclosure Project inquiry. The preliminary findings reveal that the large European energy producers are in the process of implementing strategies that reflect the need for less-carbon-intensive and more sustainable energy production. Further research should elucidate the roles that energy companies will or should play in the change-over process.

With the growing urgency surrounding climate change mitigation, large emitters of carbon are coming increasingly under scrutiny. For instance, the Carbon Disclosure Project annually requests major companies worldwide to disclose their greenhouse gas emissions and climate change strategies (CDP, 2010). In this chapter, the replies to the 2009 CDP questionnaire submitted by ten of Europe's largest energy companies are taken as the starting point to analyse their carbon strategies. Table 35.1 lists the key statistics for each of the companies studied.

Table 35.1: Key statistics for ten of Europe's largest energy companies (2008 values).

Corporation	Installed capacity within EU (MW)	Emissions from fossil fuels in the EU (Scope 1 Mt CO_2 equivalent)	Sales (M€ - 2008)
Electricité de France (EDF)	107 370	61.9	64 300
ENEL	62 003	75.8	61 184
E.ON	56 489	88.0	86 753
Vattenfall	52 122	83.1	15 041
RWE	41 895	172.1	48 950
Iberdrola	32 946	26.8	25 196
GDF Suez	30 983	25.3	83 053
Energías de Portugal (EDP)	14 969	19.8	13 894
Scottish & Southern Energy	10 571	19.3	32 052
Centrica	3 822	8.8	26 910

Source: Carbon Disclosure Project (2010)

The carbon strategies of the above companies were studied with the help of the model of analysis presented in Figure 6.1 in Chapter 6 in the *Methods and Models* book. In line with the findings of Hart (1995, 1997), the model examines corporate efforts to mitigate the impact on the climate in four categories: Emission Reduction; Product Stewardship; Clean Technology; and Sustainability Vision. Preliminary findings from an ongoing study of carbon strategies of the major European energy companies are presented for each of these categories.

EMISSION REDUCTION

Efforts to reduce emissions and increase efficiency are an important part of the studied companies' carbon strategies. These efforts are typically reflected in production-related emission reduction targets. Given the sensitive nature of these targets, which frequently embrace strategic, political, and reputational aspects (Pinkse and Kolk, 2009), and the difficulties associated with judging their stringency, the actual measures to reduce emissions are also touched upon as a further proxy for the emission reduction efforts of these companies.

In relation to emission reduction targets, two aspects are examined: 1) the type of target; and 2) its scope. Broadly speaking, two types of targets can be distinguished: *absolute targets to reduce emissions* from energy production (e.g., in $MtCO_2$) and *targets to reduce the CO_2 intensity* of energy production. The type of target can have implications for whether or not total emissions are reduced in line with political intentions. While absolute targets ensure a real reduction in emissions, intensity goals are not an obstacle for company growth, so they do not guarantee that the actual emissions will decrease (Pinkse and Kolk, 2009). Of the ten companies studied, five have adopted intensity goals, while four have established emission reduction goals in absolute numbers. One company has adopted both types of goals.

Regarding the scope of the target, time span and geographical scope are of interest. Short-term targets allow companies to demonstrate progress more frequently, and targets can be more easily adapted to new circumstances. In contrast, long-term targets offer the flexibility to wait for technological developments that create new options for the company to mitigate its emissions (Pinkse and Kolk, 2009). In the sample studied, half of the companies set rather short-term targets (to be reached within 7 to 10 years), while some companies adopted long-term targets that span over a period of 30 to 40 years, all with a 1990 baseline. Regarding geographical scope, most of the targets apply to the entirety of corporate operations, whereas three companies have restricted their targets to the home country of the corporation.

As for measures to achieve emission reductions, activities similar to those reported in the Swedish case studies, in Chapter 34, are observed. *Fuel switching* is an important measure, being mostly related to a switch from coal to gas and to substituting partially coal with biomass. Furthermore, *energy efficiency* measures are a key priority in many aspects. Regarding power generation, technical improvements in the electricity generation portfolio and improved thermal efficiency are frequently mentioned as energy efficiency measures. Moreover, the decommissioning of carbon-intensive power plants is seen as an appropriate action to curb emissions. Furthermore, the concept of eco-efficiency is addressed, whereby one opts for a reduction in the consumption of resources relative to the amount of electricity produced. In addition, some companies mention the launch of *internal environmental programs*, which promote behavioural changes to manage the carbon footprint of the organisation. The strong focus on emission reductions by the companies is not only motivated by the savings that can be made from reducing energy and resource consumption, but also by the additional costs incurred by emitting CO_2 under the European Union Emissions Trading Scheme.

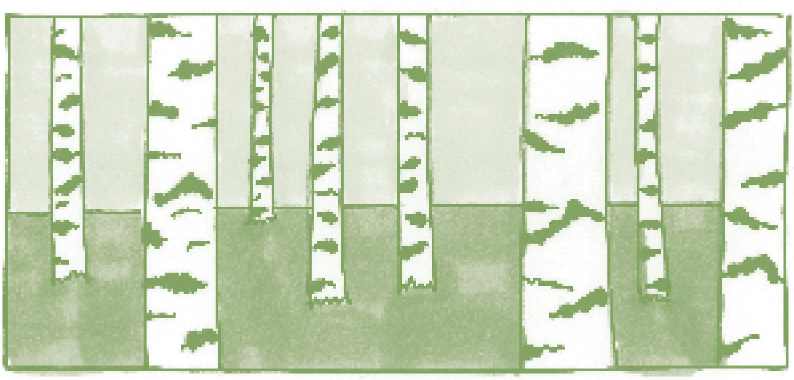
PRODUCT STEWARDSHIP

Developing new sustainable products and services or enhancing the sustainability of existing products should be a major goal for energy companies seeking to contribute to sustainable development. This section gives a brief insight into some of the efforts taken by Europe's largest energy companies to offer sustainable solutions to their customers.

To judge from the responses received from the companies, improving energy efficiency with end-users is considered to be a strategic issue. Several companies offer a wide range of products and services that encourage energy conservation. For instance, the installation of micro-power solutions, smart meters, and sustainable heating alternatives is seen as important to improve end-user energy efficiency.

Noteworthy are the efforts regarding sustainable mobility, which refers to the promotion of both natural gas- and electrical power-driven cars or transportation. Several companies are making efforts to promote low-carbon mobility, either through projects that are at the experimental stage or in ventures conducted in a commercial context.

One of the companies studied states that it wants to 'help customers reduce their environmental footprint through an integrated environmental value proposition', involving amongst other measures the provision of certified green energy. The product stewardship strategies show that the companies are attempting to break new ground by offering sustainability-oriented products and services. However, product stewardship strategies have not yet matured sufficiently to induce changes in the basic business models of the companies.



CLEAN TECHNOLOGY

Investments in renewable and bridging technology are vital for the gradual renewal of the European power plant fleet and for meeting increasing energy demands. Adopting clean technologies, e.g., those based on the best-available techniques, allows for more radical changes to the production system, as compared to a strategy based on emission reductions through continuous improvements (e.g., Hart and Milstein, 1999). In this context, research and development play an important role. The focus of this section is on the investment plans of the selected companies, as reported in the CDP 2009 report. These plans give an indication as to how the companies intend to reach their emission targets in terms of the types of investments, amounts, and time horizons. Moreover, corporate efforts to contribute to clean technology development are briefly summarised.

Seven of the ten companies described plans for investment in new production capacity. For the purpose of this work, these investments are grouped into three categories: 1) investments in *renewable capacity*; 2) investments in *thermal capacity;* and 3) *other investments.* The sum of all the investments in renewable capacity planned by the seven companies is approximately €28 billion (for 2007–2015). This is almost twice the amount to be invested in thermal capacity (approximately €15 billion) during this period. Around €6 billion will go to other investments, in nuclear power, energy efficiency improvements, natural gas infrastructure, and power grids, to name just a few. These investment levels need to be placed in context if one is to form an opinion regarding corporate efforts to convert to less-carbon-intensive energy production. At this stage, there is only an indication of the developments that lie ahead.

With regard to research and development efforts, CCS is seen as a key technology for carbon mitigation. Several companies are engaged in international co-operative efforts to advance CCS technology. Furthermore, CO_2-scrubbing technologies are being developed.

SUSTAINABILITY VISION

A sustainability vision can serve as a roadmap for corporate development towards sustainability. In their responses to the CDP report, only some companies mentioned a vision for sustainable corporate development. Nevertheless, corporate mottos, such as *'more growth, less CO_2'*, *'together for less CO_2'* and similar statements, demonstrate awareness that the energy business must be managed in a different way in the future so as to contribute to the mitigation of climate change. This is in line with the joint declaration of the executives of Europe's major energy producers, including most of the companies investigated here, who have pledged to make electricity carbon-free by 2050 (FT, 2009).

CONCLUSIONS

The preliminary findings reveal that the large European energy producers are implementing strategies that reflect the need for less-carbon-intensive and more sustainable energy production. However, when the carbon strategies are viewed through the lens of the four different strategic dimensions, the companies seem somewhat biased towards emission reduction efforts. This is perhaps not surprising, given the substantial benefits that companies can reap from reducing emissions. Clean technology investments also play an important role, allowing the companies to renew their production portfolios and meet future needs. Renewable capacity investments represent the largest chunk of the investments, although investments in thermal capacity also are significant. This underlines the importance of new mitigating technologies, such as CCS, for making real progress towards CO_2 abatement.

Overall, the portfolio of measures that constitute the companies' carbon strategies seems geared more towards internal efforts than towards customers and stakeholders. The reason for this may be that the empirical material does not emphasise these external aspects, resulting in a somewhat unbalanced portfolio of mitigation measures. Nevertheless, if these large energy companies are to make a broader contribution to sustainable development, product stewardship and the corporate vision have to be geared towards sustainability. Further research should elucidate the roles that energy companies can play in the transition towards more sustainable energy production and consumption.

For more information:

Gabriela Schaad and **Anders Sandoff**
School of Business, Economics and Law,
University of Gothenburg