Chapter 10
The System Value of CCS Technologies in the Context of CO_2 Mitigation Scenarios for Germany

Dag Martinsen, Heidi Heinrichs, Peter Markewitz, and Wilhelm Kuckshinrichs

Abstract This chapter analyses the system value of CCS in Germany within the context of consistent greenhouse gas reduction scenarios with and without the implementation of CCS technologies. The system value of CCS is determined using additional CO_2 avoidance costs that would occur if climate change mitigation targets were to be met without using CCS even though CCS technology was available. The development of important parameters, assumptions and energy- and climate-policy targets are represented in scenarios. The methodological basis for the scenario calculations is the bottom-up energy system model IKARUS. The energy economics results comprise energy and CO_2 balances, capacity development, and the costs of CO_2 reduction strategies. From this, the system value of CCS and the contribution of all sectors to it are derived.

Keywords System value • Energy system model • CO_2 avoidance costs

10.1 Introduction

Binding greenhouse gas reduction targets necessitate a huge range of greenhouse gas reduction measures covering all energy sectors as well as industry, trade, transport and traffic, and households. More than 40 % of global CO_2 emissions are caused by electricity generation in fossil-fired power plants. This is therefore of particular significance in the context of greenhouse gas reduction.

The German Federal Government has set CO_2 reduction targets of 40 % for 2020 and 80 % for 2050 in relation to levels in 1990. In addition to CO_2 reduction, German energy and climate policy comprises further ambitious targets. These include increasing energy efficiency and increasing the use of renewable energy.

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These targets themselves, as well as how to achieve them, must be taken into account when projecting the capacities of fossil power plants.

Current scenarios for the reduction of greenhouse gases in Germany show that CCS technologies can play an important role within the context of national greenhouse gas reduction strategies with binding reduction targets. Analyses show that for CO_2 reduction targets of more than 35 % (for 2030) the use of power plants with CCS can represent an attractive reduction measure from an economic perspective. Sensitivity calculations concerning investments, energy carrier prices, etc. show that this is a robust reduction measure (Martinsen et al. 2007).

Other scenarios deal with pathways of energy supply completely based on renewable energy (e.g. Krewitt et al. 2009 or DLR et al. 2012). The future usage of CCS technology is sometimes explicitly excluded. This is explained by the fact that CCS technologies are not commercially available and that they have been implemented on a power-plant scale today in no more than a few demonstration projects at best. In addition, it is often argued that the implementation of CCS technologies on a commercial scale will come up against considerable acceptance problems, and that the construction of CCS infrastructures for the transportation and storage of CO_2 appears unrealistic. Furthermore, it is often denied that there is a need for the implementation of CCS technologies, because, after all, when the political targets for energy efficiency and renewable energy have been met, a sufficient energy supply will be available.

This is where determining the system value of CCS technologies comes into play. The system value is a term that has been borrowed from the area of the economic analysis of environmental resources. It is calculated on basis of the difference between the values that individuals are willing to pay to ensure continued availability of a specific natural resource and the expected one of future usage. It is therefore a value for the system of being able to use the resource in future. In the case considered here, the reverse applies and the value arises for not using a technology. The system value therefore implicitly indicates the willingness to pay which is necessary should CCS technology not be used.

This chapter analyses the system value of CCS in Germany within the context of consistent greenhouse gas reduction scenarios with and without the implementation of CCS technologies. The development of important parameters, assumptions and energy- and climate-policy targets are represented in scenarios. The methodological basis for the scenario calculations is the bottom-up energy system model IKARUS.

The methodological approach and scenario design are explained in Sect. 10.2. The energy economics results are presented in Sect. 10.3. These comprise energy and CO_2 balances, capacity development, and the costs of CO_2 reduction strategies. From this, the system value of CCS can be derived. In Sect. 10.4, conclusions are drawn.

10.2 Methodological Approach and Scenario Design

10.2.1 System Value

The system value of CCS is determined using additional CO_2 avoidance costs that would occur if climate change mitigation targets were to be met without using CCS even though CCS technology was available (Bauer et al. 2009; Pietzcker et al. 2009; Manger et al. 2009). It basically represents a monetary value for refraining from using climate change mitigation technologies, and can be interpreted as a measure of the necessary willingness to pay for refraining from using this technology.

The system value of CCS technologies is not a statically given variable. It depends on numerous parameters and general assumptions, including first and foremost technical parameters such as the costs and potential of competing technologies, as well as targets for the reduction of CO_2 together with those for the use of other technologies such as renewable technologies, energy-efficient technologies, or nuclear energy. Figure 10.1 is a schematic demonstrating this correlation.

In a multi-option scenario (I), all technical options are allowed, and an energy mix is established which leads to CO_2 reduction with minimal costs. The more stringent the reduction targets, the higher the reduction costs. In an alternative scenario (II), the share of competing technical options must be higher, because CCS technologies are not permitted in this scenario. If we follow the assumption of increasing marginal costs of the technologies for CO_2 reduction, then for the given CO_2 reduction targets, the respective reduction costs in scenario (II) are higher. If the technical alternatives for substituting the use of CCS were further regulated, and existing fossil-fired power plants, for example, were only replaced by highly efficient new ones, the costs for a given CO_2 reduction would increase further. The reverse is also true that the costs for a given CO_2 reduction would be lower if

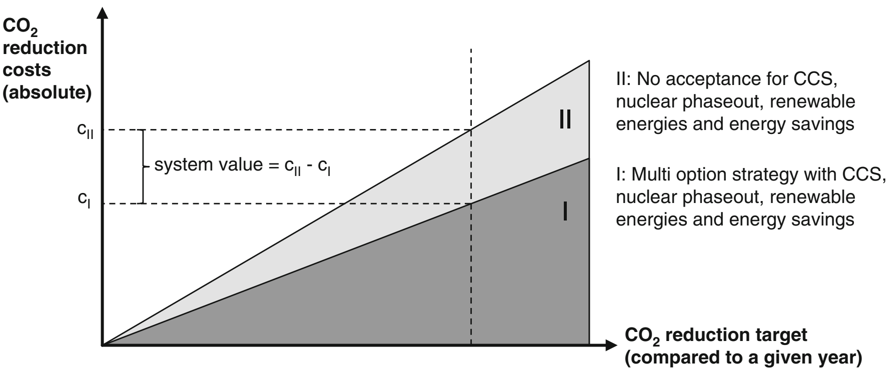

Fig. 10.1 Schematic of the system value of CCS technologies (Linearity used for the purpose of schematic representation)

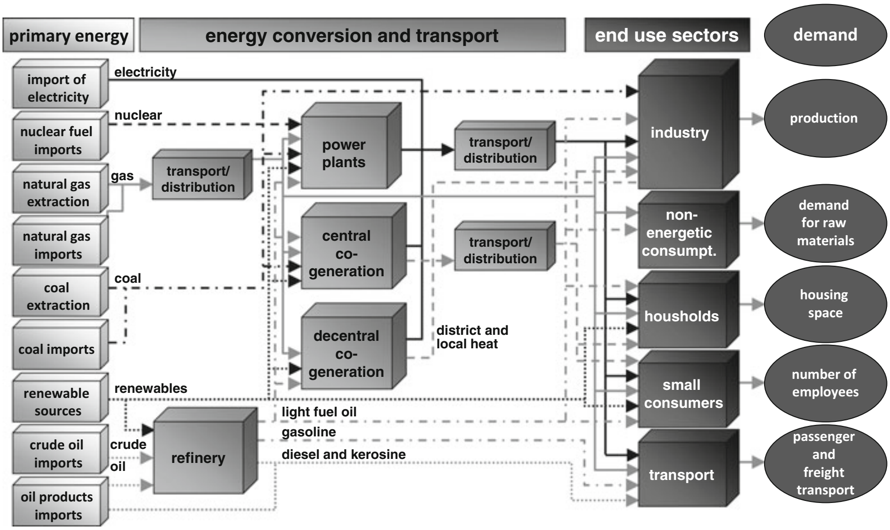

Fig. 10.2 Structure of the IKARUS energy system model (Source: Hake et al. 2009)

restrictions for the technical alternatives were to be relaxed, e.g. by extending the operating time of nuclear power plants.[1]

The respective CO_2 reduction costs of the two cases I and II shown schematically here are indicated by c_I and c_{II}. The associated system value is calculated as $c_{II} - c_I$.

10.2.2 The IKARUS Energy System Model

The scenarios were calculated with the energy system model IKARUS. IKARUS is a demand-driven bottom-up energy model, which represents the German energy system and depicts energy technologies in detail (Fig. 10.2).

It depicts the energy flows from the primary energy via the end-use energy to the demand governing energy consumption, and differentiates between the primary energy resources (domestic and import), conversion sector, energy transport, need for end-use energy in the fields of industry, non-energy consumption, households, small consumers, and transport and traffic, as well as demand, which is described by industrial production, energy-intensive production, living space, number of employees, and passenger and freight transport. Particular emphasis is on saving

[1] With regard to the use of nuclear energy, this aspect does not come into play. Both scenarios assume that nuclear energy will be phased out and that no nuclear power stations will produce electricity from 2023 onwards. On the other hand, CCS power plants will effectively only be available from 2020. See Sect. 10.3.

energy using technologies designed to increase energy efficiency by linking the demand and need for end-use energy.

The approach allows the definition of restrictions for the energy system, e.g. regarding the use of certain energy technologies. With respect to climate change mitigation, the emphasis is on defining CO_2 target values respectively upper limits. In principle, the approach would also allow an upper limit to be set for reduction costs.

The model calculates primary and end-use energy consumption, corresponding greenhouse gas emissions, the (necessary) capacity development of technologies, and reveals the total costs. The results for all variables are consistent with the scenario requirements, basic assumptions and technology data. They are reproducible and sensitivity calculations can thus be performed for the main assumptions and parameters.

10.2.3 Scenario Structure, Underlying Data and Basic Assumptions

The following outlines the main assumptions and framework upon which the scenarios are built. The scenarios cover the period 2005–2050.

For the period 2010–2050, it is assumed that the gross domestic product (GDP) increases by 1.4 %/a and that the population decreases by 2050 to around 77 million. Although the GDP is not directly incorporated into the model calculations, it sets the framework for the exogenously determined demand for energy services.

Figure 10.3 shows the demand over time of the most important areas of demand determining energy consumption. The development of energy services depends heavily on the sector being considered. While demand in passenger transport services remains almost constant, it is assumed that freight transport services almost double by 2050. The gross value added of industry also increases considerably (+84 % by 2050) and is characterized by structural changes in favour of less energy-intensive sectors. Here, steel and aluminium production would be particularly affected as would the cement industry. Living space increases moderately by 25 % in the period 2005–2050. The number of employees in the sectors of commerce, trade and services drops by around 17 % due to the underlying demographic development.

For CCS power plants and for power plants based on renewable energy, upper limits up to 2050 have been set in the model because their potential is limited by factors such as usable amounts of biomass and the maximal amounts of CO_2 that can be stored. For CCS, both new plants and the retrofitting of existing plants are considered. Figure 10.4 shows the maximal possible expansion of the capacity of these power plant types as installed net capacity up to 2050.

Costs for investments and net efficiencies for the most important fossil power plant types as well as other technical and ecological data are selected analogously to the data in Chap. 7. The analysis also incorporates fixed and variable operating

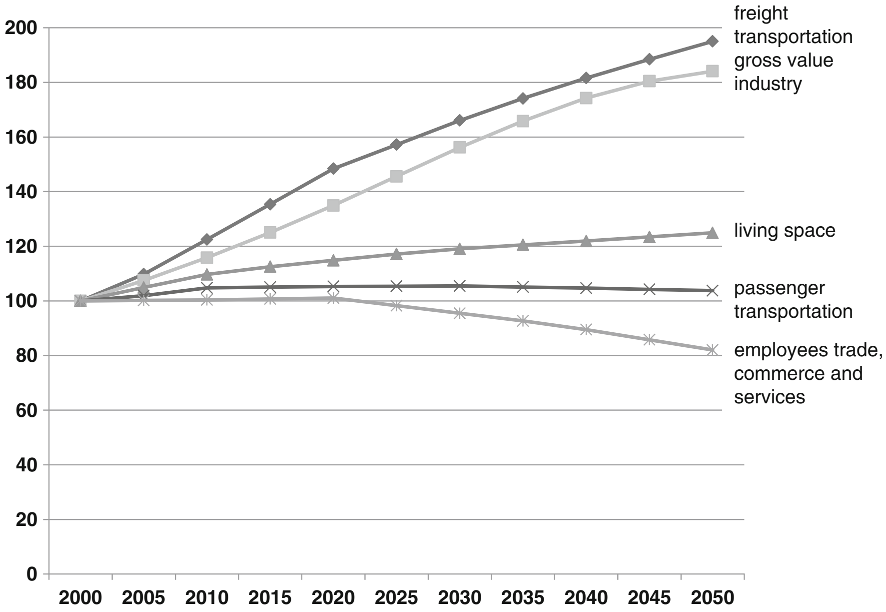

Fig. 10.3 Development of demand according to energy services (Source: Hake et al. 2009)

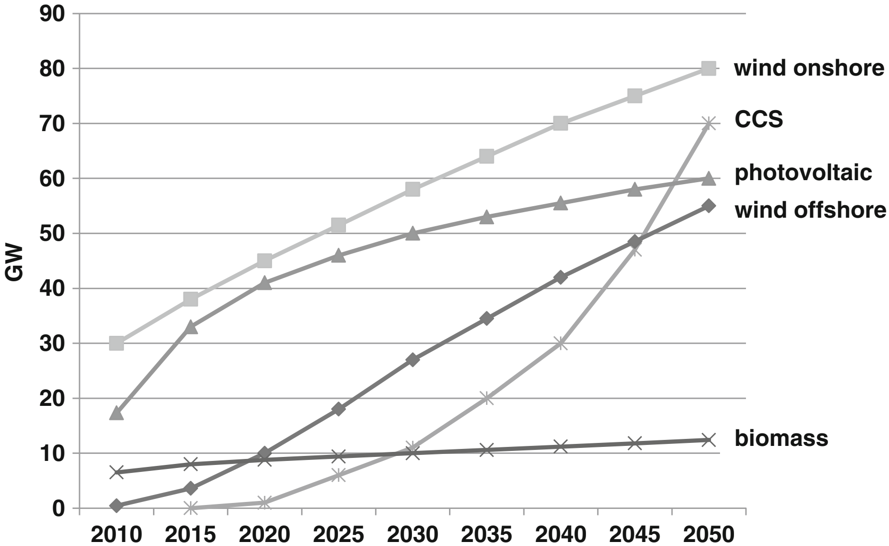

Fig. 10.4 Upper limits for net installed power plant capacity

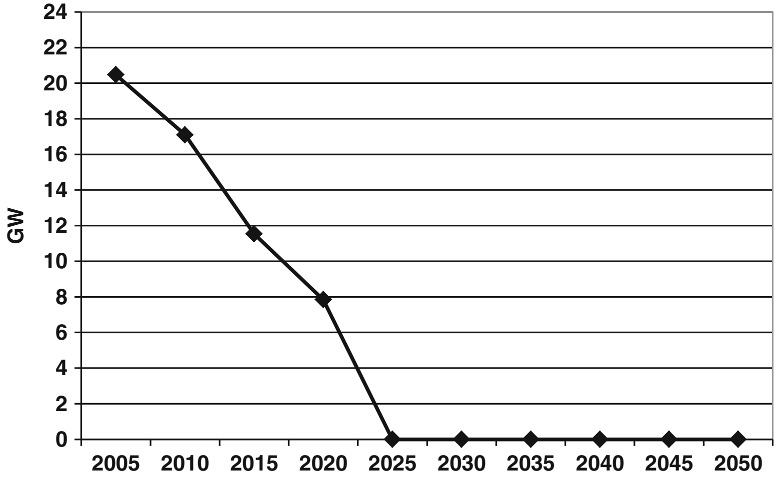

Fig. 10.5 Limitation of installed net nuclear power plant capacity

costs, which also include mean transportation and storage costs for CO_2. Furthermore, the subsequent calculations assume the phasing out of nuclear power. In the model, this means reducing the (net) nuclear power plant capacities in accordance with current legislation, as shown in Fig. 10.5.

The assumed price development of the most important imported energy carriers is shown in Fig. 10.6 in monetary value as of 2010. The real crude oil price in 2050 is equal to US$$_{2010}$ 130/bbl (with US$ 1.3/€ in 2050).

With respect to the import of solar power from North Africa, it was assumed that this will be available in larger quantities from 2030 onwards, and that the price will decrease over time. However, there is a cap on the maximal quantities that can be imported:

- Import price of € 0.19/kWh in 2030 decreasing to € 0.15/kWh in 2050 (see Komendantova et al. 2010; Williges et al. 2010).
- Upper limit for imports in 2050: 70 TWh or approx. 20 % of the total electricity needed.

The following scenarios were generated with the IKARUS model:

- REF: reference scenario without CO_2 reduction targets
- CA: CO_2 reduction targets with a CCS option
- CD: CO_2 reduction targets without a CCS option

In the scenarios with CO_2 reduction targets (CA, CD), energy-related CO_2 emissions are limited after 2010, as shown in Fig. 10.7. By 2050, the energy-related CO_2 emissions may not exceed 23 % of the 1990 level (temperature adjusted). The development over time is mapped based on the mid-term targets of −40 % in 2020 and −55 % in 2030.

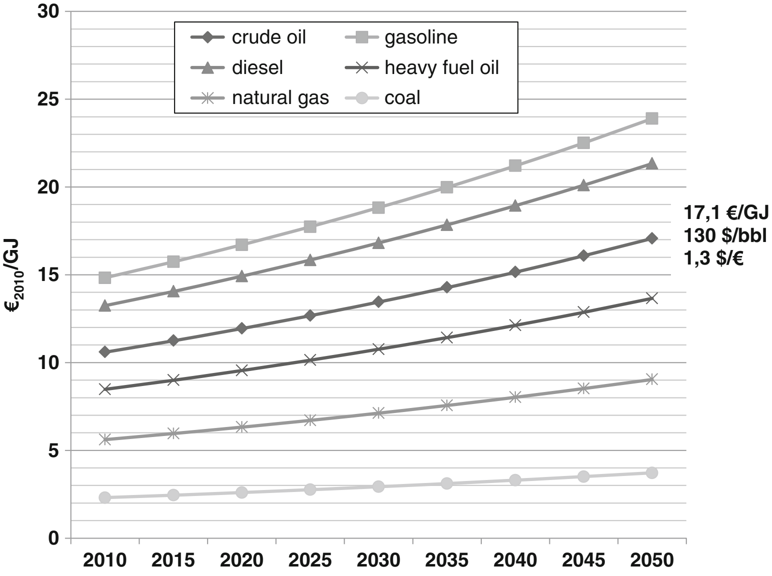

Fig. 10.6 Price development of imported energy carriers

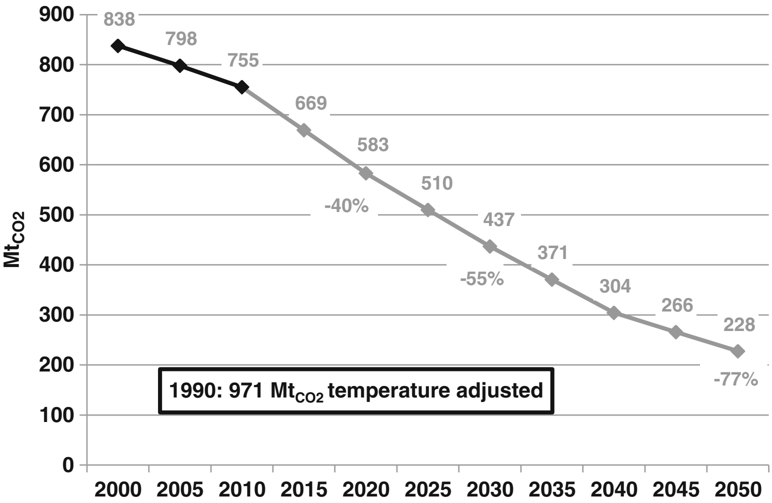

Fig. 10.7 CO_2 restrictions in scenarios CA and CD (Source: Hake et al. 2009)

10.3 Energy Economics Results

10.3.1 Energy and CO_2 Balances

For the scenarios defined in the previous section, the following will be compared for 2005–2050: primary energy balances according to energy carriers, electricity generation and power plant capacities according to kind/type, end-use energy by sector, and CO_2 emissions broken down into sectors.

10.3.1.1 Primary Energy

Even without a CO_2 reduction target, i.e. in the reference scenario (REF), a clear drop in primary energy demand can be seen (−23 % from 2005 to 2050). Renewables account for a relatively constant share, while oil becomes less important in the primary energy mix. The CO_2 scenarios CA and CD show the same development qualitatively, but over time renewable energy from wind and biomass increasingly replaces the energy carrier hard coal, oil, gas and nuclear energy. In addition, the changes in scenario CD in particular are more pronounced (CA: −28 %, CD: −35 %). In the scenario without CCS (CD), the primary energy efficiency is higher than in the scenario with CCS. This is due to greater energy savings and the larger share of renewable energy in this scenario as chosen by the model. Overall, the share of renewables in primary energy in 2050 increases in both scenarios with CO_2 restrictions to 38 % (CA) and 48 % (CD) (Fig. 10.8).

10.3.1.2 End-Use Energy

Overall, the end-use energy demand decreases in the period 2005–2050 by approx. 16 % (REF), 27 % (CA) and 31 % (CD). The changes in end-use energy consumption are very different in the individual sectors. In the transport and traffic sector, the energy demand only drops slightly (−4.5 % in CA and −6 % in CD) or even grows slightly (+5 % in REF) despite a considerable decrease in the mean specific fuel consumption. This can be explained by the strong growth in freight transport services. In all other sectors, the end-use energy demand drops distinctly due to energy savings measures (e.g. thermal insulation) (Fig. 10.9):

- Households: from −18 % (REF) to −41 % (CD)
- Industry: from −29 % (REF) to −41 % (CD)
- Commerce, trade and services: from −28 % (REF) to −54 % (CD)

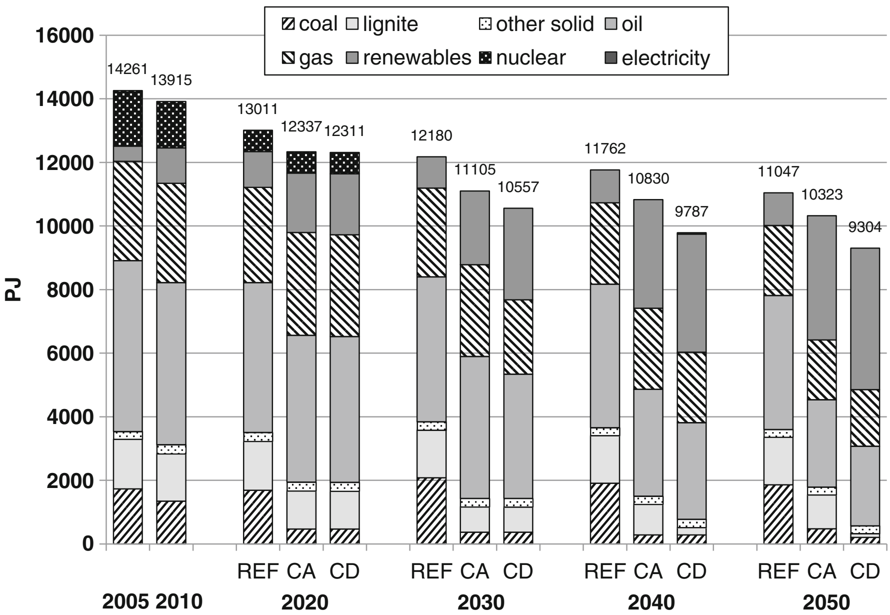

Fig. 10.8 Comparison of primary energy according to energy carriers

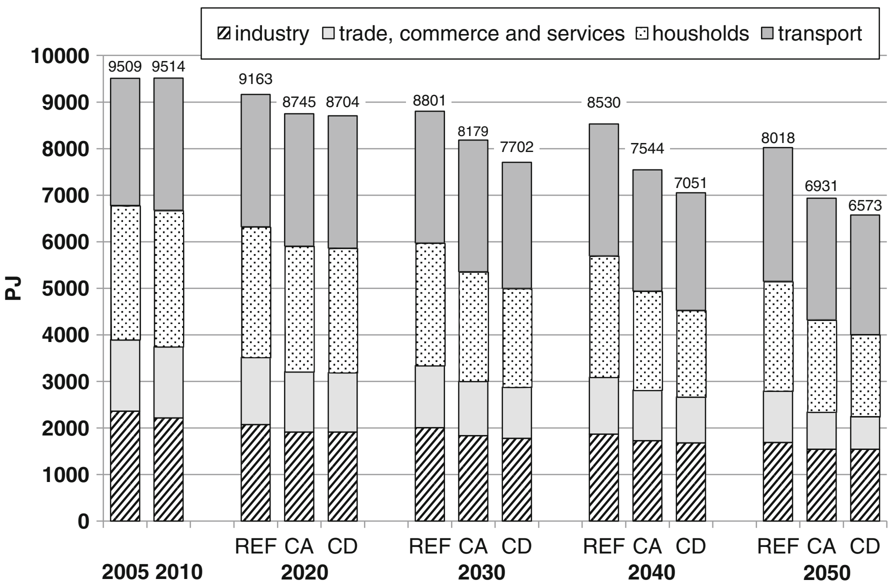

Fig. 10.9 Comparison of end-use energy demand by sector

10.3.1.3 Installed Net Capacity

In the reference scenario, the installed net capacity of the electricity generation plants remains almost constant at slightly more than 150 GW for the period 2010–2050. The following trends can be discerned: The decommissioned nuclear power plant capacity is replaced primarily by building lignite and hard coal power plants. The installed wind power capacity (on-shore and off-shore) remains at 30 GW after 2010 and is not further expanded before 2050. Gas power plants are used as reserve capacity (at very low utilization) for short-term wind fluctuations. In the reduction scenarios, the required power plant capacity is much higher than in the reference scenario, whereby the capacity in the CD scenario increases continuously to more than 300 GW in 2050, while in the CA scenario it initially increases to approx. 260 GW by 2040 and then decreases to almost 220 GW in 2050. The capacity of wind turbines in particular is expanded (max. 87 GW (CA) and 116 GW (CD) in 2040 and 2050, respectively) and PV plants in the scenario without CCS grows slightly to max. 36 GW from 2030 onwards, while biomass power plants (in Fig. 10.10 under 'others') almost constantly account for 10 GW of the installed power plant capacity. In the scenario CA (with CCS), the CCS option for reducing CO_2 is taken from the model, where a total of some 41 GW power plants with CCS are erected by 2050. Of this, lignite CCS accounts for approx. 19 GW, hard coal CCS for approx. 5 GW, and gas CCS for approx. 17 GW. In addition, CCS power plants increase the utilization of the installed power plant fleet, which means that less capacity is required overall in 2050. In scenario CD (without CCS), the existing

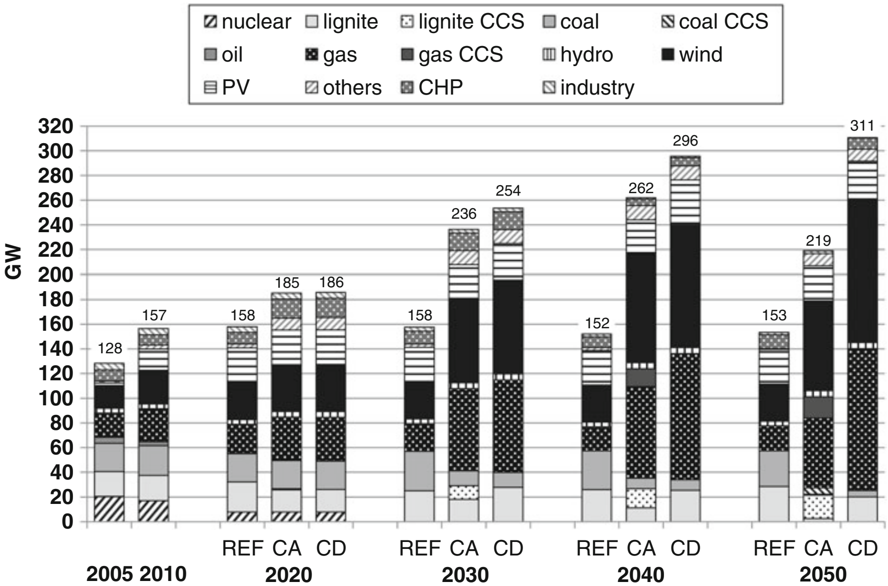

Fig. 10.10 Comparison of installed net capacity by power plant type

lignite and hard coal power plants are hardly used at all in the later periods. However, compared to the scenario with CCS, additional capacities such as PV and wind are incorporated in the model. Overall, the increase in intermittent power plant types leads to a greater need for reserve capacity, which is provided by gas power plants.

10.3.1.4 Net Electricity Generation

In contrast to the strong growth in power plant capacity, electricity generation in the reference scenario experiences a minimal drop by 2050 (−4 %) (Fig. 10.11).

In the reduction scenarios, there is either a transition to CCS power plants (CA) or wide-reaching electricity savings measures are introduced (CD), which in scenario CA results in almost no drop in the net electricity generation (−2 %), but in a clear drop in scenario CD (-8 %). The share of electricity generated from renewables increases considerably in the reduction scenarios from approx. 11 % in 2005 (approx. 18 % in 2010) to nearly 50 % (CA) and even almost 80 % (CD) in 2050. In scenario REF without CO_2 restrictions, the share of electricity from renewables increases slightly to approx. 18 % in 2050. In the CO_2 scenario without CCS, a large share – in 2050 up to approx. 68 % – of the total energy demand is covered by wind and biomass power. In contrast, the CCS power plants in the scenario with CCS (CA) cover approx. 50 % of the demand for electricity. Overall, in the CO_2 reduction scenarios, electricity generation in 2050 is almost CO_2-free.

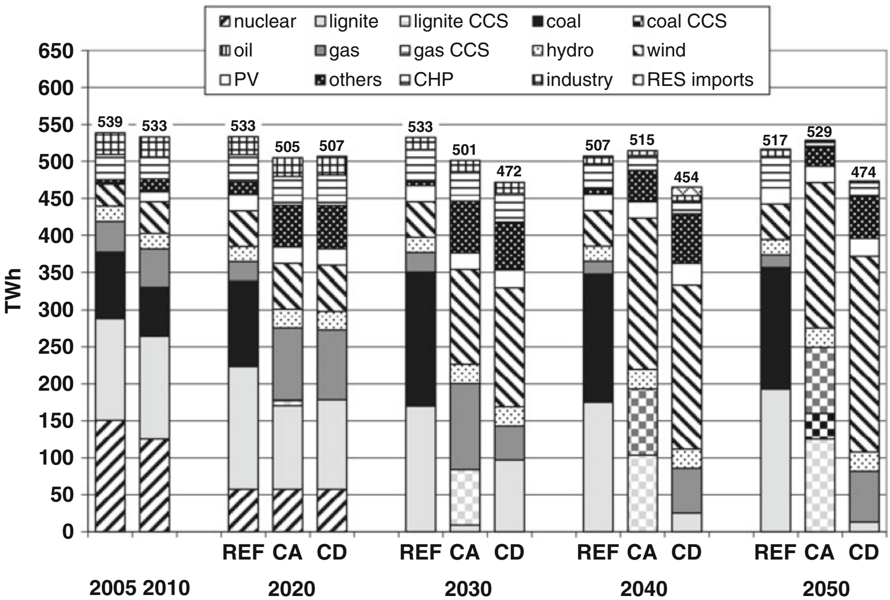

Fig. 10.11 Comparison of net electricity generation by power plant type

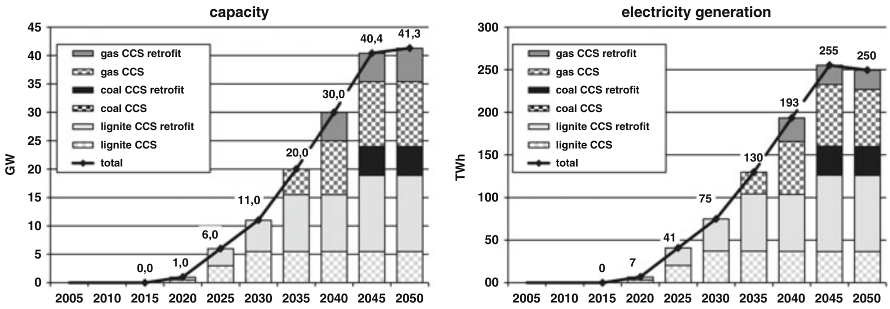

Fig. 10.12 Installed net CCS capacity and net CCS electricity generation according to power plant type in the CCS scenario (CA)

10.3.1.5 Installed Net CCS Capacity and CCS Electricity Generation

Figure 10.12 shows the development of CCS capacity for the reduction scenario CA in more detail. We assume that CCS technology will be available from 2020, and the upper capacity limit therefore expands from this point on. In addition to differentiating according to power plant type, the model also differentiates between new plants and carbon capture retrofits for existing power plants (built after 2005). For lignite power plants – because of inexpensive domestic lignite and the base-load requirements – the option of CCS new plants and that of CCS retrofitting are both selected by 2050. Hard coal power plants are almost only retrofitted because the construction of new hard coal power plants is avoided in the model. The same should hold for gas power plants, but as these have to be available as operating reserve, they are retrofitted and new plants with CCS are constructed.

10.3.1.6 CO_2 Emissions

Figure 10.13 shows the CO_2 emissions broken down into sectors. Even in the reference scenario (REF) without a CO_2 reduction target, there is a decrease in CO_2 emissions by 2050 of approx. -14 % compared to levels in 2005. This can be explained mainly by developments in the sectors industry, commerce, trade and services, and households. The most important drivers are increasing energy prices, which induce energy savings measures and structural changes in industry. In contrast, the CO_2 emissions in the sectors of transport and traffic and electricity generation remain constant. In the electricity sector, the emissions increase temporarily (in 2030) to around 30 $MtCO_2$ due to the phasing out of nuclear energy.

Although there is an emission cap in the CO_2 scenarios with and without CCS (CA and CD), the model selects cost-optimized sector-independent measures, which are essential for compliance with the upper limit, i.e. the sectoral breakdown shown in Fig. 10.14 is a result of the model calculation. In relation to the reference scenario, the emissions are halved in the transport and traffic sector by 2050 and

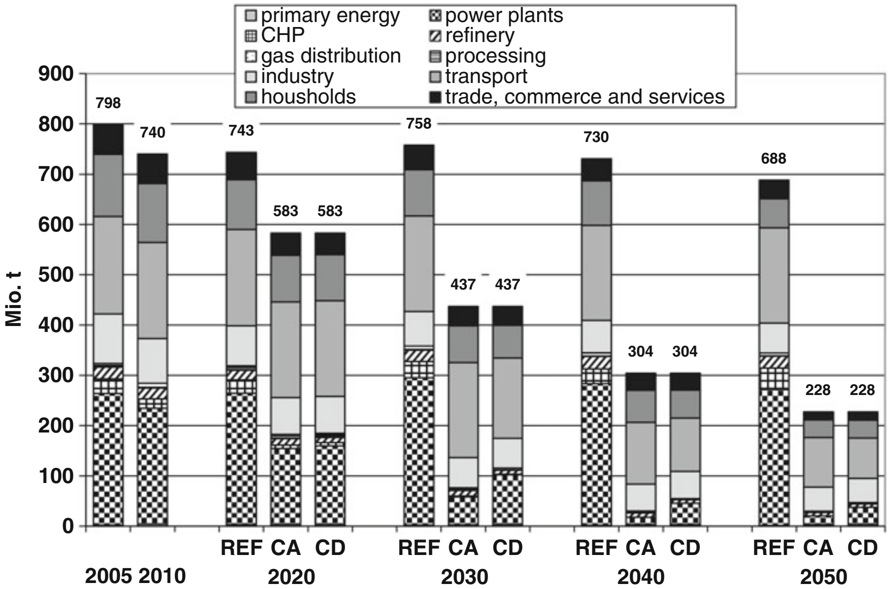

Fig. 10.13 Comparison of CO_2 emissions by sector

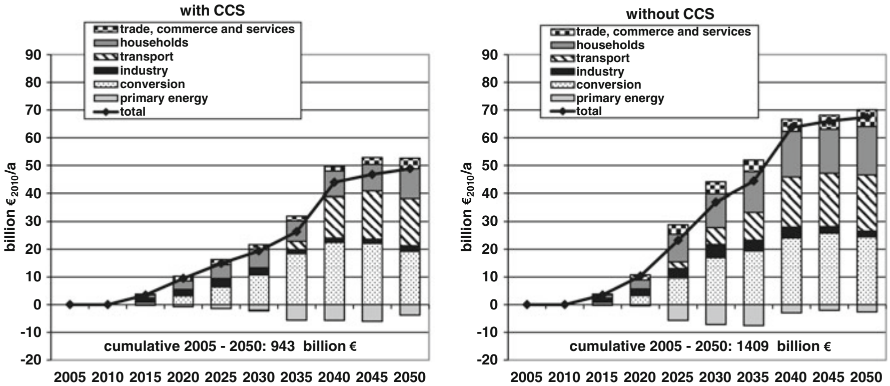

Fig. 10.14 Annual additional costs of the CO_2 scenarios in relation to the reference scenario

there is an even stronger CO_2 reduction in the electricity sector. Compared to 2005, the following reductions are calculated for 2050 in scenarios CA and CD:

- Electricity sector: 87–93 % (REF: +4 %)
- Industry: 51–52 % (REF: 40 %)
- Commerce, trade and services: 72–73 % (REF: 27 %)
- Households: 71 % (REF: 53 %)
- Transport and traffic: 49–59 % (REF: 2 %)
- Total: 71 % (REF: 14 %)

10.3.1.7 Comparison of CO_2 Reduction Scenarios

The comparison of sectoral CO_2 emissions and of the measures for the two CO_2 reduction scenarios with CCS (CA) and without CCS (CD) is particularly interesting here. In summary, the following can be concluded:

By 2050, in the scenario without CCS (CD) the amount of CO_2 in the conversion sector will increase while end-users will emit less CO_2 than in the scenario with CCS (CA). In other words, more measures affecting end-users must be introduced in order to compensate for the additional emissions in the electricity sector and to achieve the overall reduction target. As the CO_2 reduction measures affecting end-use sectors are generally more expensive than measures in the conversion sector (particularly electricity generation), additional costs arise here compared to the scenario with CCS (see section on system value of CO_2, see also Fig. 10.14). The realignment of these measures and the associated additional costs correspond to a displacement of the reduction loads ('displacement solution') in order to achieve the overall reduction target. However, sector-specific changes also occur at times (mainly savings), which have no impact on CO_2 emissions. In practice, this affects energy carriers that do not emit CO_2, such as renewables, local and district heating networks, as well as electricity. This also gives rise to additional costs, which do not lead to CO_2 reduction but should be interpreted as the result of minimizing the total costs without a CCS option ('CO_2 neutral solution').

10.3.2 Cost of Reduction Strategies

10.3.2.1 CO_2 Reduction Costs

Figure 10.14 shows a breakdown of the annual additional costs (monetary value 2010) that arise because of CO_2 reduction targets in relation to the reference scenario according to sector. The additional costs in the scenario without CCS are higher over the whole period than the costs of the scenario with CCS, i.e. the CCS option is used and cuts the costs.

In the scenario with CCS, additional costs arise especially in the sectors of energy conversion (including extra costs for CCS), transport and traffic, and households. Savings measures decrease the demand for primary energy and thus the primary energy costs.

In the scenario without CCS, additional costs arise in the household and transport and traffic sectors, as well as to a smaller extent in the industrial sector. In the conversion sector, the additional costs in the reduction scenarios are very similar. However, in the scenario without CCS (CD), the cost savings for primary energy carriers decrease continuously as a result of the increase in wind power and the associated decrease in fossil power plants (see Fig. 10.11).[2]

[2] For reasons of space, it is not possible to discuss the individual measures and the resulting additional costs or cost reductions here.

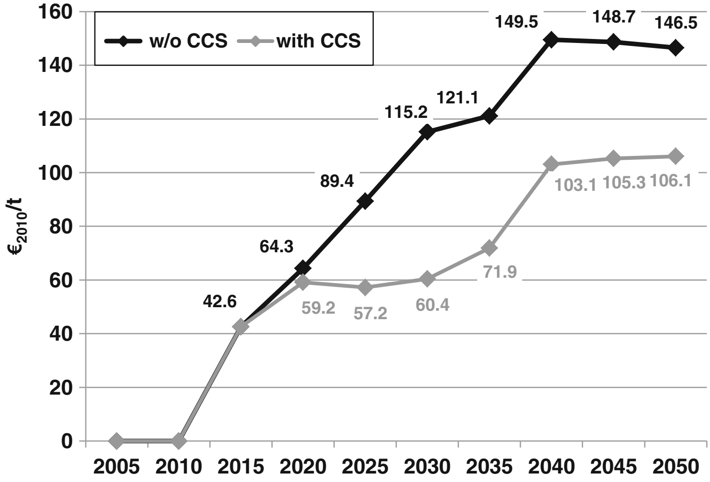

Fig. 10.15 Average specific CO_2 reduction costs

Overall, the integral additional costs for the period 2005–2050 are approx. €$_{2010}$ 940 billion for the scenario with CCS and approx. €$_{2010}$ 1,410 billion for the scenario without CCS in relation to the reference scenario.

Particularly in the long term, the discounting of costs becomes more important.[3] If the additional costs are discounted to 2005 at a constant discount rate of 5 %/a, then we get the following actual cash values in monetary values as of 2010:

- With CCS: €$_{2010}$ 203 billion
- Without CCS: €$_{2010}$ 302 billion

The mean specific CO_2 reduction costs that make up some of the additional costs in Fig. 10.14 are shown in Fig. 10.15. Until 2050, the CO_2 costs increase irregularly with a tendency to level off after 2040 to €$_{2010}$ 106/t in the scenario with CCS and with a tendency to decrease after 2040 to €$_{2010}$ 147/t in the scenario without CCS. The difference in the specific CO_2 reduction costs between the scenarios with and without CCS increases from 2020 to 2030 from approx. €$_{2010}$ 5/t to approx. €$_{2010}$ 55/t. For the period thereafter, this difference becomes smaller and is approx. €$_{2010}$ 40–49/t.

The marginal CO_2 reduction costs are much higher (up to approx. €$_{2010}$ 430/t in the scenario with CCS and approx. €$_{2010}$ 580/t in the scenario without CCS).

[3] For more information on modelling discounting and selecting discount rates, see the extensive discussions in the specialist literature (Cairns 2006; Dasgupta 1982; Hellweg et al. 2003; Kenley and Armsteasd 2004; Newel and Pizer 2004; Rabl 1996), which comprise the economic, engineering, and scientific perspectives.

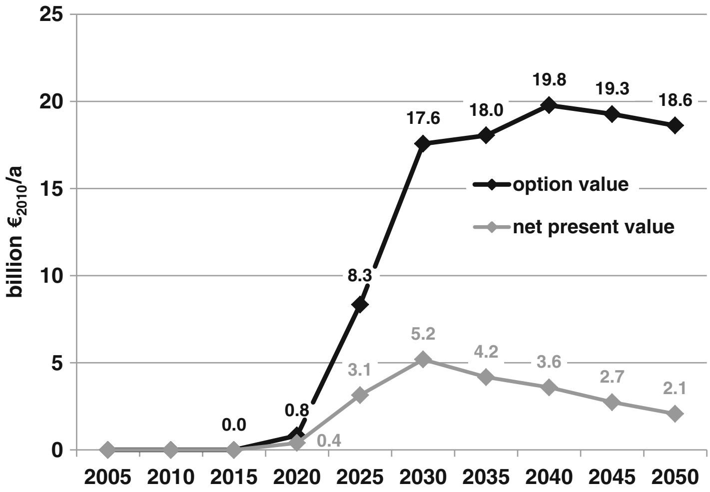

Fig. 10.16 System value of CCS per annum

10.3.2.2 CCS System Value

From the difference between the additional costs with and without CCS in Fig. 10.14, the current system value and actual cash value of CCS is derived and shown in Fig. 10.16 over time. The current system value increases rapidly from $€_{2010}$ 0.8 billion/a in 2020 to $€_{2010}$ 17.6 billion/a in 2030, after which it increases slightly until 2040 and then decreases slightly to € 18.6 billion/a in 2050. The corresponding actual cash value$_{2005}$ increases from $€_{2010}$ 0.4 billion/a in 2020 to $€_{2010}$ 5.2 billion/a in 2030 before subsequently decreasing continuously to $€_{2010}$ 2.1 billion/a in 2050. The cumulative system value for the period 2005–2050 amounts to approx. $€_{2010}$ 466 billion. The corresponding actual cash value$_{2005}$ is approx. $€_{2010}$ 101 billion.

Figure 10.17 shows the contributions of the sectors to the CCS system value. All end-use sectors contribute to the system value in such a way that the use of CCS helps to avoid relatively expensive savings measures. Such a contribution is also made by primary energy, where additional costs for the import of biomass products (e.g. bioethanol) can generally be avoided when CCS is implemented. However, these are offset by additional costs for fossil fuels, which results in a negative sectoral contribution of the primary sector to the CCS system value by 2035. In the conversion sector, additional costs are mainly due to the increased expansion of renewable energy capacity (e.g. wind).

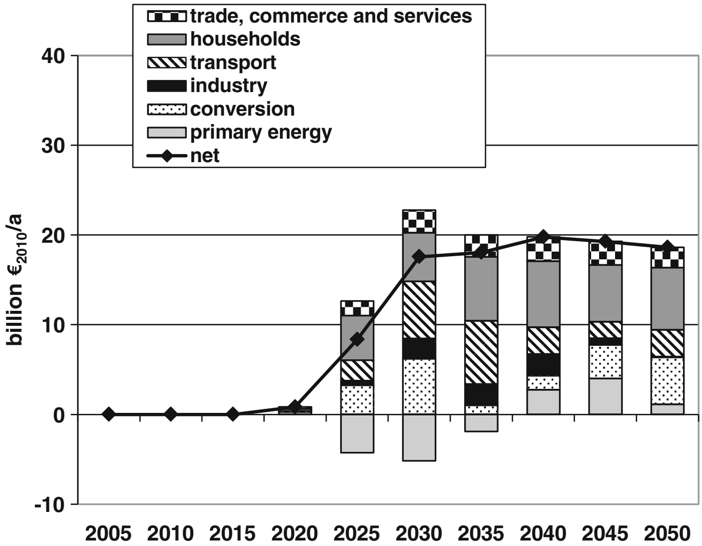

Fig. 10.17 Sectoral contributions to CCS system value

10.4 Summary and Conclusions

This chapter analysed the system value of CCS technologies in Germany within the context of consistent greenhouse gas reduction scenarios. In this context, the system value of a technology is determined by the additional avoidance costs that would occur when climate change mitigation targets are to be achieved without these technologies. The system value is therefore an implicit measure of the level of willingness of society to pay for refraining from the use of CCS technologies.

The methodological basis for calculating the system value of CCS technologies is the IKARUS energy system model, a bottom-up approach with detailed depictions of the technical energy supply structures in Germany for scenario-based analysis of CO_2 reduction strategies. The approach allows the variation of important parameters and general assumptions for which different developments are possible in future.

The system value of CCS technologies was analysed within the framework of a reference scenario without CO_2 reduction targets (REF) and two scenarios with CO_2 reduction targets (CA: without CCS; CD: with CCS). For renewable energy, the framework was extended e.g. via electricity imports from the DESERTEC Initiative, while for nuclear energy the decision as of early 2010 to phase out nuclear energy is implemented. The period considered is from 2005 to 2050.

The cumulative system value (in current values, with no discounting) for CCS technologies is $€_{2010}$ 466 billion for the period 2005–2050. If additional costs are discounted at a constant discount rate of 5 %/a, the result is an actual cash $value_{2005}$ of the cumulative system value of $€_{2010}$ 101 billion. For actual cash value analysis, the development of costs over time and the level of the discount rate are important. The later the costs are incurred over time (burden on future generations) and the higher the discount rate (high preference for the present), the lower the actual cash value.

The system values presented here are calculated by balancing across all model sectors (end-use sectors, conversion sector, primary energy sector incl. imports). All end-use sectors (industry, households, transport and traffic, commerce, trade and services) contribute to the system value in such a way that the implementation of CCS (in the conversion sector) helps to prevent relatively expensive savings measures. In the same way, the primary energy sector including imports also plays a role, where most of the additional costs associated with the import of biomass products (e.g. bioethanol) are avoided when CCS is implemented, but additional costs are incurred for fossil fuels, which predominate until 2035. Despite the additional costs caused by CCS technologies, the conversion sector also contributes to the system value because an additional increase in renewable energy capacity is avoided. To summarize, all sectors contribute to the system value even if to a different extent.

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