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Co-production of biofuels in district heating systems:

assessment of the national possibilities

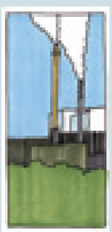
Assessment of the techno-economic potential to integrate second generation biofuels produced in Europe with district heating systems indicates that the systems in most of the countries can easily absorb the excess heat from biofuel production. All the investigated countries, apart from Italy, would be able to absorb excess heat from a production level of biofuels greater than that designated by national targets for biofuels. An integration of biofuel production could improve the overall energy efficiency (and economic viability) of biofuels for transportation.

In the EU25, there are more than 5000 district heating (DH) systems, which together provide about 15% of the total annual heat demand (including heat for residential hot water and industrial demands, but not including electricity for heating). The importance of DH varies among member states, reaching at most about 30-40% of total annual heat demand in the Baltic States and Denmark (estimates for 2003 based on IEA, 2005 and Werner, 2006). In 2003, about 80% of the DH in the EU25 was generated using fossil fuels, in either combined heat and power (CHP) plants (about 75%) or heat-only boilers (HOB) (about 25%) (Werner, 2006).

The EU promotes increased use of bioenergy for heat and electricity production, as well as for the production of biofuels for transportation (EC, 2005). For example, each member state is supposed to achieve a minimum of 10% renewable energy, primarily biofuels, in the transportation sector by 2020 (EC, 2008).

Since the potential for biomass is limited, high efficiencies in processes using it are desirable. To improve the overall energy efficiency (and economic viability) of biofuels for transportation, biofuel plants that employ gasification processes can be designed and located so that part of the surplus heat can be used in DH systems.

The purpose of the work presented in this chapter was to estimate the *heat sink capacity* (the heat sink capacity represents the amount of heat that the DH systems demand) of DH systems in the EU member states, and thereby assess the possibility for biomass-gasification-based co-generation of synthetic biofuels for transportation and heat for DH systems in the EU member states. Thus, the potential for DH systems to form the basis for the production of synthetic biofuels for transportation was assessed. It was investigated whether the DH systems in the EU are sufficiently large to accommodate heat from combined biofuel and heat production (hereinafter referred to as CBH) that is in line with the EU target for 2020 (i.e., 10% renewable fuels in the transportation sector). The term *synthetic biofuels* is used as a generic term for any biofuels for transportation than can be produced based on CBH. This means that a specific production process or specific types of biofuels for transportation was not considered.



Methodology

The techno-economical potential for combined biofuel and heat production (CBH) is assessed based on a description of both the existing (base year of 2003) and potential DH systems in Europe (year 2020). The existing DH systems are characterised at the national aggregated level and include the size of the heat sink and relevant characteristics, such as the present fuel use and heat supply option used to provide the DH. This characterisation, along with the estimate of the sizes of the DH systems in 2020, forms the basis for investigating the possibilities for CBH in the EU25 countries. The Euroheatspot model is applied to analyse changes in the DH systems when heat from CBH is introduced.

The CBH unit is assumed to be in the form of second-generation biofuel production, where 50% of the energy input (biomass) is converted to biofuel and 10% ends up as usable surplus heat (this corresponds to a gasification process). More about the methodology can be found in Chapter 21 in the *Methods and Models* book.

THE DISTRICT HEATING SYSTEMS CAN ABSORB THE HEAT

The DH systems in most of the countries can easily absorb the excess heat from biofuel production (assuming that heat from CBH is more cost-competitive than heat from fossil-fuel based CHP). In Figure 36.1, the heat from CBH (producing biofuel to meet the EU's 2020 target) in relation to the total heat production in different countries are presented. All the investigated countries, apart from Italy, would be able to absorb excess heat from a production level of biofuels greater than that designated by national targets for biofuels.

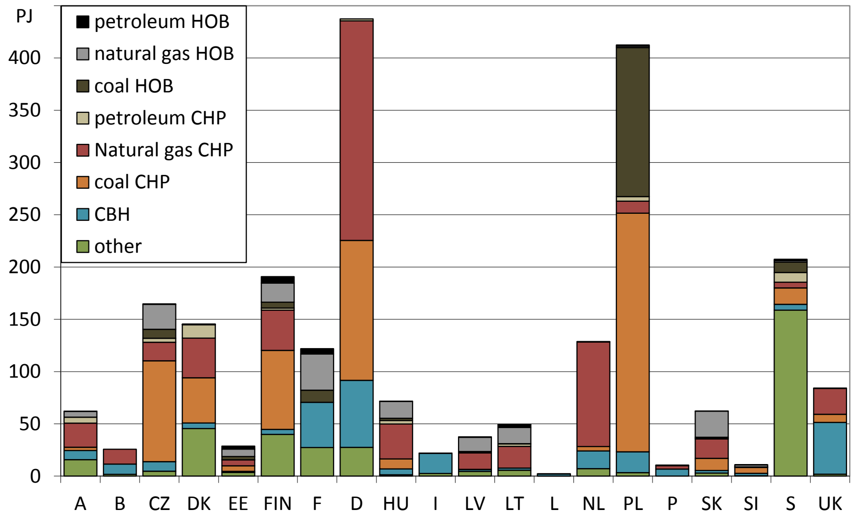


Figure 36.1. Distribution of heat sources in aggregated national DH systems where heat from CBH corresponds to the EU's biofuel target for 2020 (assuming that this heat is cheaper than heat from fossil-fuel based CHP). The category "other" includes industrial waste heat, heat from waste incineration, and waste heat from nuclear power plants, biomass CHP, geothermal heating, and solar energy. Source: Egeskog et al. 2009.

For many of the examined countries, there is a lack of information regarding the individual levels of the DH systems, so the overall potential is based on the aggregated national DH. However, the size of an individual DH system is crucial in terms of the potential for cost-effective biofuel (CBH) integration. Therefore, assessments that take into account the sizes of individual DHs are performed for Finland, Lithuania, Sweden, and Germany (for which information on different systems levels is available). The assessment shows that if the size of the biofuel production unit needs to be 1000 MW (biomass input) to be profitable, about 20-30% of the DH systems are large enough to absorb the heat. If instead, the minimum required size is 250 MW of biomass input, 60-75% of the systems are sufficiently large.

Assessing the possible increase in the use of the potentially low-cost heat options, industrial waste heat, and waste incineration in the DH systems shows that in the majority of the member states the potential for DH expansion is lower than the estimated expansion potential for DH from these options.

Recently, it has been proposed that the contribution to the 10% target for renewable energy for transportation made by biofuels produced from wastes, residues, non-food cellulosic material, and lignocellulosic material should be considered to be twice that made by other biofuels (EP, 2009). This implies that only half the amount of biofuel/heat co-generation used as the reference in our analysis would be needed to meet the 2020 targets. This increases the possibility for the DH systems to accommodate surplus heat from biofuel/heat co-generation.

An additional factor that might influence the potential of CBH is the ownership of the DH distribution network. An increasing share of the DH systems is owned by power companies (Werner, 2006). These owners may be more reluctant to support CBH than CHP.

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Further reading:

Egeskog, A., Hansson, J., Berndes, G. and Werner, S., 2009, Co-generation of biofuels for transportation and heat for district heating systems—an assessment of the national possibilities in the EU, Energy Policy 37(12): 5260-5275.

Egeskog, A., 2010, Improving the greenhouse gas balances of bioenergy systems: The cases of European district heating and Brazilian ethanol production, Thesis for the degree of licentiate, Chalmers University of Technology.

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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Development towards a sustainable European industry

European industry has the potential to contribute substantially to both reduced CO_2 emissions and development towards sustainability. However, to reach low emission levels, all types of measures, including structural change, energy efficiency improvements, fuel substitution, and carbon capture and storage (CCS), are needed. Energy-intensive industries play a key role in this process, and have substantial potential for large step-wise reduction measures. However, implementation of these measures is crucially dependent upon energy market conditions and infrastructure, and therefore on interactions with other parts of the energy system. Industrial CO_2 emissions are shown to have potential for large reductions in both pathways studied. Total direct emissions in 2050 could be up to 50% and 60% lower in the Policy and Market Pathways, respectively, as compared to the corresponding values for year 2000. In the Policy Pathway, energy efficiency improvements, and the use of biomass for energy, are important means. The lower levels of direct emissions in the Market Pathway depend primarily on increased implementation of CCS and on conversion to efficient electricity use.

DECREASING CO_2 EMISSIONS DESPITE STRONGLY INCREASING PRODUCTION VOLUMES

The development of energy use and CO_2 emissions in European industry is estimated for the Policy and Market Pathways. The estimate is based on projections of strongly increasing production volumes (in terms of value added). The approach taken has been to estimate techno-economic emission reduction potentials that take constraints, based on for instance process-related practical conditions and available infrastructure, into account. Finally, implementation rates for these potentials have been used that are estimated to be realistic, given strong climate policy measures.

The results show decreasing development of total energy use and strongly decreasing CO_2 emissions. According to this synthesis, the total emission levels in 2050 would be up to 50% and 60% lower in the Policy and Market Pathways, respectively, as compared to the corresponding levels in year 2000 (Figure 37.1). Since the assumed total production would more than double during the same period, the CO_2 emissions per value added would decrease by about 80%.

A large share of these major reductions would be realised should past development trends, in terms of decreasing specific energy use and reactions to energy price changes, continue into the future. This synthesis shows that in most industrial sectors there are technological potentials for improvements, which would make such a development possible. However, realisation would require considerable structural changes in terms of product and process development and investments in energy efficiency improvement measures. Advances in process technology and the realisation of CCS would increase the reductions in specific emissions well beyond the historical levels.

Combining top-down modelling results with detailed industrial sector analysis

Within the Pathways project, an analysis group for industry and a number of sub-projects directed towards the industrial sector have been included. In these sub-projects, the development of specific industrial subsectors and/or types of measures for reducing CO_2 emissions is studied in great detail. These studies have focused on energy-intensive industry sectors, with a high share of process-dependent energy use and relatively few, albeit large, industrial plants. Furthermore, a top-down analysis of the European industrial sector as a whole has been made (see Chapter 16 in the *Methods and Models* book). Thus, the methodological approaches used in these sub-projects vary significantly.

In addition to the analytical results from each sub-project, the results provide a basis for estimating the potential contributions of technological and structural changes within industry to the development of overall energy systems pathways. The challenge is to utilise fully the knowledge gained in all these studies, so as to reach a coherent and well-founded synthesis for the entire industry (see further reading). In this way, the analysis provides an overview of the potential contribution of European industry to reducing CO_2 emissions and a basis for continued efforts to provide coherent and extensive systems analyses of the entire industrial energy system. The three methodological steps of the synthesis are described in Chapter 24 in the *Methods and Models* book.

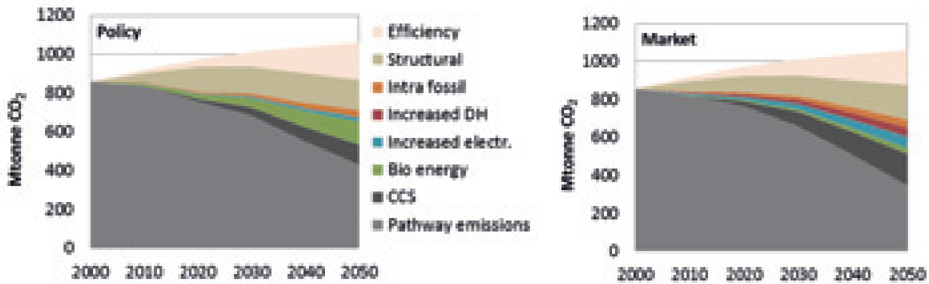

Figure 37.1. Development of CO_2 emissions in the Policy and Market Pathways, divided according to the type of measure. Fuel substitution is divided into intra-fossil fuel substitution and increased district heating, electricity, and biofuel use. The methodology used makes the distinction between structural change and energy efficiency improvements inherently uncertain and primarily indicative.

ALL TYPES OF MEASURES NECESSARY TO ACHIEVE LARGE REDUCTIONS

In the synthesis, the measures required for reductions have been divided into four different groups: 1) structural change; 2) energy efficiency improvements; 3) fuel substitution (or rather change of energy carriers); and 4) CCS. The results clearly show that in order to achieve reduced emission levels from industry, in the face of continuing increases in production volumes, all types of measures are needed and contribute significantly to the development (Figure 37.1). The differences between the two pathways primarily reflect the primary assumptions behind each pathway. In the Policy Pathway, these include a stronger focus on demand-side energy efficiency improvements and fuel substitution for biomass. In the Market Pathway, greater implementation of CCS and conversion to electricity and district heating lead to lower levels of direct emissions.

Structural change and energy efficiency improvements are important measures throughout the industry and account for, in total, more than half of the total emission reductions. However, the distinction between these types of measures is inherently uncertain and primarily indicative. Structural change, as shown in the above figures, is based primarily on the results from the top-down model and may include a combination of measures. Fuel substitution for biomass is primarily an important option in the pulp and paper and food industries, although it may also play a significant role in primary metals industries if new processes are introduced to produce charcoal, as well as in the chemical industry if biomass becomes more widely used as a raw material. The potential for CCS in industry is primarily linked to large, energy-intensive plants with relatively concentrated CO_2 streams, which are found primarily within the steel, cement, refinery, and pulp and paper industries (see Chapter 18 and Chapter 19). Moreover, in these industries, available surplus heat often makes the conditions even more favourable.

ENERGY-INTENSIVE INDUSTRY IS IMPORTANT FOR SUCCESS

Energy-intensive industry, which encompasses the sub-sectors of primary metals, chemicals, pulp and paper, non-metallic minerals, and refineries, accounts for, in total, about 80% of the total emissions from industry and 83% of the estimated reductions in emissions. The energy-intensive industry share of reductions in emissions is more dependent upon capital-intensive technology investments and infrastructural conditions than is, for instance, the equipment goods sub-sector. This implies a substantial potential for large, step-wise reduction measures, while it also indicates a higher level of dependency on energy market conditions, economic development, and infrastructure. Therefore, the inclusion of geographical information and infrastructural parameters in the Pathways analyses is crucial. One example is kraft pulp production, which has several options for delivering surplus energy, and the most profitable choice depends on development of the energy market. The largest reduction in CO_2 emissions would be achieved if new technologies, such as CCS or lignin export, were implemented, while more conventional options (electricity production, district heating, and bark export) have greater economic robustness (see Chapter 39). Thus, the directions for development in these sectors are particularly uncertain.

The large share of reductions ascribed to the refinery sector (Figure 37.2) reflects primarily the assumptions made regarding the growth of this sector. In the refinery sector, production volume is expressed in terms of physical demand for oil products in the pathways and, in contrast to all other sectors, is assumed to be strongly decreasing. In comparison, the reductions in the pulp and paper sector,

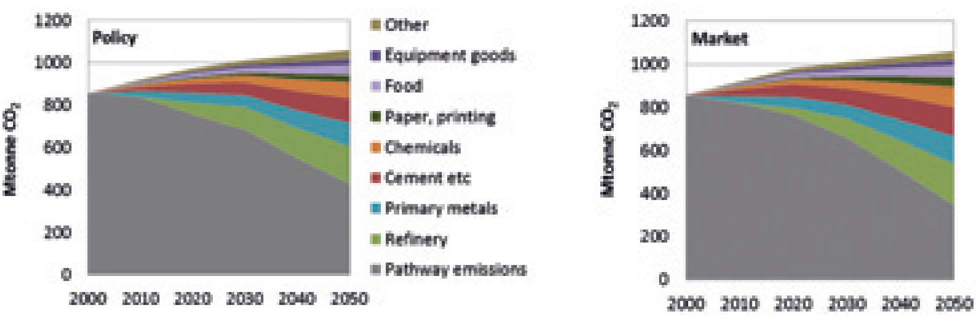

Figure 37.2. Development of CO_2 emissions in the Policy and Market Pathways, divided according to industrial sub-sector. The estimate for refineries are based on the future demand for oil products in the Pathways, and the values do not include production of transportation fuels from biomass.

included in Figure 37.2, appear small. This is partly a result of the sector being largely dependent upon biomass for energy and the fact that energy efficiency measures have less of an impact on direct fossil-based CO_2 emissions.

INDUSTRY ALSO PLAYS A SIGNIFICANT ROLE IN REDUCING INDIRECT EMISSIONS

All the figures above describe the development of direct fossil CO_2 emissions from industry. Industrial energy use, and the industrial energy system in total, impact also indirectly on total CO_2 emissions. These indirect effects include the use of district heating and electricity, but also industry-based co-generation, district heating deliveries and, since biomass is a limited resource, changes in the use of biomass for fuel. The total changes in energy flows into and out of the "industrial energy system" may be substantial, depending on the direction of development (Figure 37.3). The potential for increased use of biomass for energy in industry is, for example, highly dependent upon the total demands for biomass in a future energy system, which can be expected to increase dramatically. The potential for increasing use and the delivery of district heating in industry as a result of intra-industry integration within industrial clusters may be substantially larger. Such analyses, including geographical information, have been initiated within the Pathways project but the full potential is as yet uncertain.

The total impact on global CO_2 emissions depends on the parallel development of the energy system as a whole. The "global" emission change associated with biomass use depends therefore on the alternative use (if any) of biomass resources. Likewise, reduced electricity use in Policy Pathway year 2050 compared to the baseline in 2050 will result in a reduction of about 600 Mtonne of indirect CO_2 emissions per year if electricity is produced in conventional coal plants, but there will be no change at all in emissions if electricity production is CO_2-free. In the Policy and Market Pathways, an almost CO_2-free electricity production system is foreseen by 2050.

However, CO_2-free power production does not necessarily make electricity efficiency improvements less valuable, since the prospects for realising such a development of the power system improve substantially with decreasing or stabilising levels of electricity demand.

A COHERENT AND EXTENSIVE ANALYSIS OF INDUSTRIAL ENERGY USE IS NEEDED

Industrial development is important for a successful climate policy, through its impact on both direct and indirect CO_2 emissions. To understand fully the complexities of industry, especially energy-intensive industry, and the potential policy impacts, a coherent and extensive analysis of industrial energy use is needed. This type of analysis includes both detailed studies of potential measures

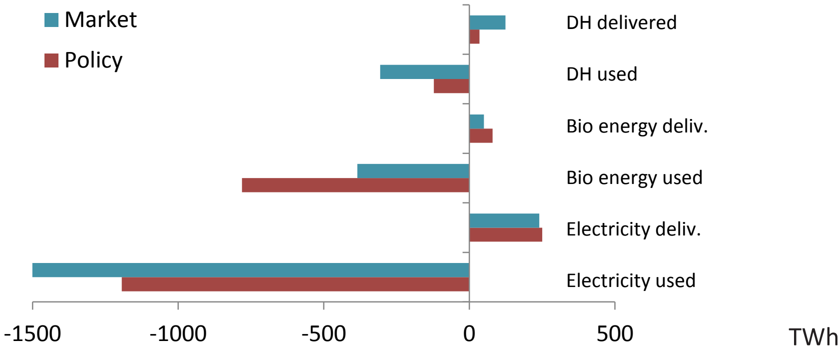

Figure 37.3. Industrial energy use (negative) and deliveries (positive) in the year 2050 for the Market and Policy Pathways, that could imply indirect effects on total CO_2 emissions.

and technologies, the development of aggregate techno-economic potentials, energy policy design, and overall syntheses of the results. Furthermore, the interconnections between energy use and the development of production volumes, production structures, and products need to be better understood and included in an integrated analyses framework.

This synthesis is performed as an ex-post exercise, based on analyses presented in other research studies. There are significant uncertainties associated with the presented results. Nevertheless, the overall results are useful for increasing understanding of the roles of industry in a climate policy context. For the future, it would be valuable to use the experiences gained here to design the synthesis work in parallel to the analytical work and construct it on a more rigid methodological framework.

For more information:

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Further reading:

Andersson E. and Nyström I., 2010, Opportunities for reducing CO_2 in European industry until 2050 – a synthesis of industry analyses within the Pathway project. AGS Pathway reports; 2010:EU3 Göteborg.

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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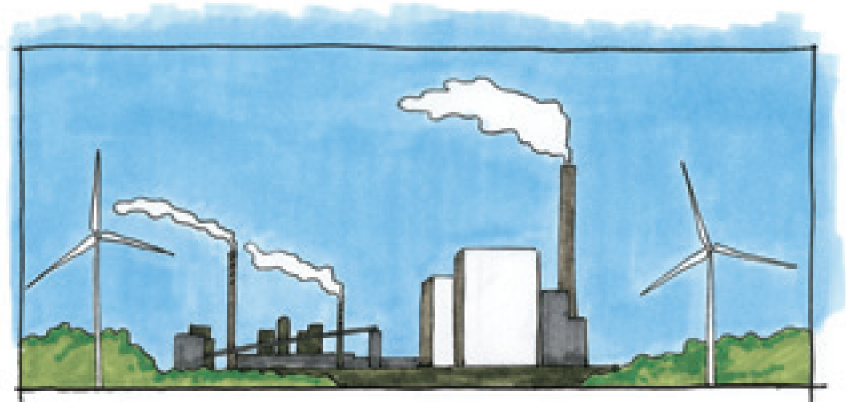
Technical potentials for use of solid biofuels in European industry

Biomass might be used as a substitute for fossil fuels and other energy carriers in industrial processes in the EU. On the basis of estimates for German industry, the technical potential for the use of solid biofuels for heating purposes in EU industry is estimated as 4 EJ, which is approximately equivalent to 8-times the current level of use. The CO_2 mitigation corresponding to this potential use of biofuels is estimated to be 0.25-0.3 Pg CO_2 per year, or about 25-30% of the current levels of industrial emissions.

In the EU, a great deal of attention has been focused on how biomass energy might contribute to lowering the CO_2 emission levels of the transportation and heat and power sectors, and to a lesser extent on those of industry. In general, data and knowledge about the economics and technical potentials for replacing fossil fuels with biomass in industrial processes are lacking. This scarcity of knowledge means that there is no accurate basis for defining the extent biomass to which might be a cost-effective CO_2 mitigation option in industry. In addition, there is currently no accurate basis for analysing the cost effectiveness of bioenergy use in the entire energy-consuming system (i.e., the combined transportation, heat and power, and industrial sectors).



Analysis of temperature structure of industrial energy use

The study presented in this chapter focused on the industrial use of biomass energy in solid forms, and did not consider converted forms, such as gases or liquids. The conversion of biomass into gases or liquids entails lower overall energetic efficiency and higher costs, which means that it is a less attractive option. However, biomass energy in solid form has limited applicability in industrial processes. For example, some industrial processes require high temperatures, which cannot be attained through the burning of solid biomass. Thus, the temperature structure of the heat demand in industrial processes is a key factor for bioenergy potential.

The main basis for estimating the bioenergy potential in industry was an analysis of the temperature structure of the industrial uses of heat for processes and space heating. The potential for using solid biofuels was assumed to correspond to all heat use at temperatures <400^{o}C (minus already existing biofuel use). In addition, for temperatures >400^{o}C, the potential use of solid biofuels was assumed to exist in terms of co-combustion of solid biomass and coal. Due to the general lack of data on the temperature structure of heat use in industry, this study was limited to industry in Germany. The data used were obtained from the literature (most notably, Lutsch and Witterhold, 2005) and from interviews conducted with representatives of German industries.

BIOMASS USE IN INDUSTRY CAN EIGHTFOLD

Figure 38.1 shows the estimated structure of energy end-use in the entire German industry. Energy is used mainly for process heat purposes (65% of the total), followed by mechanical work (24%), and space heating (9%). The use of heat at temperatures <400^{o}C accounts for about 45% of total heat use (process heat and space heating), and the use of heat at temperatures >400^{o}C represents about 55% of total heat use.

Fossil gas is currently the major carrier for both process heat use and space heating, with gas supplying about half of the process heat demand and as much as two-thirds of the space heating demand. In contrast, biomass supplies a mere 3% of the total process heat demand.

Figure 38.2 shows the estimated heat use structure in each industry branch, using three different temperature ranges, as well as the total use of heat. The branches

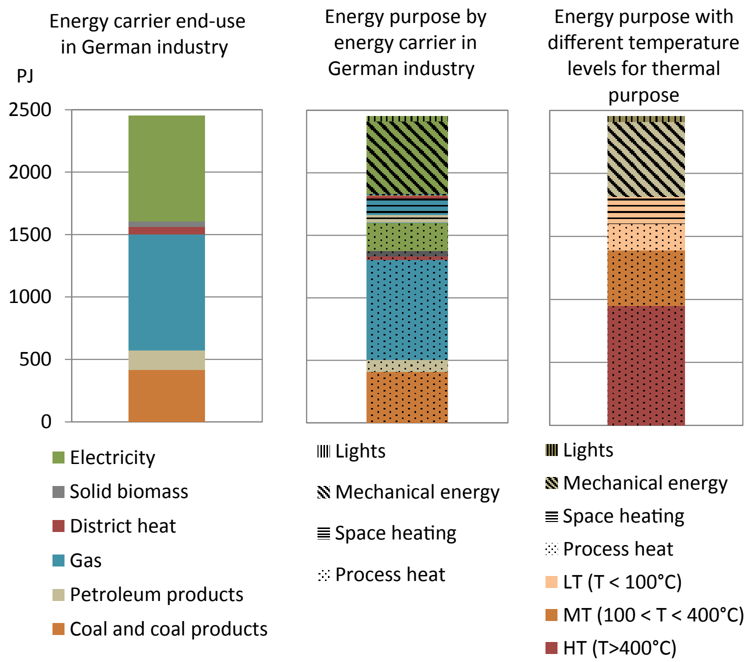


Figure 38.1. Estimated end-use of energy by category in German industry in 2005. The left-hand column shows end-use by type of carrier, whereas the middle column shows for which purposes these energy carriers were used. The right-hand column shows energy end-use by purpose, for which the heat is specified by temperature range. Compiled from VDEW/AGEB (2005).

that have both high heat use and temperature structures that are favourable from a biofuels potential perspective include the food and pulp and paper sectors. In contrast, in the metals and minerals branches, almost all heat use is at temperatures >400°C.

A rough estimate for EU industry using the energy end-use characteristics of the German industry sectors (Fig. 38.2) gives a technical potential for using solid biofuels for heat purposes of the order of 4 EJ, which represents about 8-times the current level of usage of biomass in EU industry. The technical potential for co-combustion with coal is a mere 0.1 EJ, assuming a 10% co-combustion rate, which in the case of coal use in steel production is not technically feasible, since coal is consumed in the form of coke. The CO_2 mitigation level that corresponds to a biofuel potential of 4 EJ is roughly 0.25-0.3 Pg CO_2 per year, or about 25-

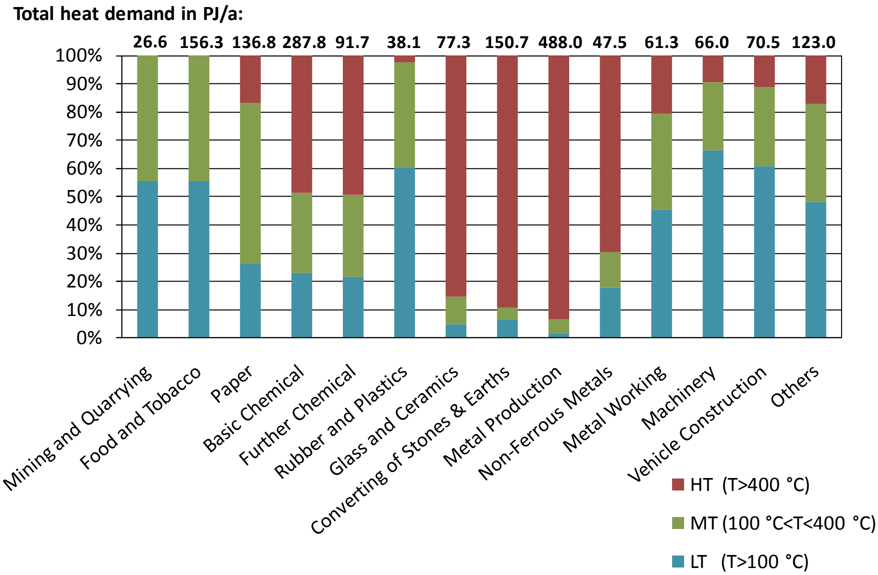


Figure 38.2. Estimated use of heat (for processes and space heating) in German industry in 2001. The columns represent the share of temperature levels in total heat demand in percent. The absolute value is shown above each column. Compiled from Lutsch and Witterhold (2005).

30% of the current level of emissions in EU industry (including emissions from electricity production). It should be noted that this CO_2 mitigation estimate does not include emissions from the production and distribution of biofuels. Therefore, depending on the biofuels supply characteristics, the net CO_2 mitigation level could be considerably lower. The results presented here are used for the top-down modelling of the industry described in Chapter 16 in the *Methods and Models* book.

For more information:

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Further reading:

Göckeler, K., 2007, Potentials for the Use of Solid Biomass for Energy in German Industry and Dairy Industry. Division of Physical Resource Theory, Chalmers University of Technology.

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Pathways for the pulp industry:

trade-offs between profit and CO_2 emissions reduction

There is a trade-off, in terms of annual net profit for the mill and the reduction of global CO_2 emissions, between different technology pathways for utilisation of the excess steam from kraft pulp mills. The trade-off was analysed for four future energy market scenarios having different levels of CO_2 charge. The results show that the proven pathways (increased electricity production, bark export, and district heating production) are economically robust, i.e., they are profitable for all of the studied energy market scenarios. Although the new and emerging technology pathways (carbon capture and storage and lignin extraction) have greater potentials for reducing global CO_2 emissions, the economic profitability of these processes is more dependent upon the development of the energy market. The conclusion is that to realize the higher potential for reducing of global CO_2 emissions, a high-carbon cost alone may not be sufficient; other economic stimulations are required, e.g., technology-specific subsidies.

For the kraft pulp industry, there are many technologies and system solutions (hereinafter called ‘technology pathways’) that can increase energy efficiency with economic profitability and thereby contribute to sustainable development. Previous studies have demonstrated the potential for up to a 30% reduction in process steam demand through improved process integration and the introduction of new and efficient equipment (Axelsson et al., 2006).The savings in steam offer opportunities for energy export in the form of increased electricity production, lignin extraction and/or production of heat for district heating (Olsson et al., 2006; Jönsson et al., 2008). Steam savings also facilitate the introduction of carbon capture and storage (CCS) (Hektor and Berntsson, 2007) and conversion to black liquor gasification (Pettersson and Harvey, 2009).

The main aim of this part of the Pathways project was to compare the trade-offs in terms of annual net profit and global CO_2 emission reduction of different energy-related technology pathways for the utilisation of excess steam and heat from kraft pulp mills. A further aim was to analyse how the future development of the energy market will affect this trade-off and to identify “robust” technology pathways, taking into account the uncertainty of the future energy market.

MODELLING THE PULP INDUSTRY

The studied system is a model of a kraft pulp mill (FRAM, 2005) that has the possibility to invest in energy efficiency measures (reducing the process steam demand) and/or new energy-related technology pathways (new turbines, export of district heating or bark, lignin extraction, and CCS). The model mill and surrounding energy market were constructed in the energy systems modelling tool reMIND (Figure 39.1). The constructed model was optimised with the objective of minimising the total annual system cost of the studied energy system (the mill), assuming a surrounding system (the energy market, including policy instruments). To evaluate the future trade-off between the different pathways studied, four energy market scenarios, reflecting different future energy market prices, were used (see pages 269-270). The scenarios reflect futures with high or low fossil fuel prices coupled with high or low CO_2 charges (Table 39.1). In this study, the mill's energy system is in focus. Therefore, the economic and CO_2 emission effects of other parts of the system, such as the sales of pulp, have been excluded.

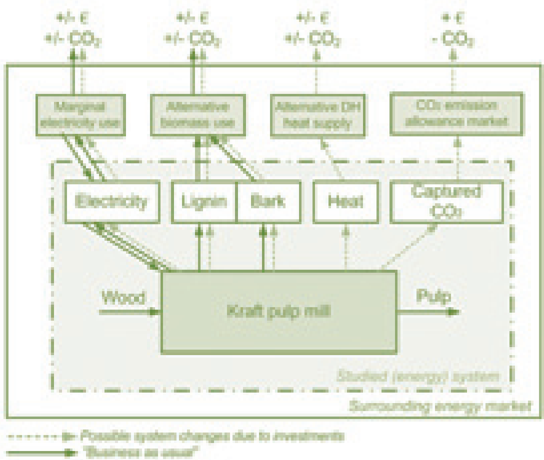


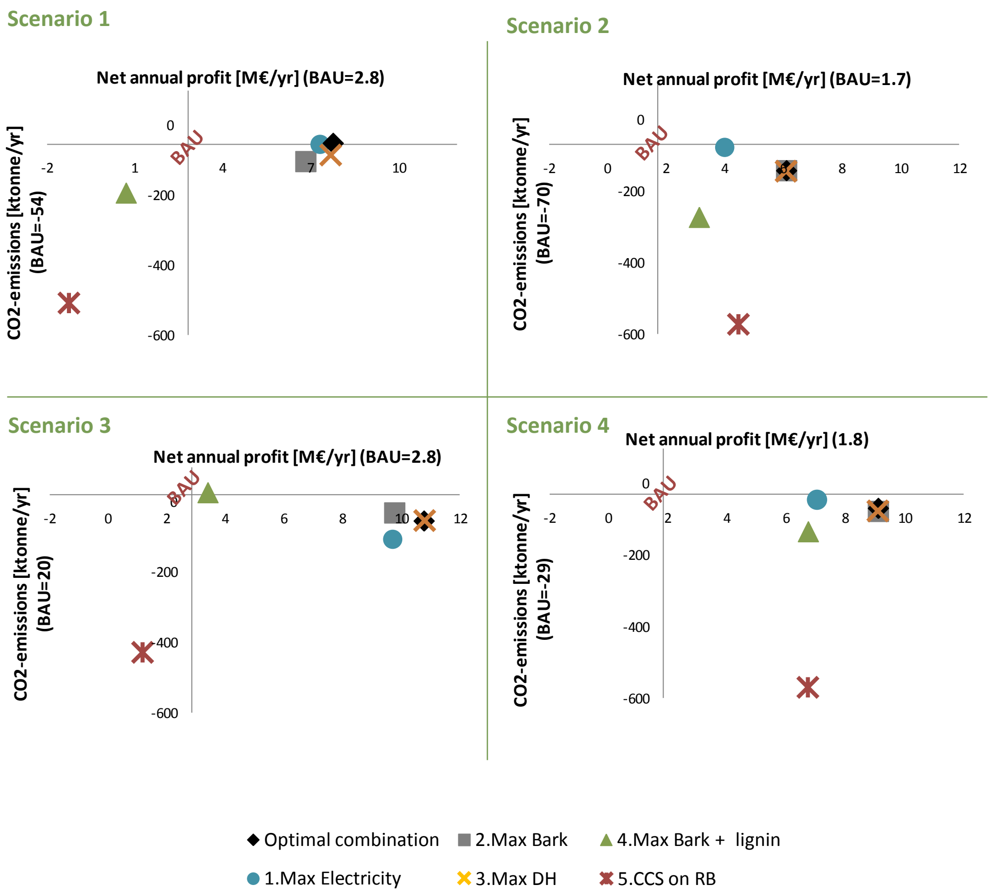
Figure 39.1. The studied energy system (a model of a kraft pulp mill) and the surrounding energy system.

Table 39.1. The four energy market scenarios.

Scenario	1	2	3	4
Fossil fuel prices/CO_2 charge	Low/Low	Low/High	High/Low	High/High

PROFITABLE INVESTMENT THAT DECREASES GLOBAL CO_2 EMISSIONS

The changes in annual profit and global CO_2 emissions for the optimal solution compared to the business as usual (BAU) case are presented in Figure 39.2. For all four BAU cases, no investments are made and the energy balance of the kraft pulp mill is unchanged. The optimal solution is a combination of increased electricity production and/or the selling of bark and/or the production of district heating (Table 39.2). Besides the optimal solution, the consequences of adopting only one of the studied technology pathways are presented (Max Electricity, Max Bark, Max DH, Max Bark + lignin, and CCS on the recovery boiler [RB]).



Note that the intersection of the x-axis and the y-axis is not 0 at the BAU values for the different scenarios!

Figure 39.2. Changes in annual net profit and global CO_2 emissions compared to the BAU case for the optimal solution and the five technology pathways.

Table 39.2. Optimal solution compared to BAU for the four energy market scenarios.

	BAU	Scenario 1 Optimal	Scenario 2 Optimal	Scenario 3 Optimal	Scenario 4 Optimal
Annual net profit compared to BAU [ΔM€/yr]	0	+5.4	+5.2	+9.0	+7.3
Global CO_2 emissions compared to BAU [Δktonnes/yr]	0	-23	-87	-64	-41
Pulp produced [ADt/d]	1000	1000	1000	1000	1000
Electricity produced [GWh/yr]	190	375	287	359	287
Bark sold [GWh/yr]	242	0	242	0	242
District heating [GWh/yr]	0	121	198	198	198
Lignin extracted [GWh/yr]	0	0	0	0	0
CO_2 captured by CCS [ktonnes/yr]	0	0	0	0	0

The BAU cases are used as a baseline for the comparison for each scenario, and are represented by the intersection of the x-axis and the y-axis in the four diagrams in Figure 39.2. Thus, each diagram is divided into four quadrants. The solutions in the lower-right quadrants are the most interesting, since they yield both higher annual net profits and lower global CO_2 emissions than the BAU case.

As shown in Figure 39.2, the pattern of the trade-off between the different technology pathways is similar for the scenarios that have the same level of CO_2 charge. For the two scenarios with low CO_2 charge (Scenarios 1 and 3), the solutions based on the proven pathways (Max Electricity, Max Bark, and Max DH) are substantially more profitable than the solutions based on new emerging pathways (Max Bark + lignin, and CCS on RB), the CCS pathway being directly unprofitable for both scenarios and the lignin extraction pathway being directly unprofitable in Scenario 1. For the two scenarios with high CO_2 charges (Scenarios 2 and 4), all of the studied solutions are profitable compared to doing nothing new (BAU). However, the variability in the level of reduction of global CO_2 emissions between the solutions based on the different pathways is large for all the scenarios, with CCS giving by far the largest reduction. Consequently, for Scenarios 2 and 4, the marginal cost is low for further and large-scale reduction of CO_2 emissions (compared to the optimal solution). This means that if the future energy market resembles the one described in Scenario 2 or 4 (high CO_2 charge), there is a potential for achieving large reductions in CO_2 emissions with only small additional economic incentives (such as technology-specific subsidies), since in these two scenarios, the differences in net annual profit between the different technology pathways are small while the differences in global emissions of CO_2 are high.

Furthermore, it is evident that the optimal solution gives a significant increase in annual net profit, generating an additional 5.2-9.0 M€ depending on the energy market scenario. The global CO_2 emissions are also reduced for the optimal solution in all the scenarios.

GLOBAL CO_2 EMISSIONS CAN BE REDUCED THROUGH PROFITABLE INVESTMENTS

The following conclusions can be drawn from the analyses of the economic and CO_2 emissions trade-offs between different technology pathways for the utilisation of the excess heat from kraft pulp mills:

- The global CO_2 emissions associated with the studied system can be significantly reduced through profitable investments in energy efficiency and different technology pathways.
- The new and emerging technologies (lignin separation and CCS) create the largest reductions in global CO_2 emissions, although the profitability levels of the proven technology pathways, (electricity production, district heating production and selling bark) are more robust in terms of resistance to changing energy market prices.
- To achieve the full potential of the new, emerging technology pathways, some additional economic incentives may be needed (e.g., technology-specific subsidies); however, these economic incentives do not need to be large.

For more information:

Johanna Jönsson and **Thore Berntsson**
Heat and Power Technology, Chalmers

Further reading:

Jönsson, J., Algehed, J., 2010, Pathways to a sustainable European kraft pulp industry: Trade-offs between economy and CO_2 emissions for different technologies and system solutions, Applied Thermal Engineering, 30 (16) pp. 2315-2325.

40

CO_2 emission scenarios in the pulp and paper industry:

capital vintage modelling on mills in EU15

This chapter presents future energy use and CO_2 emissions in the pulp and paper industry in the EU15, assuming the implementation of different policy options aimed at reducing CO_2 emissions in this sector. Depending on which policies are implemented, the CO_2 emissions from this sector in the year 2020 are likely to be 8-23% lower than those in the baseline scenario.

Capital vintage modelling of five scenarios

For the analysis a capital vintage model of the EU pulp and paper industry was used, which was developed as part of this project, to assess the policy-induced changes in energy use and carbon emissions. Capital vintage models capture the age structure of the capital stock and its associated age-specific attributes, such as size, rate of replacement, input efficiency, and input substitution possibilities (see Chapter 17 in the *Methods and Models* book for further information on capital vintage modelling).

Capital vintage modelling

Capital vintage modelling is an attempt to avoid the pitfalls of the more traditional bottom-up and top-down modelling systems by incorporating both technological descriptions of the capital stock and top-down representations of the economies that stimulate change in the capital stock. It also captures more effectively the inherent inertia of capital investments, thereby reflecting the real world situation more accurately.

Five scenarios were investigated: a baseline scenario, in which carbon costs are assumed to remain at current levels in the EU ETS, i.e., at around €25/tonne CO_2, and four different policy scenarios.

- The **baseline** conditions were generated for a low carbon cost scenario and an increase in biomass use from 30 to 45% between 1990 and 2020. This fuel-mix transition schedule is an intermediate of the estimates from the CEPI countries and EU25 estimates based on ICCS-NTUA (2008).
- The **Medium carbon cost** and **High carbon cost** scenarios, in which carbon costs are assumed to increase gradually to €40/tonne CO_2 and €60/tonne CO_2, respectively, by 2020. These scenarios assume lagged fuel-switching triggered

by price increases, consistent with historical production methods and industry behaviour. In the medium-cost scenario, biomass use is exogenously set to increase at a faster rate than the baseline scenario, from 30% to 55% between 1990 and 2020. In the high-cost scenario, biomass use increases from 30% to 60% over the same time period.

- In the **Efficiency** scenario it is assumed a more rapid adoption of energy-efficient technology compared to the historical trajectory of the capital learning curve implemented in the fuel-switching scenarios. This scenario uses the baseline biomass and carbon cost conditions, but increases the efficiency of new capital by 10% and decreases the capital recovery factor for the industry to 15% rather than the typical 33%. This scenario reflects the implementation of policies aimed specifically at increasing energy efficiency, e.g., subsidies for investment in more efficient equipment.
- A **Combined Policy** scenario that combines the **Efficiency** and **Medium carbon cost** policy scenarios.

Paper production was the same for all the scenarios, to allow a fair policy comparison. The assumed annual growth rate of paper production was 1.3%, based on EC (2006).

COMBINATION OF DIFFERENT POLICIES IS MOST EFFICIENT

In the baseline scenario, energy use increases by 61% between 1990 and 2020 (Figure 40.1). However, owing to the learning curve of capital efficiency in the industry coupled with increased fuel switching, the energy use and carbon emissions per amount of pulp and paper produced decrease substantially (Figure 40.2).

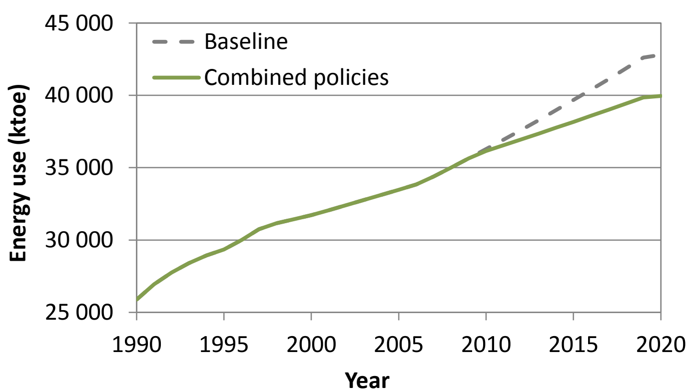


Figure 40.1. Total energy use in proposed scenarios for the EU15 pulp and paper industry.

The Efficiency and Combined policies scenarios reduce total energy use by 8% and 9%, respectively, compared to the baseline. For the scenarios in which carbon costs are assumed to increase, i.e., the Medium carbon cost and High carbon cost scenarios, total energy use is not reduced because these scenarios present the same capital learning curve as the baseline scenario. Therefore, the level of energy use to produce the same output is the same for these scenarios, even though they generate lower carbon emissions through switching to a less-carbon-intensive fuel.

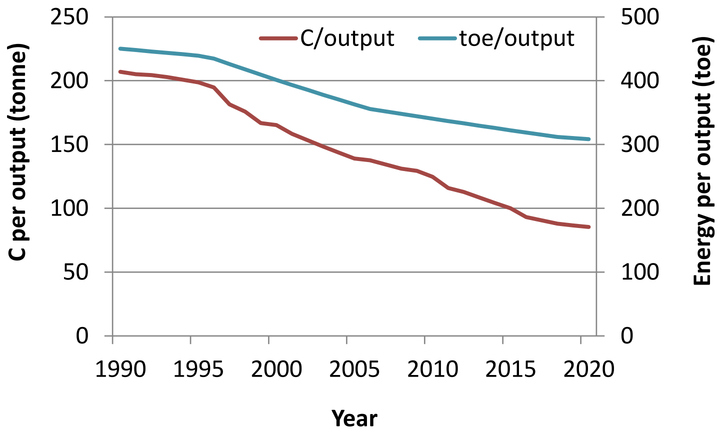


Figure 40.2. Energy use (toe/100 000 tonnes paper) and carbon generation (tonne C/100 000 tonnes paper) in the EU-15 pulp and paper industry in the baseline scenario.

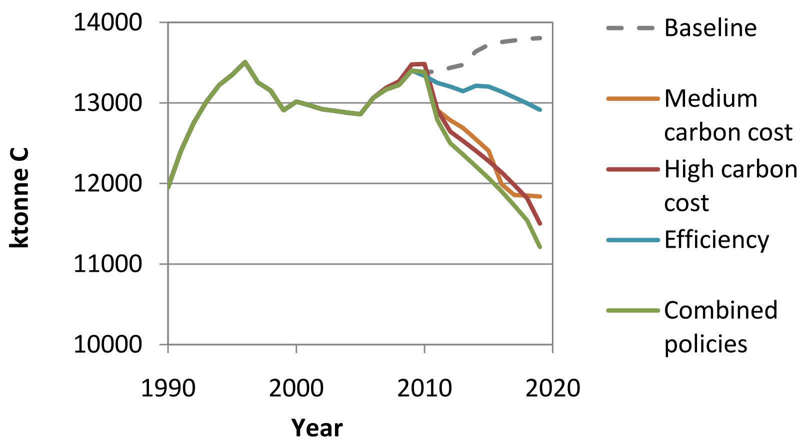
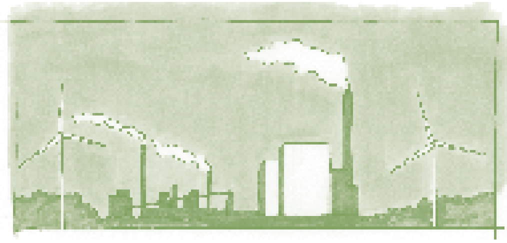


Figure 40.3. Carbon emission levels for the different scenarios in the EU15 pulp and paper industry.



In the baseline scenario, carbon emissions increase by 16% between 1990 and 2020 (Figure 40.3). All the policy options simulated reveal reduced carbon emissions compared to the baseline conditions, although the efficiency gains alone do not generate emission reductions that are lower than the 1990 levels by 2020. The Combined policies scenario generates the most pronounced drop in emissions within this time frame, cutting emissions to nearly 10% of the 1990 levels by 2020. This represents a difference of -22% from the baseline conditions in 2020.

The results suggest that a combination of different policies, such as an increase in carbon cost and an incentive for the industry to invest in more efficient new capital, could be successful in stimulating a reduction in carbon emissions by producing changes in fuel mixes and improving efficiencies. In contrast, the use of carbon price instruments exclusively is unlikely to increase permanently the industry's aggregate energy efficiency. A major reason for this is that energy expenditures represent a small percentage of the total production cost, which is dominated by feedstock and capital costs. Another reason is that the total cost of installing new and more energy efficient equipment, e.g., more efficient recovery boilers that use black liquor gasification, may be significantly greater than the amount saved through energy savings. For these reasons, investments in energy-saving equipment are often a side-bonus to other investments in energy-intensive industries, for instance, capacity expansion. Thus, purely price-based policies, such as an increase in the cost of carbon, may fall short in affecting the evolution of the capital stock towards increased efficiency.

For more information:

Stefan Wirsenius
Physical Resource Theory,
Chalmers

Further reading:

Gasper, R., Ruth, M., Wirsenius, S., 2010, Short-term Emissions Reduction Potential in the EU Pulp and Paper Industry. In review at Energy.

41

Energy and CO_2 emission scenarios in steel industry:

capital vintage modelling

The total CO_2 emissions of the EU iron and steel industry can be cut by some 20–40% up to the year 2030, as compared to current levels. The reduction potential emanates from structural changes within steel production, combined with process optimisation and fuel substitution. Moreover, the CO_2 emissions profile of the electricity supply system affects the total steel industry emission level heavily due to the increased reliance on electricity as an energy input; 3–22 % of the potential CO_2 emissions reduction will occur external to the steel industry.

The iron and steel industry has played, and continues to play, a vital role as a mainstay of European industry. The European share (EU15) of global steel production was 9.5% in 2009 (WSA, 2010), which is equivalent to 116 million tonnes, of which roughly 60% was ore-based and 40% was scrap-based production. The iron and steel industry is highly intensive in both materials and energy, and more than 40% of the inputs end up as off-gases and solid co-products and residues (EC, 2009). The iron and steel industry is responsible for approximately 30% of the industrial CO_2 emissions in Europe, which is equivalent to about 4% of total European CO_2 emissions (EEA, 2009).

The purpose is to assess the energy intensity reduction and CO_2 mitigation potentials in the European iron and steel industry. The assessment covers EU15, representing approximately 85% of EU27 total steel production, until the year 2030 (for full details see Torén (2010)).

Econometric modelling including age structure

To build scenarios of energy use and CO_2 emissions for the European iron and steel sector, a dynamic computer model that uses econometric forecasting techniques and which captures the main productions stages and technologies, has been applied to the industry. Embedded in the overarching econometric model is a capital vintage module that explicitly accounts for the age structure of the stock, including age-specific efficiencies, production levels, and capacity utilisation (for further details, see Chapter 18 in the *Methods and Models* book). The EU iron and steel model is founded on studies conducted by Ruth et al (2000; 2002; 2004), in which capital vintage modelling regimes were applied to the US iron and steel industry.

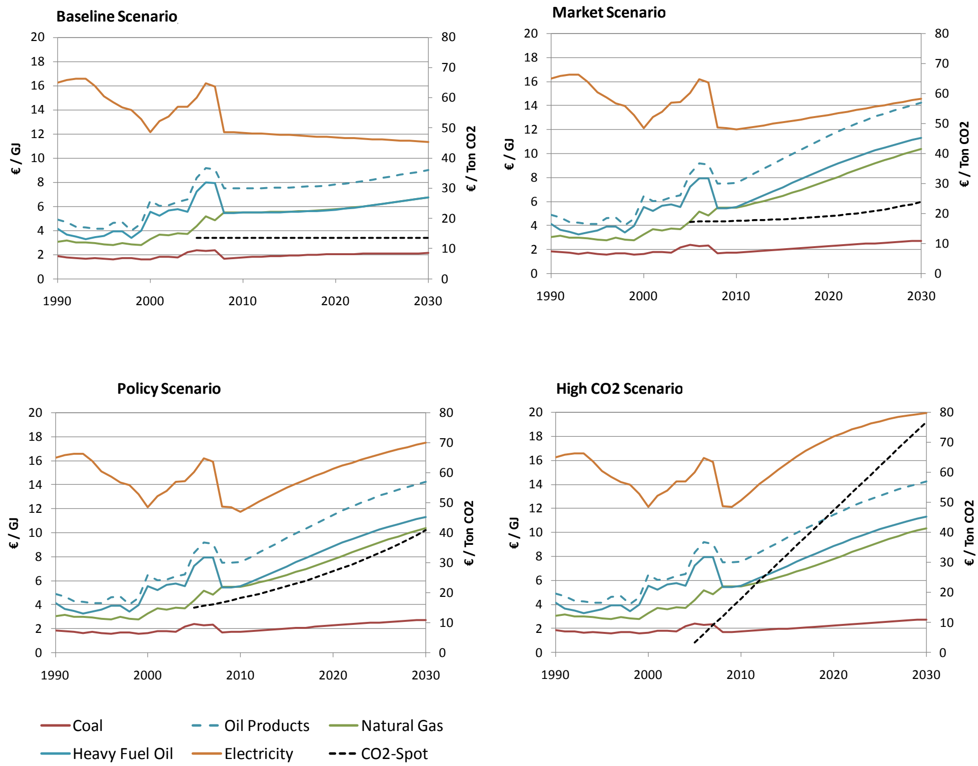


Figure 41.1. Scenarios for energy prices and CO_2 spot prices.

STRUCTURAL CHANGE CAN CUT EMISSIONS SIGNIFICALLY

To assess the potential for energy intensity reductions and CO_2 mitigation, several scenarios for energy prices and carbon cost have been adapted from the Pathways framework (see Chapter 20 in the *Methods and Models* book). The scenarios are used to analyse how the iron and steel industry reacts to high or low future energy prices and how lax or stringent CO_2 emission reduction policies affect the industry structure, fuel mix, CO_2 intensities, etc. (Figure 41.1).

Modelling indicates that the CO_2 emissions of the steel industry can be cut by 20–40% up to 2030, as compared to current levels, with emission reductions stemming both from structural changes and process-specific improvements and optimization (Figure 41.2). Primary ore-based steel production (Blast Furnace/ Basic Oxygen Furnace route) would, using the assumptions of the scenario, lose its role as the main mode of steel production. Instead, secondary scrap-based production (Electric Arc Furnace route) would account for approximately 55–60% of the total EU15 steel production by 2030 (Figure 41.3).

Coupled with the increased importance of secondary steel production is the effect of the CO_2 intensity of the electricity supply system for the steel industry's cumulative CO_2 emission profile. This is especially evident in the *High CO_2* scenario, in which where *Coal with CCS* reduces the CO_2 intensity of electricity towards the end of the modelling period. Reductions in CO_2 emissions that are external to the steel industry, i.e., reductions in power production, are expected

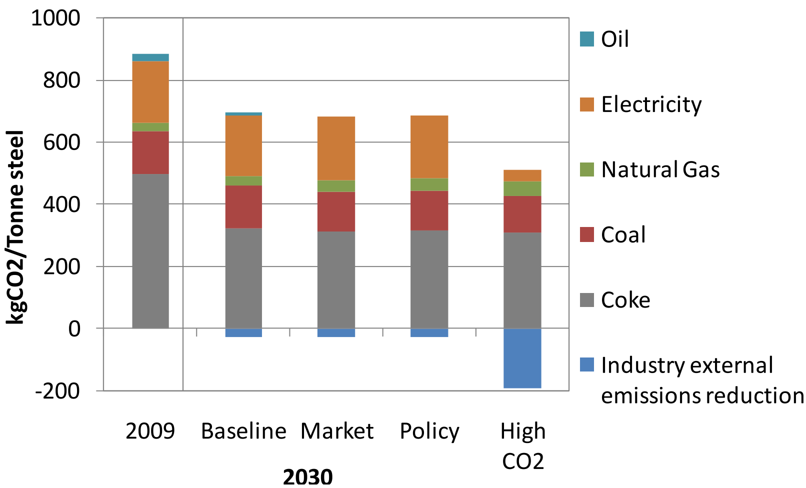


Figure 41.2. Average CO_2 emissions per tonne of produced steel, the including effects of changes in production structures, for years 2009 and 2030.

to account for 3-22% of the overall reduction potential up to 2030, as compared to current levels (Figure 41.2). However, since the effects of CCS in the electricity supply system will impact only towards the end of the modelling period, the difference between the four scenarios for industry-wide cumulative emissions emanating from electricity use are quite minor (Figure 41.4).

The single greatest consumer of energy in the production of steel is the blast furnace, and the potentials for industry-wide energy efficiency improvements and CO_2 mitigation are highly dependent upon efficiency gains in this process. Econometric analysis has also shown that blast furnace fuel composition is extremely sensitive to the relative price of fuel oil, as compared with other primary energy sources. This sensitivity is also evident in the modelling results, with regard to both the average emissions per tonne of produced steel in 2030 (Figure 41.2) and the industry-wide cumulative emissions (Figure 41.4). In all four scenarios, fuel oil is substituted with less-carbon-intense natural gas.

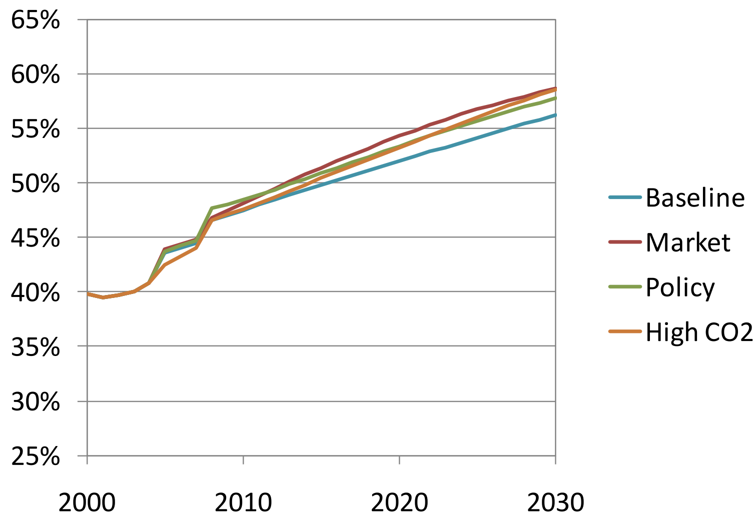


Figure 41.3. Electric Arc Furnace share of total steel production in EU15 for the period 2000-2030.

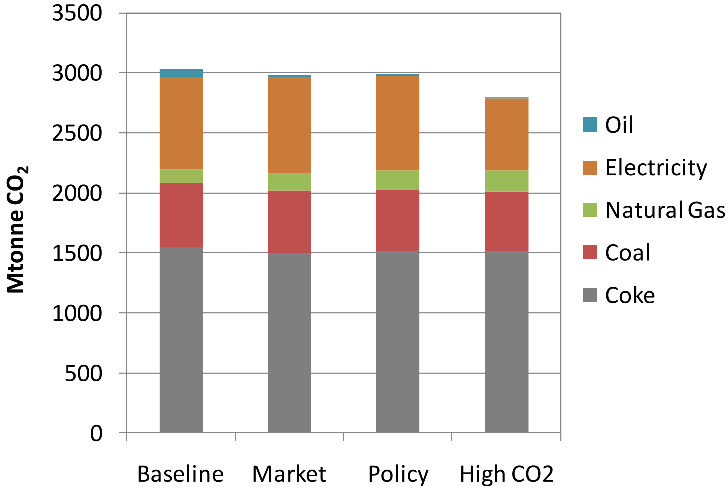


Figure 41.4. Cumulative CO_2 emissions from the steel industry in EU15 for the period 2010-2030.

For more information:

Johan Torén and **Stefan Wirsenius**
Physical Resource Theory, Chalmers

Further reading:

Torén, J., 2010, ”Scenarios to 2030 of Energy Use and CO_2 Emissions in EU Steel Industry - An Application of Capital Vintage Modeling Technique”. Thesis for the Degree of Master of Science in Industrial Ecology, Department of Energy and Environment, Chalmers University of Technology.

42

Strategies for CO_2 abatement in the European petroleum refining industry

Petroleum oil refineries account for almost 3% of the total greenhouse gas (GHG) emissions in the European Union (EU). Options for CO_2 abatement in the refinery industry are limited. However, CO_2 emissions associated with the petroleum conversion process could be lowered by more efficient use of the surrounding infrastructure, such as district heating networks, natural gas grids, neighbouring industries, and CO_2 transport and storage systems. Nevertheless, the prospects for utilising the surrounding infrastructure to facilitate CO_2 abatement vary significantly across countries.

The refinery industry is, by its very nature, part of the fossil fuel supply chain, and thus is unlikely to contribute significantly to a shift away from fossil fuels. While both the overall CO_2 emissions and fossil fuel-related CO_2 emissions have declined in the EU since 1990, emissions from European petroleum refineries have increased by around 17%. This trend has primarily been driven by increasing demand for fuel in the transportation sector. While the share of alternative fuel is expected to grow considerably, petroleum-based fuels will most likely continue to play an important role in the transportation sector over the coming decades. Therefore, assuming that EU refineries are to continue to supply the EU market, it is important to consider options to reduce the CO_2 emissions associated with the petroleum conversion process, while in parallel, changing the feedstocks to refineries and transforming the fuel sources for the transport sector to renewable fuels and electricity.

This chapter summarises the current status of the European petroleum refining industry and assesses the prospects for future CO_2 abatement options. This analysis was carried out by combining information on potential CO_2 abatement options (Johansson et al., 2010; Rootzén et al., 2010; Worrel and Galitsky, 2005) with industry-specific information (Oil and Gas Journal, 2007; Reinhaud, 2005; Concawe, 2008).

THE EU PETROLEUM REFINING INDUSTRY AT A GLANCE

The European petroleum refining industry remained limited in size up to World War II. After the war, rapid economic growth, an abundant supply of inexpensive crude oil, and the discovery of domestic oil and gas deposits led to a rapid increase in oil consumption and expansion of the petroleum refining industry. In the period 1950-1970, the oil refining capacity in Western Europe grew 40-fold (Molle and Wever, 1984). A considerable share of the current capital stock is derived from this post-war expansion. More than 90% of the European refineries were built before 1980 (IPPC, 2003). As part of the work presented here, the Chalmers Industry database (which is a part of the Chalmers Infrastructure databases) was updated with facility-level data for the European refinery industry. This database includes data on all 114 operating refineries in EU and Norway, which have a total crude capacity of approximately 16 million barrels per day (Mb/d). For a description of the database, see Chapter 3 in the *Methods and Models* book.

Emphasis is placed on refineries with CO_2 emissions that exceed 1 $MtCO_2$/year (representing 58 out of the 114 refineries in the EU27 and Norway), accounting for more than 80% of the total CO_2 emissions of the refinery sector. This group of refineries includes all countries with refining capacity, except the Czech Republic, Denmark, and Ireland. The oil refineries differ regarding configuration, process integration, feedstock, feedstock flexibility, products, product mixture, design, and control systems. These variations reflect many factors, such as owner strategy, market situation, location, age of refinery, historical development, available infrastructure, and local regulations (e.g., environmental regulations). The refineries are divided into configurations of complexity (Configurations: base to 4), which range from a base configuration, which includes refineries with no converting units and only heavy fuel production, to refineries of high complexity (Configuration 4), which have a high number of converting units and high value-added products (e.g., diesel and aviation fuel). The 58 refineries with the highest CO_2 emissions include those with the highest level of complexity (Configuration 4) but only 50% (7/14) of the refineries with Configuration 3, which indicates that not all refineries of high complexity have, in absolute terms, the highest CO_2 emissions. A summary of the key characteristics is given in Table 42.1.

REDUCING CO_2 EMISSIONS FROM EU REFINERIES

The options for CO_2 abatement in the refinery industry are limited. Measures that could be taken in the near future include continued energy efficiency improvements, fuel switching (using natural gas instead of residual fuels as energy source), and increased use of biomass feedstock as fuel. CO_2 capture could be an option in the longer term. Increased use of renewable feedstock for fuel

Table 42.1. Country-level summary of the crude oil capacities, CO_2 emissions (share of total in brackets), and complexity levels for the 58 refineries included.

Country	Number of refineries	Crude oil capacity [Mb/d]	CO_2 emissions [Mt/year]	Level of complexity			
				Base + Config. 1	Config. 2	Config. 3	Config. 4
Austria	1	0.21	2.7 (2%)	0	1	0	0
Belgium	2	0.66	5.5 (4%)	0	2	0	0
Bulgaria	1	0.12	2.1 (2%)	0	1	0	0
France	8	1.56	14.2 (11%)	0	6	0	2
Germany	8	1.53	20.2 (16%)	1	3	2	2
Greece	2	0.26	3.6 (3%)	0	1	0	1
Hungary	1	0.16	1.4 (1%)	0	1	0	0
Italy	8	1.68	20.4 (16%)	0	4	1	3
Lithuania	1	0.19	1.8 (1%)	0	1	0	0
Netherlands	4	1.14	10.8 (8%)	1	0	2	1
Norway	1	0.20	1.5(1%)	0	1	0	0
Poland	1	0.37	5.1 (4%)	0	0	0	1
Portugal	1	0.21	1.9 (1%)	0	0	0	1
Romania	2	0.14	2.5 (2%)	0	1	0	1
Slovakia	1	0.12	2.0 (2%)	0	0	0	1
Finland	1	0.20	2.9 (2%)	0	0	0	1
Spain	6	0.98	12.2 (9%)	0	2	1	3
Sweden	1	0.21	1.7 (1%)	0	0	0	1
UK	8	1.72	16.5 (13%)	0	7	1	0
Total	**58**	**11.64**	**128 (100%)**	**2**	**31**	**7**	**18**

production, i.e., diesel production, could be a way for refineries to contribute to reducing CO_2 emissions off-site, particularly in the transportation sector. Providing excess heat for district heating or integrating process flows with adjacent industries (e.g., petrochemical industries) are additional ways for refineries to contribute to reducing CO_2 emissions off-site. The latter measures rely on access to appropriate infrastructure. The distances and connections to district heating networks, natural gas grids, neighbouring industries, and CO_2 storage sites have therefore been evaluated individually for each of the 58 refineries.

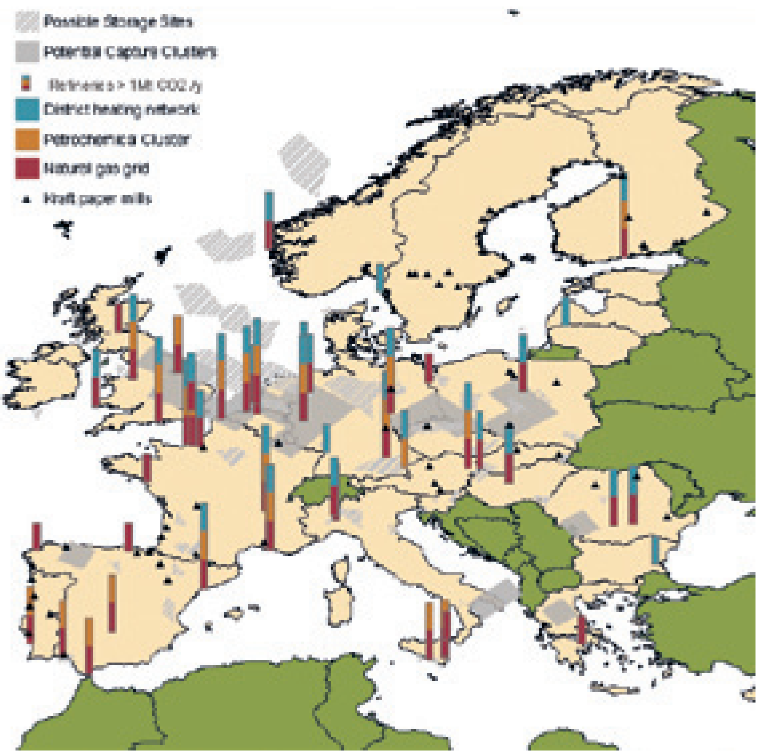
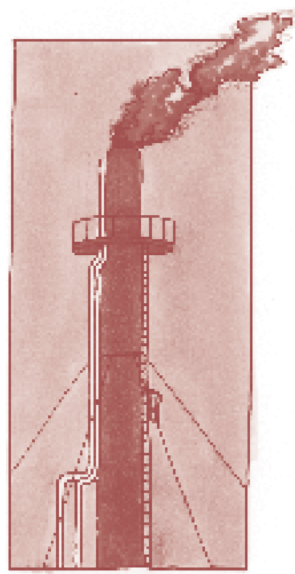


Figure 42.1. Geographical distribution of refineries with CO_2 emissions >1 Mt/year in relation to district heating systems, chemical clusters, and natural gas grids. The bars in red, orange, and blue represent refineries. The red bars indicate refineries with the possibility to connect to a natural gas grid. The orange bars indicate refineries within chemical clusters. The blue bars indicate refineries with the possibility to connect to a district heating network. Possible CO_2 storage sites are represented with grey lines. Since Kraft pulp and paper mills are possible producers of renewable feedstock to refineries, their locations are indicated in the map as black triangles. Potential capture clusters, regions in which emissions from large stationary point sources (including emissions from power plants and pulp and paper plants) exceed 20MtCO_2/year, are highlighted in grey.

As illustrated in Figure 42.1, the potential for utilising the surrounding infrastructure to create synergy effects for CO_2 abatement varies significantly across countries. The general conclusions are that:

- Refineries located along the North Sea coastline generally are in the most advantageous locations with respect to utilising the surrounding infrastructure.
- With respect to the prospects for implementing CCS technology, refineries might benefit if they could co-ordinate CO_2 transport with other industries, and with the power industry in particular. Areas highlighted in grey in the map (Figure 42.1) represent regions with favourable conditions for the clustering of CO_2 emission sources. However, only 13 of the 58 of the refineries are located in these regions.
- Regarding the prospect for implementing energy efficiency measures, refineries could benefit from the co-ordination of energy efficiency measures and process flows with other industries, in particular, with chemical industries located in clusters. Industrial process cluster sites can also be attractive for emerging biorefinery concepts with a focus on large-scale conversion of biomass to high-grade materials and fuel energy products. The largest chemical clusters that include refineries are located in the Netherlands, Belgium, France, Germany, and the UK. However, most of the refineries in Europe are located within 10 km of at least two chemical industries.
- Refineries that lie in proximity to available district heating systems are associated to countries with high district heating market saturation, such as Sweden, Finland, and Lithuania, as well as countries with high annual district heating growth rates, such as Norway and Austria. In addition, in Bulgaria, Belgium, France, Germany, Romania, Slovakia, Hungary, and the Netherlands, district heating systems can be found within 50 km of a refinery.



Here we have assumed that the total demand for refined petroleum products will remain relatively constant over the coming decades. If, however, the demand is reduced drastically due to fuel shift in, i.e., the transport sector as assumed in Policy and Market Pathway, many EU refineries will likely be decommissioned which would lead to further CO_2 emission reductions (see Chapter 37).

In summary, there are siginificant opportunities for the refinery industry to reduce its CO_2 emissions and to create synergy effects for CO_2 abatement. However, several of the abatement options will rely on appropriate infrastructures and integration between sectors. To date, no appropriate infrastructures for these options have been established and co-ordination across different sectors remains a challenge that must be overcome before the full potential of these options can be exploited.

For more information:

Daniella Johansson, Heat and Power Technology, Chalmers
Johan Rootzén, Energy Technology, Chalmers

Further reading:

Johansson, D., Rootzen, J., Berntsson, T. and Johnsson F., ”Strategies for CO_2 abatement in the European Petroleum Refining Industry”, to be submitted for journal publication.

Rootzén, J., Kjärstad, J. and Johnsson F., 2010, “Prospects for CO_2 capture in European Industry”, accepted for publication in Management of Environmental Quality, Vol. 22 No. 1.

43

Biomass gasification for hydrogen production in refineries

An assessment of integrating a biomass gasifier to produce hydrogen in a refinery in comparison with a conventional steam reformer shows that if biomass is considered as an unlimited resource biomass gasification concepts have potential to reduce CO_2 emissions. However, if biomass is considered as a limited resource, which is a likely future scenario, all the studied concepts point to an increase in CO_2 emissions.

This chapter is a summary of a gasification study presented in Johansson et al., 2010.

One example of integrating biomass in the fossil fuel-based oil refinery industry is to produce hydrogen through biomass gasification instead of producing hydrogen from a conventional natural gas steam reformer. Biomass gasification for hydrogen production is interesting for several reasons:

- Several factors will ensure an increasing demand for hydrogen in the future, including increasing demand for lighter petroleum products (e.g., diesel), decreasing demand for gasoline, the tightening of sulphur specifications, and increasing use of heavier crude oil
- Increasing concerns related to CO_2 emissions and increasingly stricter reduction targets are incentives for novel solutions
- Biomass gasification is a renewable alternative that could possibly reduce CO_2 emissions

PROCESS INTEGRATION AND EVALUATION WITH FUTURE MARKET SCENARIOS

To evaluate the CO_2 impact of integrating a biomass gasifier as opposed to a steam reformer, the results from simulation studies for different gasification technologies have been combined with process integration studies using the Pinch Analysis method and evaluated using future energy marked scenarios (see Chapter 8 in the *Methods and Models* book).

The approach creates a system boundary around the specific refinery but the CO_2 emissions for different integration possibilities are evaluated taking into account that the net energy streams leaving or entering the system are assumed to cause a change in the surrounding energy systems (Figure 43.1).

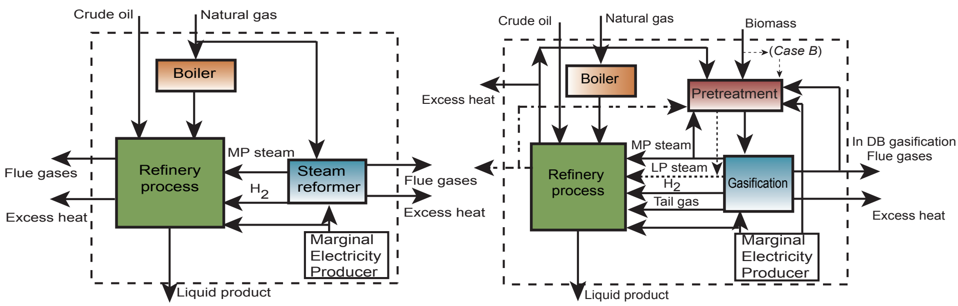


Figure 43.1. Main energy and material streams in a refinery with a steam reformer (left figure) and with a gasification plant (right figure), covering the increased H_2 demand.

EVALUATING THREE DIFFERENT GASIFICATION TECHNOLOGIES WITH DIFFERENT FEEDSTOCKS

The system boundary is around the refinery, i.e., for the biomass gasification case, this includes drying, pre-treatment, cleaning, and upgrading of the syngas (Figure 43.2). The case refinery in this study is a simple refinery with a crude capacity of 5 Mtonnes/year. The main process units are the crude distillation unit, the catalytic reformer unit, a light gas oil hydro treatment unit and a mild hydro cracker unit, which recently has been rebuilt to operate partly on renewable feedstock (tall oil) to produce diesel. Since biomass gasification is most likely to be commercialised after 2020, a future scenario for the refinery energy balance is used, which is based on decreased demand for gasoline, increased demand for diesel, and increased use of renewable feedstocks. The basis for the calculation was H_2 production of 16000 Nm^3/h and the key data for the calculations were taken mainly from the literature (Andersson, 2007; Larsson, 2010; Rohdin, 2008; Hamelinck and Faaij, 2002).

The following gasification concepts were included and evaluated:

- Atmospheric, Double Bed gasification (DB)
- Pressurised, Oxygen-blown, Circulating Fluidised Bed gasification (CFB)
- Pressurised, Oxygen-blown, Entrained Flow gasification (EF)

An average biomass mixture was used as feedstock in the DB and the CFB gasifiers. Due to difficulties associated with the feeding of biomass powder into the EF gasifier, torrefied biomass and pyrolysis oil were used in this gasifier.

The CO_2 effect is evaluated using future energy market scenarios (created by Axelsson and Harvey, 2010) with two marginal producers of electricity:

- Scenario 1: Coal power plant (679 kg CO_2/MWh_{el})
- Scenario 2: Coal power plant with CCS (129 kg CO_2/MWh_{el})

Two cases involving the evaluation of biomass availability are used:

- Case A: Sufficient biomass is available, i.e., the usage of biomass is CO_2 neutral.
- Case B: Biomass is considered to be a limited resource, i.e., sufficient biomass is not available to substitute all fossil fuels. Consequently, marginal users of biomass are coal power plants, and 336 kg CO_2/MWh is allocated to the biomass user.

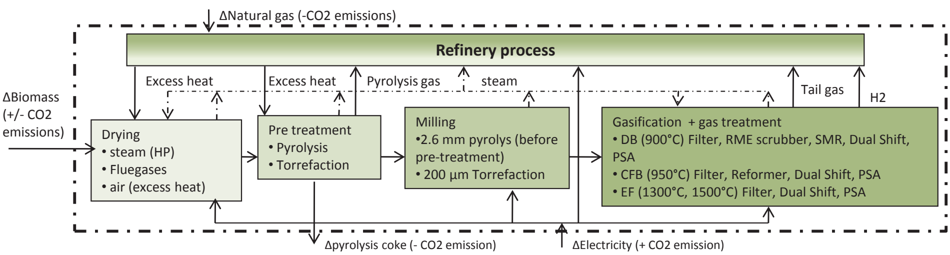


Figure 43.2. The evaluated system, including the boundaries and assumptions. Only streams that change in comparison with the reference case (refinery + SMR) are included.

THE CO_2 CONSEQUENCE DEPENDS ON HOW BIOMASS IS EVALUATED

The potential for CO_2 emission reduction associated with integrating a biomass gasifier for H_2 production instead of a conventional natural gas steam reformer depends heavily on how biomass is evaluated. The results show that if biomass is considered to be an unlimited resource (Case A), all biomass gasification concepts have negative CO_2 emissions compared to a conventional steam reformer. In this case, an entrained flow gasifier with pyrolysis oil gives the largest CO_2 reduction (Figure 43.3). However, the results show a net increase in CO_2 emissions for all the biomass gasification concepts when biomass is limited, i.e., the marginal user of biomass is coal power plants (Case B).

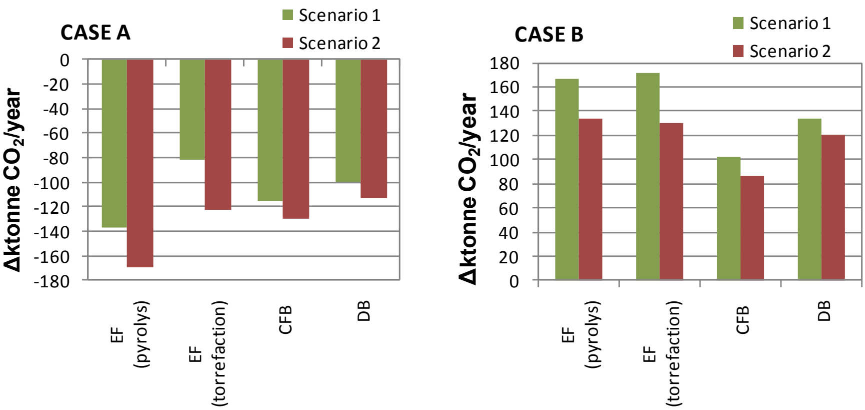


Figure 43.3. Left panel shows the results when biomass is considered to be an unlimited resource (Case A). The right panel shows the results when biomass is considered to be a limited resource (Case B). The CO_2 emission levels are relative to those of a steam reformer.

The results show that assumptions regarding marginal production of electricity and biomass availability strongly affect the CO_2 emissions balance for integration of biomass gasification for H_2 production in an oil refinery. When the biomass is changed from being an unlimited resource to a limited resource, the biomass gasification concepts change from a decrease in CO_2 emissions to an increase of in CO_2 emissions. Therefore, in the future when biomass is a limited resource, biomass in the global CO_2 emission perspective will be, in this case at least, more suited to co-firing in a coal power plant than for hydrogen production in a refinery.

For more information:

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Further reading:

Johansson D., Franck P-Å., Berntsson T., 2010, A process integration analysis of hydrogen production from biomass in the oil refining industry, Proceeding of the 19th International Congress of Chemical and Process Engineering and 7th Congress of Chemical Engineering 2010.

44

Future end use energy demand in the European building stock

Efficiency improvement in the building stock is a key issue in attempts to reach climate and energy goals. If energy efficiency was frozen at today's level, expansion of the building stock and other increases in standards would increase energy end use by almost 70% by 2050. Continuing efforts at efficiency along the present rates could stabilise energy end use. A reduction consistent with the EU's 20% efficiency improvement target for the year 2020 is profitable in an overall analysis, but needs very forceful policy for success.

The demand side is the driver of the energy system. The work presented in this chapter concerns the buildings sector (dwellings and service buildings, including both commercial and official buildings) and the energy needed for space heating, water heating, cooling, and cooking, as well as for powering appliances and other electrical equipment. The purpose is to provide a comprehensive description of the building stock and its energy use in the EU27 countries, and to develop a working tool that can be used to introduce key assumptions con-cerning development up to the year 2050, which would enable calculation of the future end use of energy for this sector.

DATA AND WORKING TOOL FOR THE BUILDING STOCK

The analysis of the building stock requires data for floor areas, levels of energy end use, increases in standards, and efficiency improvement options. The major part of the data applied in the present analysis derives from the GAINS online database (IIASA, 2010). This database contains a comprehensive dataset on the building stock in the EU27 and other countries, with data for the present stock as of 2005, as well as information on the possible future development of the stock up to 2030. All the data in GAINS is derived from pan-European sources. When available, national data (e.g., for Sweden) has been used instead of the GAINS data. In general, the GAINS database is very useful, in that it contains a full dataset for all countries with consistent definitions, and it is used as the basis for many of the EU Commission's studies and official assessments.

Separate calculations were made for eight countries, including the largest countries of the EU, namely France, Germany, UK, Italy, Poland, Spain, Ireland, and Sweden. These eight countries represent about 75% of the energy use in the EU. The other EU countries were grouped together as one unit, so the sum gave the results for the EU as a whole. All the calculations were executed in an Excel-based model developed for the Pathways project (see Chapter 23 in the *Method and Models* book).

BASIC DEVELOPMENT OF THE STOCK

End use energy demand has three main drivers: growth in the building stock, increase in standards (see below), and energy efficiency development. The growth of floor area is expressed as annual rates for newly built areas and demolished areas according to the GAINS database. Thus, these rates include population growth, as well as increased floor area standard per inhabitant or employee. These rates differ between countries, with an average new building area rate of about 1% per year and an annual demolition rate of 0.14%. These assumptions are common to the three scenarios presented in this chapter (see further below), and result in an almost 40% increase in total floor area by 2050, as compared with 2005 (Figure 44.1).

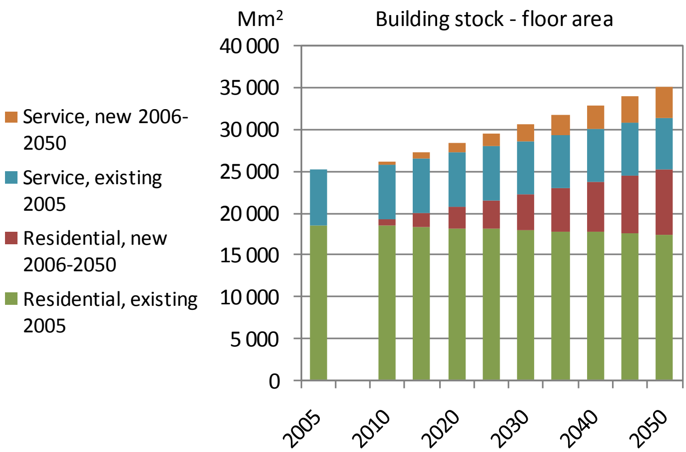


Figure 44.1. The development of the European building stock is the same for the Baseline, Market, and Policy scenarios.

In the year 2050, about 33% of the total floor area will be in "new" houses (built after 2005). In the long run, the share of new buildings is important, since they have a much lower demand for energy, especially after implementation of the so-called recast of the Energy Performance of Buildings Directive (EPBD), which imposes a "nearly zero" energy demand on new buildings after 2020. However, in general, the biggest potential for energy reduction lies in retrofit measures for the existing stock, both in the short-term and long-term.

CAN ENERGY EFFICIENCY MEASURES OFFSET THE INCREASE IN STANDARDS?

In the analysis, one can distinguish an increase in standards (higher demands for service, such as higher indoor temperature or more TV sets per m^2) from pure energy efficiency measures (e.g., insulation that enables a specified indoor climate using less energy or the same type of TV with lower electricity consumption). Although the GAINS database makes this distinction, it is generally difficult to interpret available statistics in this way. Analyses made in Sweden suggest that the interaction between efficiency and standard increases often result in an almost constant total energy use, as ever-increasing affluence is balanced by higher energy performance levels of buildings, appliances, and equipment (Göransson, 2010). In countries such as Sweden, the standard for space and water heating is not likely to increase significantly (all rooms are heated, and the indoor temperature is high already). In other countries, there still exists demand for a better indoor climate, which needs to be met. In contrast, for electrical equipment, the demand for new devices appears to be limitless. Still, if these new devices are more energy efficient, electricity use due to the standard increase might be offset by technical developments, regulations or wiser use.

THE SCENARIOS – PENETRATION OF EFFICIENCY MEASURES IS THE MAIN DIFFERENCE

Several assumptions have been applied in the scenario analyses. In general, separate values have been used for the individual countries. Table 44.1 presents the average values applied in the analyses.

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.

Table 44.1. Assumptions for the parameters of the model for the different scenarios.

	Baseline	Market scenario	Policy scenario
New construction, demolition of buildings	Same for all scenarios. Measured as heated floor area. Average rate of new dwellings is 0.92%/yr, as compared with existing stock, 1.2%/yr for service buildings. Demolition average is 0.14%/yr.		
Standard increase * Space heating, water heating and cooking	Same for all scenarios. * Dwellings, 0.4%/yr; service buildings, 0.39%/yr in existing stock. Almost the same for new houses built in period 2005–2050.		
Standard increase * Electricity	* Dwellings, 1.2%/yr; service buildings, 1.12%/yr in existing stock. Same for existing stock and houses built in period 2005–2050.		
Efficiency improvements *space heating, water heating, and cooking	No further efficiency measures after 2005 in existing stock. No further measures in new houses after they are built.	* Dwellings: existing, 0.71; new, 0.63%/yr. Service buildings: existing, 0.78; new, 0.64 %/yr.	* Dwellings: existing, 2.63; new, 2.61%/yr. Service buildings: existing, 2.86; new, 2.75%/yr.
Efficiency improvements *electricity		* Dwellings: existing, 0.50; new, 0.50%/yr. Service buildings: existing, 0.65; new 0.56%/yr.	* Dwellings: existing and new, 2.52%/yr; Service buildings: existing, 2.85; new, 2.53%/yr.
Specific energy use in new buildings	New houses built until 2050 have the same level as houses built in 2005. Average for EU is around 100 kWh/m^2 for space and water heating	Much stricter building codes introduced following the recast of the EPBD. However, individual interpretations by member states. Codes often express requirements in primary energy. Assumptions made here are based on an analysis of the eight included countries. If expressed as *useful* energy for space and water heating, the average is assumed to be around 40 kWh/m^2 in 2020. The same level is assumed after 2020. Electricity demand from GAINS: average of 23 kWh/m^2 for dwellings, and 64 kWh/m^2 for service buildings.	

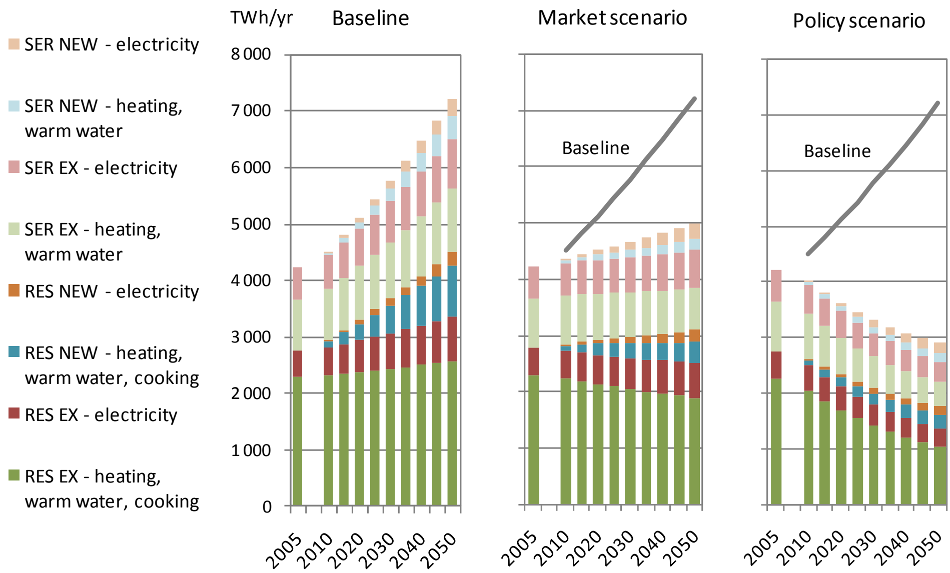
The above assumptions influence the calculation of *useful energy* of the buildings. The amount of *final energy* further depends on the fuel mix (heating system) and the conversion efficiencies of boilers, heat pumps etc. The Baseline scenario is a fuel mix that is assumed to develop following the historical trends (with some limits on the oil share), and assuming that conversion efficiencies remain as they were in 2005. In the Market scenario and the Policy scenario, fossil fuels are almost eliminated by 2050. The applied market share of district heating is taken from other studies in the Pathways project (see Chapter 32). The Market scenario has a big share of district heating and electricity-powered systems (heat pumps), while the Policy scenario has less of these components but uses more biomass.

The main difference between the three scenarios concerns the rate of energy efficiency measures, as shown in Table 44.1. In the Baseline scenario, no further efficiency improvements occur. This obviously results in increasing demand, which in this case is driven by the growth of the stock and the standard increase. The Market scenario focuses on measures for energy supply and distribution, rather than on the demand side. Because of this it is assumed (Table 44.1) that further development of energy efficiency will follow the present trends set by autonomous technical development and policy measures. This corresponds to the business-as-usual case in the Primes model, version 2007 (EU, 2007), which reflects development in line with demand side action typical of recent years. The Policy scenario assumes that the EU target of 20% improvement in efficiency from 2005 to 2020 will be fully achieved. Presently, the European Commission aims to measure this from the Primes 2007 level (ibid), so the end use energy in the Policy scenario is set at 20% below the Market scenario in 2020. The same rate is assumed beyond 2020. (Note: The Policy scenario here analysed assumes a 20% reduction in final energy. The EU efficiency goal is defined in terms of primary energy. This can however only be evaluated in a synthesis that includes also the energy supply and distribution system, see page 11).

OVERALL RESULTS

The overall results of the calculations are presented in Figure 44.2. The Baseline scenario (left panels in the figure) illustrates the development of energy end use as a result of increasing standard demands for floor area and energy services, when energy efficiency is maintained at current levels. By 2050, the floor area will increase by almost 40%, but the energy end use will be almost 70% higher than it was in 2005. The Market scenario calculations suggest that total *useful energy* will increase moderately (by 18%) over the studied period. The large increases in floor area and standards are balanced by continuous efficiency improvements in the remaining stock, and an increasing share of new buildings with very low energy demand. In terms of *final energy*, there will be a 14% reduction by 2050, since fuels will be replaced with district heating and heat pumps. The Policy scenario will require a massive effort on the demand side to reach the calculated end use reduction (set at 20% lower than the Market scenario by 2020) while the demand for floor area and standards will increase continuously. The Policy scenario calculations suggest that the final energy by 2050 has to be almost 50% lower than the 2005 level.

Overall results – useful energy



Overall results – final energy

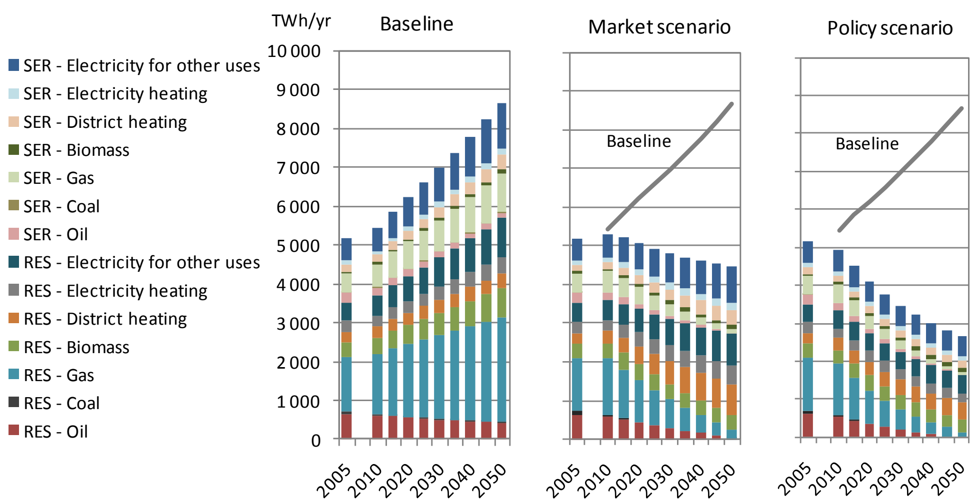


Figure 44.2. Development of the energy demand of the European building stock (TWh/yr) in terms of useful energy demand by end uses (upper panels) and final energy by fuels (lower panels). RES = residential, SER = service buildings, EX = existing in 2005, NEW = built 2006-2050.

Some characteristics of the demand side action are given below. Once again, it is important to note that the assessment against the EU goals for reductions in CO_2 emissions and primary energy can only be finalised after including measures from the energy supply sector.

DEMAND SIDE ACTION - THE ENERGY EFFICIENCY GAP

Several studies have indicated possible energy demand reductions in the building sector of around 30% to the year 2020, if all profitable measures are implemented (Levine et al., 2007). The same is stated in the European Commission's studies since the Green Paper for the efficiency goal was published (European Commission, 2006). This refers to what is profitable for house owners and tenants. In a socio-economic analysis that includes all environmental impacts, the level might even be higher (SOU, 2008:110).

However, it is difficult to accomplish energy efficiency measures on the demand side, as this involves millions of decision makers, often non-professionals, who have to make billions of decisions. There are many uncertainties and options, which are difficult to evaluate for those who seldom work with energy questions. This is in contrast to carrying out activities in the energy supply sector, in which the projects are generally much larger, a limited number of decisions are needed, and these decisions are often made by professionals. So, not all of the profitable measures on the demand side (according to the overall studies) are likely to be implemented. This is the so-called energy efficiency gap (Jaffe et al., 1994), which refers to the difference between the efficiency potential if each and every profitable measure according to an overall analysis is to be accomplished (which is an ideal situation) and how much of this is actually carried out.

The difference between the Market scenario and Policy scenario calculations is illustrative of the efficiency gap. The Market scenario roughly reflects what is done without additional pressure on the demand side, while the Policy scenario with its imposed 20% energy reduction represents a conservative estimate of utilising the profitable potential. Table 44.2 shows that the difference or gap could amount to about 900 TWh in 2020 and about 2100 TWh in 2050. Useful energy is used, since measures taken in the buildings are considered, excluding the impacts of possible fuel shifts.

WHY IS THE ENERGY EFFICIENCY GAP SO LARGE?

In Sweden, only around 15% of the ideal efficiency potential has been achieved in recent years (SOU, 2008:110). Why is the remaining 85% not realised? Analyses have revealed (ibid) the following reasons and obstacles: lack of knowledge and competence; uncertainty regarding function, real saving impact etc.; lack of time; other issues having higher priority; transaction costs (it takes time to seek information about the measures, to procure, follow up etc); high demand for

Table 44.2. Total useful energy (TWh), difference between Market and Policy scenarios.

Total useful energy (TWh)	2005	2020	2050
Market Scenario	4200	4500	5000
Policy Scenario	4200	3600	2900
Difference		900 (20%)	2100 (42%)

Return On Investment; financing problems; "split incentives"(in which one part is responsible for the investment, while the other part pays the energy bill); and a facility management organisation that does not encourage energy efficiency improvements. Many of these obstacles can be overcome, some with government policy measures and some with initiatives from the facility management sector and similar actors. However, it would be unrealistic to expect that one could bridge the whole energy efficiency gap.

Considering the typical features and problems of the demand side, it must be recognised that achieving larger reductions than those set out in the Market scenario will be difficult. The EU has acted boldly and forcefully in mandating strict demands for new construction, and in setting energy performance limits for a number of appliances in the Eco Design Directive (EU, 2009). However, the remaining major challenge is in realising the potential of ordinary construction and installation measures in the existing stock. So, equally forceful restrictions and policy measures must be implemented also on these areas (for example, to seize the opportunity when a major renovation of a building is made). This is necessary if the reduction levels listed in the Policy scenario are to be achieved.

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45

Energy efficiency strategies in the residential building stock

Demand-side energy efficiencies and CO_2 mitigation strategies in the existing stock of the residential sector were analysed for the Baseline, Market, and Policy scenarios up to year 2050. A technical and economic assessment of certain energy-saving measures was performed, providing outputs for end-use demand, final energy demand, and CO_2 emissions. The costs, potential energy savings, and avoided CO_2 emissions related to the application of such measures were estimated. Application of the measures studied could reduce the final energy demand and associated CO_2 emissions of the Swedish residential sector by 70%, largely in a cost-effective way. However, such improvements will not happen spontaneously but will depend on indirect costs and market realism. Therefore, further work is required to arrive at a more comprehensive assessment of the best actions to reduce the energy demand and CO_2 emissions of the Swedish residential sector.

Methodology

To assess energy savings and CO_2 mitigation potentials, and thus the related costs in the existing building stock, a methodology and a so-called bottom-up engineering model, the ECCABS model, were developed (for a more detailed explanation of the methodology and model see Chapter 14 in the *Methods and Models* book and Mata et al., 2010c). The Baseline, Market, and Policy scenarios were examined using this model. These Pathway scenarios relate to the comprehensive pathways proposed for the Pathways Project (as described on page 5). Outputs from other models developed within the Pathways Project, such as ELIN and EPOD, (see Chapter 11 and Chapter 12 in the *Methods and Models* book), were used as inputs to describe the Market and Policy scenarios, so as to include synergies between the energy systems and to ensure the quality of the results obtained. The methodology was also used together with a top-down approach (see Chapter 19 in the *Methods and Models* book), to provide a comprehensive overall assessment of the energy efficiency and CO_2 mitigation strategies in the European existing building stock.

POTENTIAL ENERGY SAVINGS AND AVOIDED CO_2 EMISSIONS

An analysis of the Swedish existing residential building stock reveals that annual savings of 53.4 TWh could be achieved by applying all measures aggregated according to cost-efficiency, with the cheapest first (see Mata et al., 2010a, 2010b for details). In total, twelve types of measures for energy savings were assessed, the measures and obtained technical saving potential are listed in Table 45.1. The savings arise from both applying the measures on an individual basis ("Individual") and applying the measures on an aggregated basis ("Aggregated"), since the effects of one measure might influence a different measure (Mata et al., 2010a, 2010b). The different measures imply annual energy savings of between 0.3 TWh and 13.3 TWh. The measures that provide the largest savings are those that involve heat recovery systems and those that involve a reduction of indoor temperature. The upgrading of the U-value of cellars/basements and the U-value of façades (different types), and the replacement of windows provide an annual energy saving of about 7 TWh each. No changes in the energy supply system or the fuels used in the buildings' systems are assumed in the calculations of these potential savings.

Figure 45.1 shows the final energy saved by fuel (TWh/yr) for each of the "Individual" energy saving measures studied. For the measures that would only affect demand for space heating (measures 1 to 4 and 12 in Table 45.1), the share of the fuels in the calculated savings correspond to the average fuel mix for space heating of the dwellings in which the measure can be applied. Measures 5 and 6 increase electricity consumption, although the increase is smaller than the savings obtained for space heating and is therefore not visible in Figure 45.1, since a part of the space heating demand is currently provided through electricity (especially in single-family dwellings), including both electrical heating and heat pumps. Measures for reducing electricity demand for lighting and appliances (measures 7 and 8) imply that less heat is released to the indoor air, which in turn increases the demand for space heating (this is reflected as negative values in Figure 45.1). Nevertheless, the implementation of measures 7 and 8 would generate savings in total energy use.

In contrast, the application of measures 7 and 8 increases CO_2 emissions because the production of the electricity saved is less CO_2-intensive than the fuel mix used for space heating. This effect can be seen in Figure 45.2, where the potential reductions in CO_2 emissions and final energy are given as percentages of the baseline and for each of the energy-saving measures studied for the Swedish residential stock. It should be mentioned that the level of CO_2 emissions from the Swedish building stock is generally low, considering that district heating, as well as electricity production, is more or less CO_2-free in Sweden. For instance, only 15 gCO_2/kWh are in average emitted for electricity production (Chapter 10).

Table 45.1. Results of energy-saving potentials (TWh/yr) in the Baseline scenario.

Measure No	Measure description	Individual	Aggregated
	Total	**63.2**	**53.4**
1	Change of U-value of cellars/basements	5.3	4.4
2	Change of U-value of façades (different types)	7.2	6.1
3	Change of U-value of attics/roofs (different types)	2.7	2.3
4	Replacement of windows (U-value)	6.5	5.5
5	Ventilation with heat recovery, SFD	12.0	10.2
6	Ventilation with heat recovery, MFD	9.6	8.1
7	50% reduction in power for lighting	0.3	0.3
8	50% reduction in power for appliances	1.0	0.9
9	Reduction of power used for the production of hot water to 0.80 W/m^2 (SFD)	2.6	2.2
10	Reduction of power used for the production of hot water to 1.10 W/m^2 (MFD)	2.1	1.8
11	Change of electrical power to hydro pumps	0.6	0.5
12	Use of thermostats to reduce indoor air temperature to 20°C	13.3	11.2

SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling.

The modelling results indicate that if all measures are implemented, the total annual potential for CO_2 reduction is 3.5 $MtCO_2$, corresponding to 70% of all CO_2 emissions from the Swedish residential sector. However, as indicated above, this is a small reduction and will only play a minor role in the overall strategy for reducing CO_2 emissions from the Swedish energy system. In Sweden, the CO_2 emissions of the residential sector represent only 10% of the total emissions, while in the EU27, the average share of the residential sector in the total level of national emissions is 22% (Odyssee, 2010).

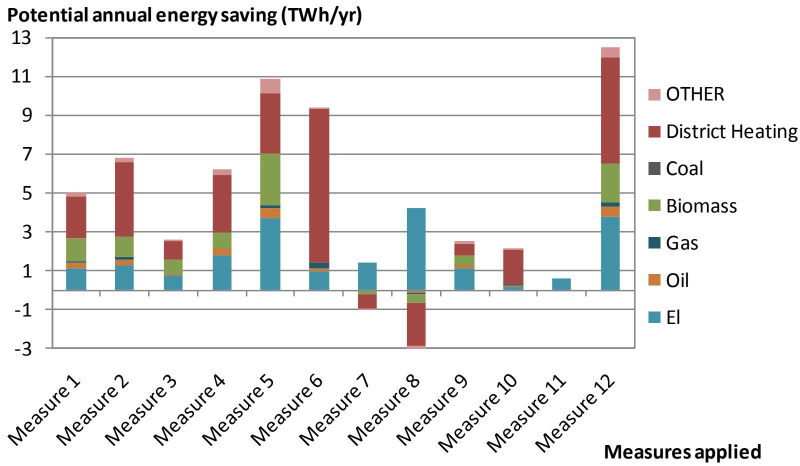

Figure 45.1. Final energy saved by fuel (TWh/yr, y-axis) for each of the energy-saving measures studied (x-axis) for the Swedish residential stock. The measures are represented by the measure number; detailed descriptions of the measures are presented in Table 45.1. Negative values represent increases in fuel use.

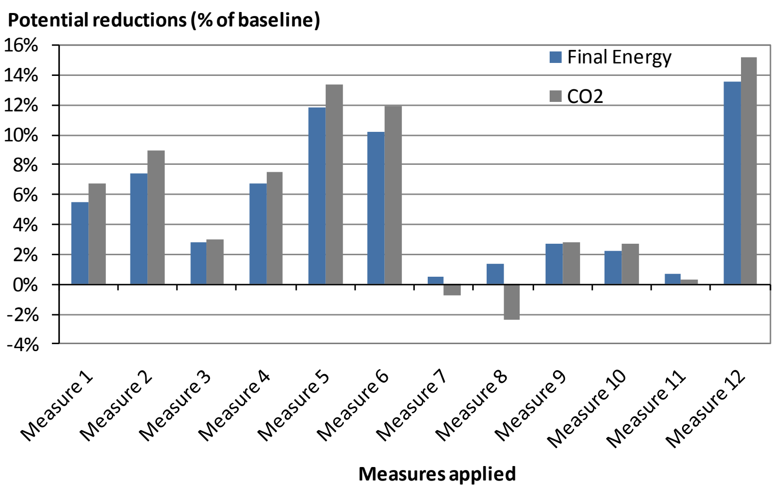

Figure 45.2. Potential reductions in the final energy and CO_2 emissions, shown as percentages of the baseline for which no measures are applied (y-axis), for each of the energy-saving measures studied (x-axis) for the Swedish residential stock. The measures are represented by the measure number; detailed descriptions of the measures are presented in Table 45.1.

COSTS IN RELATION TO ENERGY SAVINGS AND CO_2 EMISSION REDUCTIONS

Investments amounting to €5.7 billions are required to achieve the aggregated technical potential savings of 53.4 TWh per year (if all measures assessed in the present study are implemented), representing a 55% reduction in energy use in the residential sector. The current goals for the specific energy use in Sweden are a 20% reduction by 2020 and a 50% reduction by 2050, compared to the reference year of 1995, as stated in the program of the Swedish Environmental Objectives Council (EOC, 2009). The results indicate that an investment of €0.5 billions per year is required to meet the 2020 targets, and that €3.5 billions would have to be invested annually to achieve the 2050 targets (Figure 45.3). Energy use in the residential sector in 1995 was almost the same as that in 2005. For the 2020 target, the investment would correspond to €2 per m^2 and year, i.e., for a dwelling of 100 m^2, €200 would have to be invested annually until the year 2020. For the 2050 target and for the same dwelling, €1000 would have to be invested annually from now until the year 2050. Only direct costs, i.e., for investment, operation, and maintenance, are considered in these estimations (see Mata et al. (2010a, 2010b) for details of the cost calculations).

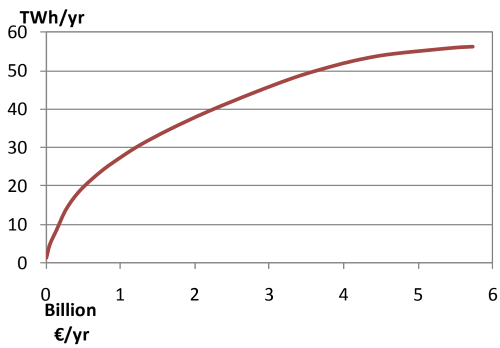

Figure 45.3. Correlation between annual investment required (x-axis) and potential energy savings (y-axis) for the Swedish residential stock according to the simulation results.

For the Baseline scenario, the average cost for the energy efficiency measures investigated is -1.3 €cent/kWh/yr (range, -29.5 €cent/kWh/yr to 33.2 €cent/kWh/yr; Table 45.2. The profitable measures (indicated as negative costs in Table 45.2) are those that depend on both technical improvements (for example, more efficient lights and appliances, installation of thermostats) and behavioural changes (such as lifestyle changes). For lighting and appliances, the equivalent annual cost of a reduction in electricity consumption is assumed to be zero, since it is assumed that there will not be any other alternatives in the future than to buy more efficient appliances and lighting. For example, in Sweden, only energy-certified appliances are sold, and the sale of incandescent light bulbs are banned in the EU. The results suggest that heat recovery measures could be applied at a relative low cost (€0.01-€0.03 /kWh/yr), especially for single-family dwellings, in which heat recovery systems are not usually installed. As for the retrofitting of the envelope, the results show that replacing windows is more cost efficient than retrofitting of the façade (Table 45.2), even if the energy-saving potentials of these measures are similar (Table 45.1).

The average abatement cost for the twelve measures analysed in the Baseline scenario is 4200 €/tCO_2. The high costs are obviously due to the characteristics of the current Swedish energy supply system, which as mentioned above, is already very low in CO_2 intensity. Nevertheless, CO_2 emissions in the Swedish residential building stock could be reduced by 36% in a cost-effective way.

Table 45.2. Annual costs of energy efficiency measures from the simulations in this work (€cents/kWh). The descriptions of the measures are abbreviated; see Table 45.1 for a full description.

Measure No	Measure description	Baseline	Market	Policy
	Average	**-1.3**	**-5.1**	**-2.4**
8	-50% Lighting	-29.5	-38.6	-28.9
7	-50% Appliances	-28.4	-37.2	-28.0
12	Reduction of indoor tempera-ture	-6.3	-8.0	-7.8
5	Heat Recovery SFD	0.1	-1.5	-1.2
9	Hot Water SFD	1.1	-0.7	-0.4
10	Hot Water MFD	2.1	0.6	0.7
6	Heat Recovery MFD	3.1	1.7	1.6
4	Window Replacement	3.4	1.0	1.4
3	Retrofit Attics/roofs	11.7	9.3	9.7
11	Hydro Pump Replacement	21.1	18.6	19.8
1	Retrofit Basements	26.1	23.8	24.0
2	Retrofit Façades	33.2	30.9	31.2

SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling

POLICY AND MARKET SCENARIOS

For both the Market and Policy scenarios, the implementation of energy-saving measures is more profitable than in the Baseline scenario (see Table 45.2), as the energy prices in the former two scenarios are higher. However, improvements in energy end-use efficiency that have been reported to be economically efficient are not always undertaken by consumers. The elasticity of the demand for energy for space heating in Sweden (1970 to 2005) was found to be - 0.16, which means that for a 1% increase in energy prices there is only a 0.16% fall in energy demand (See Chapter 46), which confirms the existence of the so-called energy efficiency gap (i.e., the difference between the actual level of investment in energy efficiency and the higher level that would be cost beneficial from the consumer's standpoint; Howarth, 2004). If one assumes that only profitable measures will be applied by 2050, the energy demand in the Swedish residential building stock would be reduced by 35% in the Market scenario and by 36% in the Policy scenario. However, corresponding estimations using a top-down modelling approach suggest energy reductions in 2050 of only 22% in the Market scenario and 30% in the Policy scenario (see Chapter 46). Therefore, comparing the results of the bottom-up and top-down analyses, the efficiency gap can be quantified as 13% of the annual energy demand for the Swedish residential sector in the Market scenario and 6% in the Policy scenario. For a development similar to the Policy scenario, it is more likely that energy efficiency measures will be implemented, since such a scenario assumes direct policy measures targeted towards energy efficiency measures (although the success of such policy measures remains to be seen).

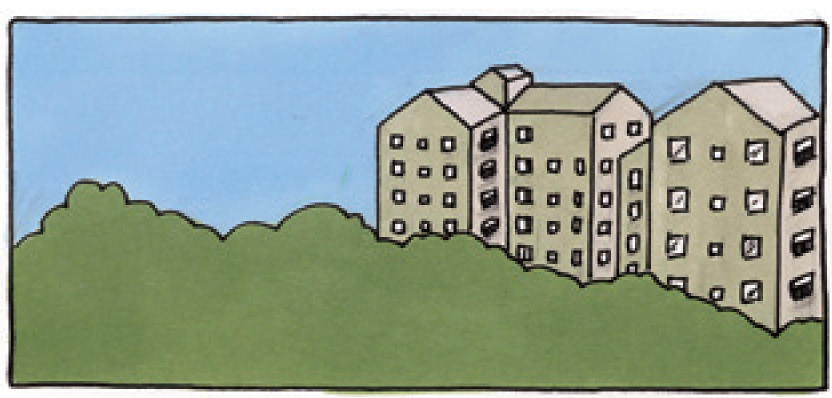

Table 45.3. Annual costs associated with potential reductions in CO_2 (€/tCO_2) for each of the measures considered in the present study. The descriptions of the measures are abbreviated; see Table 45.1 for a full description.

Measure No	Measure description	Baseline	Market	Policy
	Average	**4200**	**2600**	**3100**
8	Reduction of indoor temperature	-4575	-3959	-4112
7	-50% Lighting	-4417	-3907	-3944
12	-50% Appliances	-3784	-3707	-3918
6	Heat Recovery SFD	1210	632	756
5	Heat Recovery MFD	1388	220	398
10	Hot Water SFD	1401	693	800
9	Hot Water MFD	1847	524	690
4	Window Replacement	3237	1518	1890
3	Retrofit Attics/roofs	10457	7516	8304
11	Hydro Pump Replacement	14224	8544	11341
1	Retrofit Basements	22993	18527	19898
2	Retrofit Façades	27279	21501	23517

SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling

Table 45.3 shows the annual costs associated with potential reductions in CO_2 emissions (€/tCO_2) for each of the measures considered. In the Market scenario, energy prices are generally higher (especially for electricity), which increases the profitability of implementing these efficiency measures compared to the other two scenarios. The results obtained for the Policy scenario, show an intermediate level of profitability, which with respect to most of the measures, is still higher than that for the Baseline scenario. However, the levels of CO_2 emission reductions in the Policy scenario due to the application of the measures is lower than that in the other scenarios, since the average emissions associated with electricity production are higher in Market than in Policy, (marginal emissions are lower in Market than in Policy, see Chapter 10, nevertheless the energy saved cannot be accounted as marginally produced). The tougher CO_2 commitments in the Market scenario (due to higher demand) might lead to more pressure on the margin where prices are set. On the other hand, higher demand is likely to lead to more fossil fuels in the system, increasing average emissions.. Although this means higher profit levels for the measures that are cost-effective, it also results in higher costs per CO_2 emission avoided for the measures that are not cost-efficient. If one assumes that only the profitable measures (as obtained from this work) will be applied up to 2050, the CO_2 emissions in the Swedish residential stock would be reduced by 46% in the Market scenario and by 45% in the Policy scenario. These reductions are not much higher than the 36% potential reduction obtained for the Baseline scenario.

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Further reading:

Mata, É., Sasic, A., Johnsson F., 2010a ,Assessment of retrofit measures for reduced energy use in residential building stocks– Simplified costs calculation, Sustainable Building Conference SB10mad April 28-30, Madrid, Spain.

Mata, É., Sasic, A., Johnsson F., 2010b, Retrofitting measures for energy savings in the Swedish residential building stock – assessing methodology, Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference December 5-9, Florida, USA.

46

Future demand for space heating in buildings:

a top-down analysis

If the trends in energy demand for residential sector space heating seen in Sweden from 1970 to 2005 continue, total demand is predicted to fall from 52 TWh to 47 TWh by 2050. This fall will occur despite projected increases in average dwelling size and population size. This is because the unit consumption (kWh/m^2) of energy use for space heating continues to fall and its trajectory will offset increases in demand attributable to increases in average dwelling size and population size. These figures correspond to a reduction in unit consumption for energy for space heating from 125 kWh/m^2 to between 60 kWh/m^2 and 74 kWh/m^2. This fall can be amplified through higher energy prices and increased energy efficiency, to reduce the total to 37 TWh (60 kWh/m^2). However, the price elasticity of demand for energy for heating in dwellings has been found to be very low (-0.16), which means that improvements in energy efficiency brought about by direct regulatory intervention and incremental technical breakthroughs are of greater importance than energy price increases in bringing about reductions in energy demand.

This chapter presents the results of an assessment of the roles of energy prices, income, and general efficiency improvements in influencing energy demand for space heating in dwellings. These parameters are each measured on a national scale and thus provide the basis for a macroeconomic or top-down measure of future energy demand.

METHODOLOGY

An econometric-based model was developed that correlates three parameters to future unit consumption (kWh/m^2) of energy demand for space heating: future energy prices, trends in technical progress, and the lock-in effects of in situ heating systems and dwelling designs. The inclusion of the third parameter reflects the fact that switching heating systems or improving levels of thermal integrity in response to price increases is a slow process. Future average floor space per dwelling is related to levels of personal income, assuming that increased levels of income lead to larger dwelling sizes. In addition, projections of population increases have been included in the model (see Chapter 19 in the *Methods and Models* book for a description of the applied methodology).

An advantage of using a model that incorporates energy prices and personal income is that it provides a national economic perspective that is missing from bottom-up technological models. The model focuses on the influence of these economic forces on energy use, whereas bottom-up models focus on the impact of individual technologies. The present model attempts to quantify the known fact that economic forces have an influence on trends in energy demand. In this case, the top-down analysis complements a bottom-up study for Swedish dwellings (see Chapter 45), thereby highlighting what is known as the 'energy efficiency gap' (Jaffe et al., 1994), which is the historical difference between the technical potentials available for energy savings and the savings that are actually achieved.

The time series data used to calculate the floor areas and unit consumption functions were obtained from the OECD (Personal Income and Consumer Price Indices), IEA (Energy Carrier Prices), Odyssee database (Space Heating Demand), and other sources. The work was undertaken using the Excel software and the LINEST function to calculate price and income elasticities.

Three different scenarios were analysed: a Baseline, a Policy, and a Market scenario. These scenarios are linked to the comprehensive scenarios analysed in the Pathways project (as described on page 5 in this book), and are calculated for 5-year intervals from 2010 to 2050. In brief, the Baseline scenario is a reference scenario, while the Policy and Market scenarios include stringent CO_2 emission targets. The CO_2 reduction target is the same for the latter two scenarios. The Policy scenario incorporates substantial direct policy intervention to improve energy efficiency. In contrast, the Market scenario implies market-driven change, and therefore energy prices are expected to be higher than in either the Baseline scenario or the Policy scenario. The developments of energy prices for space heating used in the model are listed in Table 46.1; the values in parentheses indicate the carbon tax part of the total price. The same income scenario is employed for all three price scenarios. Growth of future income is set at 1.93% per annum (EC, 2008), without any adjustment for the current economic recession.

Table 46.1. Energy prices for residential sector customers to 2050, based on Axelsson and Harvey's (2010) wholesale prices for industry with adjustments for the residential sector to account for VAT, taxes, and distribution costs. Prices are normalised to 2005 prices. Prices are the weighted averages for energy calculated using EU (2007) projections for future energy demand in Sweden.

€/MWh (2005)	2010	2020	2030	2040	2050
Baseline scenario	122 (20)	82 (20)	85 (20)	71 (20)	71 (20)
Policy scenario	122 (20)	119 (25)	125 (28)	121 (38)	122 (54)
Market scenario	122 (20)	121 (30)	115 (50)	132 (60)	142 (80)

In the present project, the model was applied to Swedish conditions and data. However, future research will apply the model to other EU member states.

RESULTS AND CONCLUSIONS

For all the investigated scenarios, the average floor area per capita is calculated to grow from 51 m^2 to 60 m^2, based on the increases in personal income up to 2050. The population in Sweden is projected to grow from 9.3 million in 2010 to 10.7 million in 2050 (Eurostat, 2009). This will entail an expected 35% increase in total floor area, i.e., the floor area should increase from 471 millions m^2 in 2010 to 638 millions m^2 in 2050.

In the Baseline scenario, the combination of the assumed energy prices (shown in Table 46.1), a constant trend towards improved technical performance, and the effects of heating systems and dwelling designs in place will result in a reduction in unit consumption from 125 kWh/m^2 in 2010 to 74 kWh/m^2 by 2050. In the Market scenario, the assumed energy prices (see Table 46.1), combined with the same trend towards improved technical performance as in the Baseline scenario and the same effects of heating systems and dwelling designs in place should yield a unit consumption of 67 kWh/m^2 by 2050. In the Policy scenario, energy prices (see Table 46.1) combined with a 25% increase in energy efficiency over that of the Baseline and Market scenarios but with the same effect of heating systems and dwelling designs in place, should result in a unit consumption of 60 kWh/m^2 by 2050. These three levels of unit consumption combined with the predicted floor area for the year 2050 produce the totals for energy use for space heating shown in Figure 46.1.

In Figure 46.1, the result for year 2050 for the Market scenario is 10% lower than that for the Baseline scenario, while the corresponding result for the Policy scenario is 19% lower. Thus, based on the elasticities and coefficients calculated from the time series data for the effects of changes in prices, income, technical trends, and lock-in effects, it can be concluded that the introduction of carbon prices and efficiency legislation will accelerate a reduction in demand of at least 10% over business as usual trends. However, an examination of the individual effects of price changes, technical trends, and lock-in effects on unit consumption reveals that the influence of increased energy prices on promoting this fall in demand is minor. The continuous trends towards improved efficiency owing to technical developments and stricter regulations, as well as the delayed reaction to price effects caused by the lock-in effect of the existing heating systems stock and dwelling insulation levels, will have a far greater impact in all scenarios. This is because the price elasticity of the demand for energy for space heating has been found to be very low and very inelastic. The price elasticity of the demand for energy for space heating was found to be -0.16, which means that for a 1% increase in energy prices the fall in demand is only 0.16%. As this elasticity is calculated for a time series of data from 1970 to 2005, it is theoretically robust and reflects consumer reaction to the large price increases that occurred in the 1970´s due to the oil crises and the subsequent levelling-off of prices from the mid 1980´s onwards.

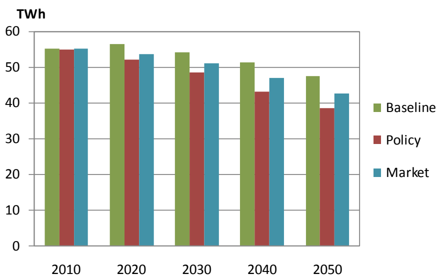

Figure 46.1. Future demand for energy for space heating in Sweden based on a Baseline scenario, an energy price increase scenario (Market), and a lower energy price increase plus legislated efficiency improvements scenario (Policy).

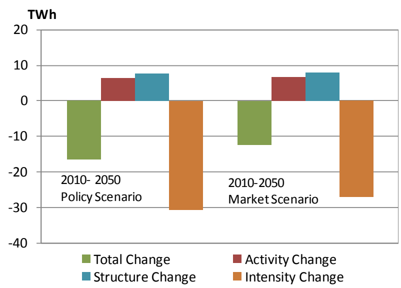

Figure 46.2. Index decompositions of the change in demand for energy for space heating in Sweden between 2010 and 2050, for an energy price increase scenario (Market) and a lower energy price increase plus legislated efficiency improvements scenario (Policy). The figure shows that the latter scenario results in a greater decrease in energy intensity, while in both scenarios, increases in population size and floor space per capita increase energy use.

Figure 46.2 shows that total energy use for space heating in both the Policy and Market scenarios decreases between 2010 and 2050, despite increases in population and floor space per capita. The reduced intensity caused by improvements in energy efficiency and increased prices offset the impact of the increases in population and floor space and cause an overall decrease in energy use. This intensity parameter is measured as energy per m^2, and its trajectory is an established indicator of energy efficiency. In the model, it is affected by price and efficiency trends. However, it is also influenced by indoor temperature and duration of heating, two parameters for which developments cannot be isolated in this model. Nonetheless, there are unlikely to be significant increases or decreases in these two parameters in Sweden, as most dwellings are heated 24 hours/day during the heating season and indoor temperatures are not expected to deviate significantly from the present average of 21.7 ^{o}C, unless there is a large increase in the diffusion of under-floor heating in bathrooms and halls. Therefore, the trajectory of the intensity bar in Figure 46.2 is mostly the result of efficiency improvements.

The decrease in space heating energy use due to higher prices and improved efficiency in the Policy scenario brings unit consumption to 60 kWh/m^2 by 2050. Prices would have to increase again and/or efficiency improvements would have to be greater in order to reduce these figures to below the average of 15 kWh/m^2 of delivered energy per annum, which would be necessary to bring the Swedish housing stock in line with the passive standard set by the Passive House Institute in Germany (Feist, 2010). Given however that 60 kWh/m^2 represents a reduction in unit consumption of more than 50% compared with the 2005 levels, this would be a significant achievement in itself. In addition, district heating is widespread in Sweden and from an energy systems perspective it may be more optimal in terms of cost to continue using distributed (waste) energy for heating. Thus, competition between end-use efficiency and supply-side efficiency could contribute to keeping energy use for space heating above the passive standard due to district heating being more cost-effective.

It can be concluded that total demand for energy for space heating in Sweden will not increase because of development of the economy but might be significantly decreased by a combination of increased prices and improvements in efficiency.

For more information:

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