How to integrate feed-in tariffs in energy system models – the case of Germany

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Abstract

Fixed feed-in tariff systems are one of the most important instruments for the promotion of renewable energies in electricity production. As these instruments have a major impact on the power sector, they should be taken into consideration when conducting energy system analyses. In this paper, the effects of the German feed-in tariff system for renewable electricity on the German energy system are assessed within the scope of the energy system model TIMES-D. The approach is to endogenously model the tariff system by integrating the tariffs directly into the model (to account for the impacts on the generation side) and by assigning the corresponding levy to the end-use electricity prices (to account for the impacts on the demand side). Different scenario settings are chosen to explore the interaction between the feed-in tariff system and the EU Emissions Trading System, to evaluate the effect of different operation times of the German nuclear power plants on the expansion of the renewable electricity production, and to compare the outcomes of the feed-in tariff system with a fixed quota system for renewable electricity.

The results of the scenario analyses show that with the help of the feed-in tariff system the use of renewable energies in electricity generation rises substantially in Germany reaching a share of 44 % in gross electricity consumption in 2030 (when additional accounting for the EU Emissions Trading System). The impact of the feed-in tariff system on power demand turns out to be comparatively small. The expansion of the renewable electricity production is, however, not the most cost efficient CO_2 abatement strategy for Germany. According to the model results, extended operation times of nuclear energy in Germany do not hamper the development of the renewable electricity generation significantly. Implementing a fixed quota system for renewable energy instead of feed-in tariffs leads to a less heterogeneous structure of the renewable electricity production, slightly lower energy system costs, but considerably higher electricity prices.

Keywords: Energy system model, renewable energy, fixed feed-in tariffs, scenario analysis

JEL classification: Q42, Q47, Q48

1. Introduction

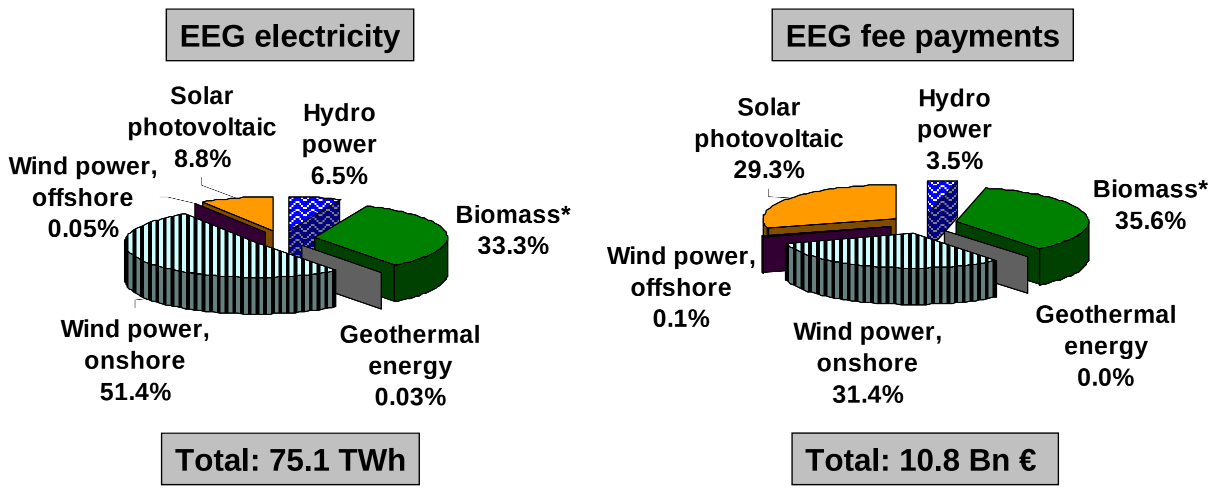
On both the European and the German level, ambitious targets have been set regarding the expansion of renewable energies. The new energy concept in Germany states that by 2020 renewable energy sources are to account for 18 % of gross final energy consumption, further increasing to 30 % in 2030 and 60 % in 2050. Electricity generation plays an important role in reaching these goals with the aim to increase the contribution of renewable energy to gross electricity consumption to 35 % in 2020, 50 % in 2030 and 80 % in 2050. The German targets are furthermore integrated into the regulations on the level of the European Union, where a minimum share of 20 % for renewable energy in gross final energy consumption by 2020 is demanded.

A variety of policy instruments can be applied to promote the use of renewable energies in electricity production. In general, a differentiation is made between price-based and quantity-based measures. Fixed feed-in tariffs form part of the first category, as the price for renewable electricity that electricity distributors have to pay is fixed beforehand, usually for a period of several years. The additional costs that distributors incur in this system can be passed through to power consumers by means of a levy on end-use electricity prices. Moreover, fiscal incentives or investment grants also belong to the price-based measures, but are usually only employed in a complementary way. One of the most important quantity-based instruments are green certificate schemes, where a fixed quota of capacity or generation of electricity has to be covered by renewable sources. Thus, the quantity of renewable electricity is set by the government, whereas the price is determined on the market. This also applies to tendering procedures where a predefined target renewable capacity or generation is assigned through a biding process to the bidder with the lowest price. Here, the government usually covers the difference between the market price and the bid price.

In environmental economics, a number of criteria are usually used to evaluate policy instruments, most importantly their effectiveness and efficiency. From a theoretical point of view, quantity-based instruments exhibit the highest market conformity, as always the least-cost options for renewable electricity are supported and the system generally is supposed to encourage competition. Feed-in tariffs, on the other hand, involve the danger of over-subsidizing and deadweight effects. In reality, however, feed-in tariff systems have proven to be very successful in the promotion of renewable electricity generation (Ragwitz et al. (2007) & Sawin (2004)). As one of the main reasons for this success the long-term stability of these systems is named giving investors high levels of planning security. The risk of over-funding can be reduced by the implementation of fixed degression rates and by constantly adjusting tariffs (for new plants) to the market conditions. Furthermore, feed-in tariff schemes are usually assumed to entail lower transaction costs than quota systems or tendering procedures. Apart from that, technology specific feed-in tariffs are more adequate to promote innovative technologies as well as small- and medium-scale producers. In the European Union, feed-in tariff or feed-in premium systems dominate the renewable electricity policy with 23 of the 27 member states using such a system at present (de Jager et al. 2011).

Germany has adopted a feed-in tariff system for electricity produced from renewable energy, the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) in 2000 obliging public energy supply companies to buy electricity supplied by renewable generators at fixed prices. The tariffs depend on the renewable energy source in use as well as the plant size and are usually paid over a period of 20 years. In order to incentivise constant efforts to increase cost effectiveness, tariffs for newly installed plants are subject to an annual degression at a certain percentage (excepting small hydro power plants). Major amendments of the EEG have been conducted in 2004 and 2009, mainly to adjust tariffs to the current competitive situation of the different renewable electricity generation technologies (BMU 2009).

With the help of the EEG support scheme, the use of renewable energies in electricity generation has risen significantly in Germany, from 37 TWh in 2000 to almost 95 TWh in 2009 resulting in an increase of the renewable share in gross electricity consumption from 6.4 % to 16.4 % (BMU 2010a). The renewable electricity generation included in the EEG scheme amounted to 75 TWh in 2009 with EEG payments of almost 11 billion € (Figure 1). The average tariff across all renewable energy sources was at 14.4 ct/kWh in 2009 ranging from 7.8 ct/kWh (hydro power) to 48.0 ct/kWh (solar photovoltaics). The EEG apportionment, i.e. the additional charge on end-use electricity prices (excluding the privileged consumers who pay a reduced levy, mainly electricity intensive industry branches and rail operators) caused by the feed-in tariffs system, has risen from 0.2 ct/kWh in 2000 to 0.69 ct/kWh in 2005 and 2.05 ct/kWh in 2010. For 2011, the levy has been fixed at 3.53 ct/kWh (BDEW 2010).



Average tariffs (ct/kWh)					
Hydro power	7.8	Wind power, offshore	15.0	Geothermal energy	19.8
Wind power, onshore	8.8	Biomass*	15.4	Solar photovoltaic	48.0

* incl. gas from landfills,mines and sewage treatment plants

Figure 1: EEG electricity generation, fee payments and average tariffs in 2009 (ÜNB 2010)

In this study, the German fixed feed-in tariff system for renewable electricity generation is evaluated in the scope of an energy system model. In the analyses, the effects both on the production side, by integrating the feed-in tariffs into the model, and on the demand side, by including the levy on electricity prices, are taken into consideration.

2. Methodological approach

The purpose of this paper is to evaluate the impact of the German Renewable Energy Sources Act on the development of the German energy system by explicitly integrating the feed-in tariffs into the framework of the energy system model TIMES. In former energy system analyses, the effects of this feed-in tariff system have often only been taken into account in an indirect way by exogenously setting minimum volumes for the electricity produced from the different types of renewable energies through user constraints (cf. UBA (2009) and IER et al. (2010)). This, however, clearly reduces the flexibility of the model, as generally no changes in the electricity generation from renewable sources will occur when the scenario assumptions are altered. Moreover, the interaction with other types of policy instruments, as for example the European Emission Trading Scheme (ETS), cannot be evaluated. Apart from that, the impact of the feed-in tariffs on electricity retail prices, as the additional costs of the tariff system are passed down to final consumers, is neglected when exogenously fixing the minimum generation from renewable energy.

Therefore, the analysis at hand uses a different approach to account for the effect of the fixed tariffs. The different tariffs of the German system are explicitly modelled within the energy system model. Thus, the competitive position of the various types of renewable energy technologies can be evaluated within the model and the development of the electricity generation base on renewable energies in Germany is endogenously determined. In addition, the impact of the feed-in tariff system on electricity prices and electricity demand is taken into consideration by integrating the EEG apportionment (levy on electricity retail prices based on the additional costs of the tariff system) into the model framework.

2.1. The energy system model TIMES-D

For the model-based analyses the energy system model TIMES-D is employed. TIMES-D is based on the model generator TIMES, which has been developed in the scope of the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). It is a multi-periodic bottom-up energy system model that follows a partial equilibrium approach for representing, optimising and analysing energy systems on local, regional, national or global scales. TIMES is based on linear optimization techniques that depict the energy system as a network of processes (e.g. different types of power plants, heating systems of transport technologies, etc.) and commodities (e.g. energy carriers, emissions, materials etc.). It usually optimises (under perfect foresight) the total energy system costs to meet the exogenously set sectoral energy demands subject to additional constraints, as, for example, a cap on total GHG emissions. This detailed, process-oriented model allows for the evaluation of technical adjustment processes within the energy system in the case of changes in the exogenously set model assumptions, e.g. in the political framework or the energy prices.

The application used for the analysis at hand, the TIMES-D model, represents the whole energy system of Germany taking into account exchange processes with neighbouring countries (with the help of cost potential curves). Demand sectors considered are the industry, service/commercial, residential and transport sector, which are further disaggregated. The German model includes more than 380 end-use technologies encompassing several vintage classes divided into the four above-mentioned demand sectors and represented by techno-economic parameters such as the utilisation factor, energy efficiency, lifetime, capital costs, operating & maintaining (O & M) costs, etc. The supply side of the model covers energy conversion processes including petroleum refining, coal processing, heat and electricity generation, etc. It includes over 120 conversion technologies for central electricity and district heating based on fossil (coal, oil, gas), nuclear and renewable (hydro, wind, solar, biomass, geothermal) resources. The techno-economic data for supply side technologies includes the availability factor, capacity factor, electrical efficiency, technical lifetime, specific capital costs, etc. Technologies with carbon capture and storage (CCS) are commercially available in the model from 2020 onwards. Moreover, assumptions are laid down concerning energy prices, resource availability, the potentials of renewable energy sources etc. In addition to the energy flows, energy and process related emissions of greenhouse gases as well as other air pollutants are accounted for in the model. TIMES-D has a high temporal disaggregation level with 32 time-slices (4 on the seasonal, 2 on the weekly and 4 on the daily level). For further information on the TIMES model generator as well as the TIMES-D model see Loulou et al. (2005) and Remme (2006).

2.2. The modeling of the feed-in tariff system

When modelling the German feed-in tariff system, both the payment side (e.g. the tariffs) and the cost side (e.g. the EEG apportionment) have to be taken into consideration. In this analysis, a time horizon to 2030 is applied, assuming that the EEG promotion system is maintained until that year. It has to be pointed out, however, that due to inflation and the annual degression rates, the tariffs are comparatively low towards the end of the time horizon.

From the point of view of the renewable plant operator, the tariffs can be understood as a subsidy on the renewable electricity generation and are therefore integrated into the model by using the TIMES parameters developed to display subsidies. Moreover, the modelling approach takes into account a number of special features of the German feed-in tariff system, as the effect of the EEG on the competitiveness of the renewable electricity generation depends substantially on these features:

- The tariffs are paid over a limited period of time (usually 20 years, in the case of large hydro power plants 15 years). As the technical lifetime of some renewable generation technologies exceeds this time span, the limitation of the payment period has to be explicitly specified within the model framework.
- According to the legal stipulations, tariffs remain constant in nominal terms during the payment period resulting in a gradual decline in real terms. In the model real monetary values are applied such that the reduction of tariffs due to inflation has to be accounted for when fixing the tariffs in the model.
- While the tariff level for a particular plant stays nominally constant throughout the payment period, each year tariffs are reduced for newly installed plants according to the degression rates stipulated by law (depending on the renewable energy source in use). Thus, tariffs for new plants depend on their vintage year.

The annual degression is taken account of by defining the parameters characterising the renewable electricity generation processes as depending on the vintage year and not – as in the default setting – the model year. In this way, also the tariffs assigned to one process decrease as a function of the vintage year. The limitation of the payment period as well as the tariff reductions caused by inflation can be established for each process by using a *SHAPE* curve. This TIMES parameter contains user-defined multiplication factors which are applied to age-dependent process parameters. Hence, for a specific renewable electricity plant built in a certain year the tariff would be paid in full height in the first year after construction (i.e. multiplication factor = 1). In the second year, tariffs (in real terms) are reduced by the annual inflation rate (i.e. multiplication factor = 1/1.023 with the assumption of an annual inflation rate of 2.3 %). Thereby, inflation can be accounted for in each year of the payment period. If the lifetime of a plant exceeds the payment period of 20 years, the SHAPE parameter is set to zero from the 21st year onwards. In addition to the standard tariffs, the German feed-in tariff system contains a number of special regulations, which are also included in the modelling approach: additional tariffs for the modernization of existing hydro power plants, a bonus system for the repowering of existing onshore wind farms, and the variable degression rates for solar photovoltaics.

After integrating the tariffs into the model, one has to bear in mind that this only constitutes one part of the feed-in tariff system. The tariffs are not a subsidy by the state, but are financed through a levy on retail electricity prices (the EEG apportionment). This additional cost burden on consumers has to be accounted for in the energy system model, as it can induce adjustments in terms of electricity savings or substitution effects. The EEG apportionment, i.e. the additional charge on electricity prices resulting from the tariff payments, is calculated as follows (Bode, Groscurth 2006):

*EEG apportionment = (Ø-EEG tariff – Ø-wholesale electricity price) * EEG quota*

Thus, the EEG apportionment in one year is obtained as the difference between the average EEG tariff (*Ø-EEG tariff*, across all renewable energy sources) and the average annual electricity price on the wholesale market (*Ø-wholesale electricity price)* multiplied by the *EEG quota*, i.e. the percentage share of electricity remunerated through the EEG in total final electricity consumption.

Furthermore, it has been taken into consideration in the modelling approach that the size of the EEG apportionment varies for different groups of consumers. According to EEG 2009 §§ 40 et seqq., the EEG apportionment is restricted to a maximum of 0.05 ct/kWh for manufacturing enterprises and rail operators with comparatively high electricity consumption in order to prevent endangering their international or intermodal competitiveness. Beside the rail operators, this regulation benefits mainly parts of the chemical, the paper, the iron and steel as well as the non-ferrous metal industry in Germany (BMU 2010b).

The components of the EEG apportionment in future model periods can be calculated on the basis of the TIMES-D model results. The process is organized as follows: in the first scenario run only the tariffs are integrated in order to evaluate the impact of the EEG on electricity generation. From the results of this first model run, the EEG apportionment can be computed. In the second scenario run, the apportionment is assigned as an additional cost term to the final electricity consumption in the different sectors (considering the reduced levy in the privileged sectors). This model run includes the effects of the EEG both on the production and the demand side. It has to be noted, however, that the integration of the EEG apportionment and the associated increase in end-use electricity prices causes modifications in the electricity consumption and consequently also in electricity generation. Hence, the components of the EEG apportionment itself are subject to changes. Therefore, in order to adjust EEG payments and the EEG apportionment to one another an iterative process of several model runs is applied. The iteration is ended when the apportionment (in ct/kWh) no longer changes in its second decimal place from one model run to the other.

2.3. Scenario assumptions

The basic demographic and economic data used in the following scenario analyses are mainly adopted from the study *Energieprognose 2009* (IER et al. 2010) (Table 1). Between 2010 and 2030 the German population declines by about 2 million inhabitants. In the same period the annual GDP growth rates amount on average to 1.1 %. A decisive factor for the competitive position of renewable electricity generation technologies compared to conventional ones is the development of fossil fuel prices. The average price of crude oil (OPEC Reference Basket) is expected to rise to 100 $US\$_{2007}$/bbl until 2030 in real term, leading to a nominal price of 169 $US\$_{2007}$/bbl in 2030 (assuming an annual inflation rate of 2.3 %). Consequently, a substantial price surge is also expected for natural gas and hard coal in the modelling period. Apart from that, lignite plays an important role in the German electricity generation. Here, the average full costs of lignite extraction in Germany are applied.

Table 1: Key socio-economic scenario assumptions

	Unit	2010	2020	2030
Population	M	81.7	81.4	79.7
Gross Domestic Product	Bn €$_{2000}$	2248	2526	2784
Crude oil price	US$$_{2007}$/bbl	74	87	100
(OPEC Reference Basket)	US$/bbl	77	117	169
Fuel prices (power plants)				
Natural gas	€$_{2007}$/GJ	6.66	8.27	9.09
Hard coal	€$_{2007}$/GJ	2.96	2.79	3.03
Lignite	€$_{2007}$/GJ	0.96	0.96	0.96

The various electricity generation technologies included in the model are characterised by a number of technical and economic parameters. Table 2 summarizes the key investment cost assumptions for the most important renewable electricity generation technologies based on IER et al. (2010) and Kaltschmitt et al. (2006). Excepting hydro power plants, considerable learning effects are expected for all renewable technologies resulting in substantial drops in investments costs, especially for solar photovoltaics and offshore wind farms. For photovoltaic roof systems, which are usually installed by private households, farmers or small businesses, a number of tax incentives (like accelerated depreciation), which on average lead to a further 4% reduction in investment costs, are taken into account. In the case of wind power, additional costs for the expansion of the power grid are included based on dena (2005). Moreover, a variety of energy storage technologies is modelled which become increasingly important to integrate the rising share of fluctuating electricity production.

Table 2: Investment cost assumptions for renewable energy technologies (selection)

Investment costs, €$_{2007}$/kW	**2010**	**2020**	**2030**
Hydropower, new plant (20 MW)	5200	5200	5200
Hydropower, new plant (3 MW)	4140	4140	4140
Hydropower, modernisation	1000	1000	1000
Photovoltaic roof system	2700	2010	1692
Free-standing photovoltaic system	2200	1629	1366
Wind power, onshore (incl. grid connection)	1040	940	870
Wind power, offshore (distance to shore 80 km, water depth 35 m, incl. grid connection & base)	3443	2308	2213
Solid biomass, CHP plant (6 MW)	1750	1600	1600
Biofuel , CHP plant (2 MW)	600	550	550
Biogas, CHP plant (0,5 MW)	800	750	700
Geothermal power plant, ORC (4,5 MW, hydrothermal, drilling depth 3500 m)	6000	4834	4326

In addition to the explicit modelling of the feed-in tariff system, other current regulations of the German and European energy and climate policy are included in the scenario analyses. At the beginning of June 2011, the German government has decided to phase out the use of nuclear energy in Germany until 2022 and to shut down 8 of the 17 existing nuclear power plants at once. The participation of Germany in the EU Emissions Trading System is taken into account by setting a fixed CO_2 reduction target of 21 % for 2020 compared to 2005 for the sectors involved in the trading system. After 2020, the average annual rate of emission reduction for the period 2013 to 2020 (1.74 %) is extrapolated to 2030.

In this study, sector-specific, subjective (or implicit) discount rates are used in order to account for the individual decision behaviour of different agents in the energy system. Thus, sectors with high hidden costs related to the investment in new equipment are assigned relatively high real discount rates (based on IEA (2005)): 13.7 % for commerce, the service sector and agriculture and 14.2 % for private households and motorised individual transport. In contrast, for utilities and the industrial sector (including freight transport) the discount rates are guided by the average cost of capital and the profitability expectations in the respective sector resulting in rates of 9.3 % and 7.8 %. An exception is made in the case of renewable electricity generation with a real discount rate of 7 %, as it has been observed that in this sector profitability expectations – especially for smaller generation units – tend to be lower (Doll et al. 2008). Moreover, an even lower discount rate of 5 % is applied for photovoltaic roof systems, where special loan programs with reduced interest rates are available.

A number of scenarios are analysed in this paper in order to evaluate the impact of the German feed-in tariff system on the energy system (Table 3). The scenarios differ in terms of the consideration of the EEG and the EU Emissions Trading System (ETS). Apart from that, the effect of different lifetimes of the German nuclear power plants on the expansion of the renewable electricity production is explored. An additional scenario includes a quota system for the promotion of the renewable electricity generation, which results in the same shares of renewable energy in total gross electricity consumption in the respective model periods as in the scenario including the EEG and the EU ETS.

Table 3: Overview of scenarios

	Promotion system for renewable electricity	**Integration of the EU Emissions Trading System (ETS)**	**Lifetime of the nuclear power plants**
EEG+ETS	EEG	YES	Phase out until 2022
EEG_only	EEG	NO	Phase out until 2022
ETS_only	None	YES	Phase out until 2022
NO_instrument	None	NO	Phase out until 2022
EEG_NUC44	EEG	YES	44 years*
EEG_NUC60	EEG	YES	60 years
RE_quota	Quota System	YES	Phase out until 2022

* According to the Energy Concept of the German government from September 2010 (BMU, BMWi 2010).

3. Results of the scenario analysis

3.1. Scenarios on the interaction between the feed-in tariffs and the emission trading system

The two most important climate policy measures that affect the German power sector are the feed-in tariff system for renewable energies and the EU Emissions Trading System. In the following, a number of scenarios are presented that analyze the interaction between these two policy instruments (Figure 2).

If both the EEG and the ETS are taken into consideration (scenario EEG+ETS), the renewable electricity generation in Germany rises substantially throughout the whole projected period. In 2020, renewable energies contribute with 236 TWh or 39 % to gross electricity consumption, in 2030 with 259 TWh or 44 %. Thus, compared to 2009 renewable electricity production is almost tripled until 2030. The targets of the German government are therefore exceeded in 2020, but missed by 6 percentage points in 2030. Despite the considerable expansion of renewable energies, the share of fossil fuels in the German electricity generation only decreases from 62 % in 2009 to 53 % in 2030, due to the simultaneous phasing out of nuclear energy.

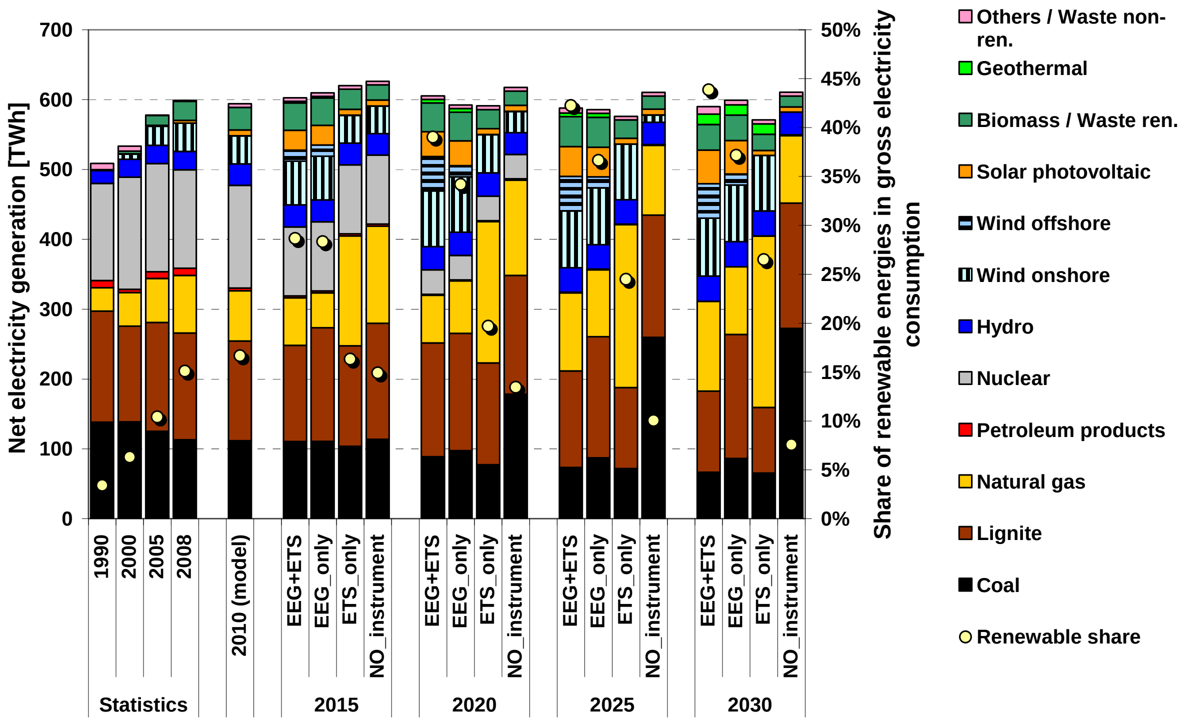


Figure 2: Net electricity generation in Germany in the scenarios with EEG and ETS (EEG+ETS), only with EEG (EEG_only), only with ETS (ETS_only) and with neither EEG nor ETS (NO_instrument)

Wind power plays a dominant role in the expansion of the renewable electricity production in Germany. In 2030, wind energy accounts for more than half of the total renewable generation in the scenario EEG+ETS (Table 4). In order to further enhance the onshore generation capacities, the repowering of older wind farms is of particular importance. In 2020, already 55 % of the onshore wind electricity generation come from repowered wind turbines. In the case of offshore wind energy, a decisive breakthrough is only achieved after 2015. Until 2030, electricity production from offshore wind increases to 49 TWh in the scenario EEG+ETS. Further model runs have shown that in the long-term a further expansion of offshore wind generation is restricted primarily by the availability of affordable storage concepts for the rising electricity production from fluctuating energy sources. In the model specifications it is stipulated that at all times a maximum of 15 % of the electricity supplied to the grid may originate from fluctuating sources without the necessity of intermediate storage. If this constraint is relaxed, the generation from offshore wind rises substantially, whereas no significant changes occur in the case of onshore wind power and photovoltaics.

After the period of dynamic growth in recent years, the tariffs for solar photovoltaics have been reduced clearly and degression has been aligned more strongly to the actual growth, resulting in possible annual degression rates between 1.5 % and 21 %. Until 2015, the expansion remains high resulting in degression rates of up to 12 % per year. Afterwards, growth weakens gradually such that annual degression drops to 1.5 % until 2030. In 2030, photovolatics contribute with 48 TWh or 19 % to total renewable electricity generation in the scenario EEG+ETS.

Table 4: Renewable electricity generation in Germany in the scenarios with EEG and ETS (EEG+ETS), only with EEG (EEG_only), only with ETS (ETS_only) and with neither EEG nor ETS (NO_instrument)

TWh	2009	2020				2030			
	statis-tics	EEG+ ETS	EEG_ only	ETS_ only	NO_ins-trument	EEG+ ETS	EEG_ only	ETS_ only	NO_ins-trument
Hydro*	19	26	26	26	23	27	27	27	24
Wind	38	129	95	55	31	132	97	79	0
onshore	38	80	79	55	30	83	81	79	0
offshore	0	50	16	0	0	49	16	0	0
Solar photovoltaics	6	36	35	8	8	48	48	7	7
Sewage and landfill gas	2	2	2	2	2	1	1	2	2
Biomass	29	39	39	26	19	35	35	22	14
Solid biomass	17	21	21	14	7	17	17	14	7
Biofuels	1	4	4	2	2	2	2	0	0
Biogas	10	14	14	10	10	15	15	7	7
Geothermal	0	5	5	0	0	15	15	15	0
Sum	**94**	**236**	**203**	**116**	**83**	**259**	**223**	**151**	**46**

*excluding pump storage

The EEG 2009 contains a variety of tariff schemes for biomass, including additional bonuses for the use of a number of renewable raw materials as well as the generation in CHP plants or in facilities with innovative technology. The electricity production from biomass exhibits, however, comparatively low growth rates throughout the projected period. In the scenario EEG+ETS, biomass accounts for 39 TWh in 2020, dropping slightly to 35 TWh until 2030. When looking at the different types of biomass, profound differences become obvious. The strongest expansion can be observed in the case of biogas, where electricity generation augments to 15 TWh until 2030. Subsequent to a slight increase, power plant capacities for liquid biomass are reduced again from 2015 onwards, due to the expected market price rises for vegetable oils like palm oil.

Hydro power has been utilized for electricity production in Germany for several decades and the potential has already been exploited almost entirely. Apart from that, stringent ecological requirements have to be met when installing new hydro power plants (Kaltschmitt et al. 2006). Hence, only a slight increase in the hydro electricity generation to 27 TWh is realized until 2030 through investments in new small-scale power plants and the modernization of existing plants (leading to improvements in efficiency).

In order to assess the impact of the two policy measures on the electricity generation in Germany separately, two additional scenarios are implemented where only the feed-in tariff system (scenario EEG_only) or only the EU Emissions Trading System (scenario ETS_only) are included in the model framework. A significant increase in the renewable electricity production can also be achieved if only the EEG without the ETS is implemented, but in the long-term the expansion is considerably lower than in the scenario EEG+ETS, as the competitiveness of the renewable generation technologies is affected by lower generation costs in fossil fuel plants. In 2030, renewable energy sources contribute with about 37 % to gross electricity consumption in the scenario EEG_only - compared to 44 % in the scenario EEG+ETS. Generation from offshore wind is primarily affected when the ETS is not implemented.

If only the Emissions Trading System is accounted for (scenario ETS_only), the renewable generation clearly falls short in comparison to the scenario EEG+ETS with shares in gross electricity consumption of 20 % in 2020 and 27 % in 2030. Only hydro power and onshore wind energy achieve competitive generation costs, such that in 2030 the expansion is almost similar to the one in the scenario EEG+ETS. This, however, also shows that the extension of the renewable electricity generation is not the most cost-efficient CO_2 mitigation measure in Germany. Hence, the extensive support for renewable energies in electricity generation cannot be justified only through climate policy aspects, but other aspects have to be kept in mind, like a reduction of import dependence or a diversification of supply.

In addition, Figure 2 contains an additional scenario describing the development of electricity generation with neither the feed-in tariff system nor the Emissions Trading System implemented (scenario NO_instrument). Without the impact of these two policy measures, the renewable electricity generation is not expanded any further after 2010 such that it drops to 46 TWh or 8 % of gross electricity consumption until 2030. Here, more than three quarters of electricity consumption are covered by hard coal and lignite. When comparing this scenario with the one that includes only the EU Emissions Trading System (scenario ETS_only), it becomes apparent that the ETS alone already has a positive effect on the renewable electricity production in Germany. The increase in generation from onshore wind and hydro power in the scenario ETS_only can be attributed to a rise in fossil fuel generation costs due to the pricing of CO_2 emissions.

3.2. Effects on the demand side

The EEG system is associated with additional costs that are eventually borne by the electricity consumers. The model approach therefore also accounts for the effect of the EEG on the demand side by including the EEG apportionment. Table 5 comprises the most relevant parameters on the development of the EEG electricity generation and the related costs.

Table 5: Overview on EEG electricity generation and costs in the scenario EEG+ETS

		2009	2015	2020	2025	2030
Renewable electricity	TWh	95	173	236	248	259
EEG electricity	TWh	75	154	212	203	135
EEG payments	Bn €$_{2007}$	10.5	25.1	26.9	22.5	13.1
EEG differential cost in the reference year	Bn €$_{2007}$	-	17.4	12.0	9.3	3.6
Cumulative EEG differential costs starting 2013 to reference year	Bn €$_{2007}$	-	52.1	122.8	174.7	204.1
EEG apportionment	€ct$_{2007}$/kWh	1.3	4.4	5.2	3.5	1.8
Effect on electricity prices*	€ct$_{2007}$/kWh	-	3.4	1.4	1.9	0.1

*Difference in household electricity prices in the scenario EEG+ETS compared to scenario ETS_only

It has to be pointed out that instead of choosing the feed-in tariffs, plant operators may also sell the generated electricity directly to the market with the possibility of entering and exiting the EEG scheme on a monthly basis. The results of the scenario EEG+ETS show that this option only becomes relevant after 2020, when rising fuel and CO_2 prices lead to significant increases in generation costs for fossil fuel plants. In 2030, however, only about 52 % of the renewable electricity generation are still remunerated through the feed-in tariff system compared to 90 % in 2020. The other 48 % comprise plants that have been built before the year 2000 (mainly hydro), plants whose payment period has expired and, most importantly, plants that could still claim the EEG tariffs but have opted for directly selling the electricity to the power market as wholesale prices exceed the tariff level for this specific plant[1]. In 2030, the direct marketing option is mainly used by onshore wind farms and, to a lesser extent, by offshore wind and hydro power plants. By contrast, photovoltaics, biomass and geothermal power plants remain almost entirely within the EEG system.

As a consequence of the substantial growth of the electricity production from renewable energies, the total EEG payments rise considerably, amounting to about 27 Bn €$_{2007}$/a in 2020. Afterwards, due to the degression of tariffs and the growing share of renewable electricity directly sold to the market, EEG payments decline to 13 Bn €$_{2007}$/a in 2030. It has to be noted, however, that the EEG payments do not correctly reflect the actual additional costs of the feed-in tariff system. Therefore, the EEG differential costs are applied which subtract from the EEG payment volume the market value of the EEG electricity generation (using the wholesale electricity price from the scenario ETS_only) (Doll et al. 2008). Hence, the EEG differential costs are considerably lower than the EEG payment sum decreasing from 17 Bn €$_{2007}$/a in 2015 to less than 4 Bn €$_{2007}$/a in 2030. When cumulated over the period from 2013 to 2030, the EEG differential costs add up to about 200 Bn €$_{2007}$.

[1] In the model, the comparison of the wholesale electricity prices and the tariffs is done on a seasonal level.

Against the background of rising EEG payments, the EEG apportionment also surges to 4.4 €-cents$_{2007}$/kWh in 2015 and 5.2 €-cents$_{2007}$/kWh in 2020, compared to 3.3 €-cents$_{2007}$/kWh in 2011. Afterwards, the apportionment is reduced to 1.8 €-cents$_{2007}$/kWh in 2030. Again, it has to be pointed out that the EEG apportionment does not reflect the actual burden on end-users of electricity, since the feed-in tariff system usually has a dampening effect on the wholesale price level. This can be explained by means of the merit order effect (Sensfuß, Ragwitz 2007): the additional renewable generation, which exhibits comparatively low marginal generation costs, replaces part of the conventional generation, namely the part which has according to the merit order curve the highest generation costs. Consequently, as the price on the spot market is formed through the generation costs of the last (and most expensive) generation unit necessary to cover demand, the support system for renewable energy results in a decrease of wholesale electricity prices. Thus, the difference between electricity prices with or without EEG for final power consumers is considerably lower than the EEG apportionment: for residential consumers the electricity price in the scenario EEG+ETS exceeds the one in the scenario ETS_only by 3.4 €-cents$_{2007}$/kWh in 2015 (compared to an EEG apportionment of 4.4 €-cents$_{2007}$/kWh). Afterwards, as the renewable energy generation rises further, the burden of the feed-in tariff system on end users gets lower, with a price increase of only 0.1 €-cents$_{2007}$/kWh in 2030 in the scenario with EEG compared to the one without.

It can be expected that the higher electricity prices resulting from the feed-in tariff system cause adjustments in the final electricity consumption (Table 6). Here, two opposing effects have to be taken into consideration. In the residential and tertiary sector (including agriculture) that have to pay the full EEG apportionment electricity consumption declines when including the EEG (scenario EEG+ETS compared to scenario ETS_only). The effect gets less pronounced in later model periods, as the electricity price levels of the two scenarios gradually converge. By contrast, the electricity consumption in the industrial sector increases slightly, especially in 2020 and 2025, when the EEG is accounted for. This is due to the energy-intensive industry of which great parts only have to pay the reduced EEG apportionment of 0.05 ct/kWh. Hence, given the merit order effect of the feed-in tariff system, these industry branches face lower electricity prices in the scenario EEG+ETS than in the scenario ETS_only. On the whole, the impact of the EEG system on final electricity demand is, however, comparatively low.

Table 6: Final electricity consumption by sector in Germany in the scenarios EEG+ETS and ETS_only

TWh	2015		2020		2025		2030	
	EEG+ETS	**ETS_only**	**EEG+ETS**	**ETS_only**	**EEG+ETS**	**ETS_only**	**EEG+ETS**	**ETS_only**
Industry	240	240	251	246	248	245	248	247
Tertiary Sector*	158	165	141	143	137	139	136	137
Residential	131	143	126	133	121	127	122	121
Transportation	23	23	25	25	28	28	31	31
Sum	**552**	**571**	**543**	**547**	**534**	**538**	**537**	**535**

*incl. agriculture

3.3. The impact of different operation times for nuclear energy

Whether an extension of the operation times of the existing German nuclear power plants has a dampening effect on the development of the renewable electricity generation is discussed controversially in Germany. By endogenously modelling the German feed-in tariff system within an energy system framework, this analysis can provide further inside into this question. Therefore, the scenario EEG+ETS, which includes the most recent decision on phasing out nuclear energy until 2022, is contrasted with two additional scenarios with different operational times of the German nuclear power plants: 44 years in the scenario EEG_NUC44, based on the decision of the German government in September 2010 (BMU, BMWi 2010), and 60 years in the scenario EEG_NUC60. All scenarios also contain the reduction targets of the EU Emissions Trading System.

From the results in Figure 3 it becomes apparent that the expansion of renewable energy sources in electricity production would not be hampered by extending the operation times of the existing nuclear power plants in Germany to 44 years compared to a phase out until 2022. Only the use of biomass is slightly lower in the scenario EEG_NUC44. In 2030, renewable energies contribute with 250 TWh to electricity production – in comparison to 259 TWh in the scenario EEG+ETS. The renewable share in gross electricity consumption is slightly lower in the case of operation times of 44 years. This is mainly due to the fact that power demand is a bit higher in this scenario as the electricity price level is reduced slightly by the larger availability of electricity from nuclear energy.

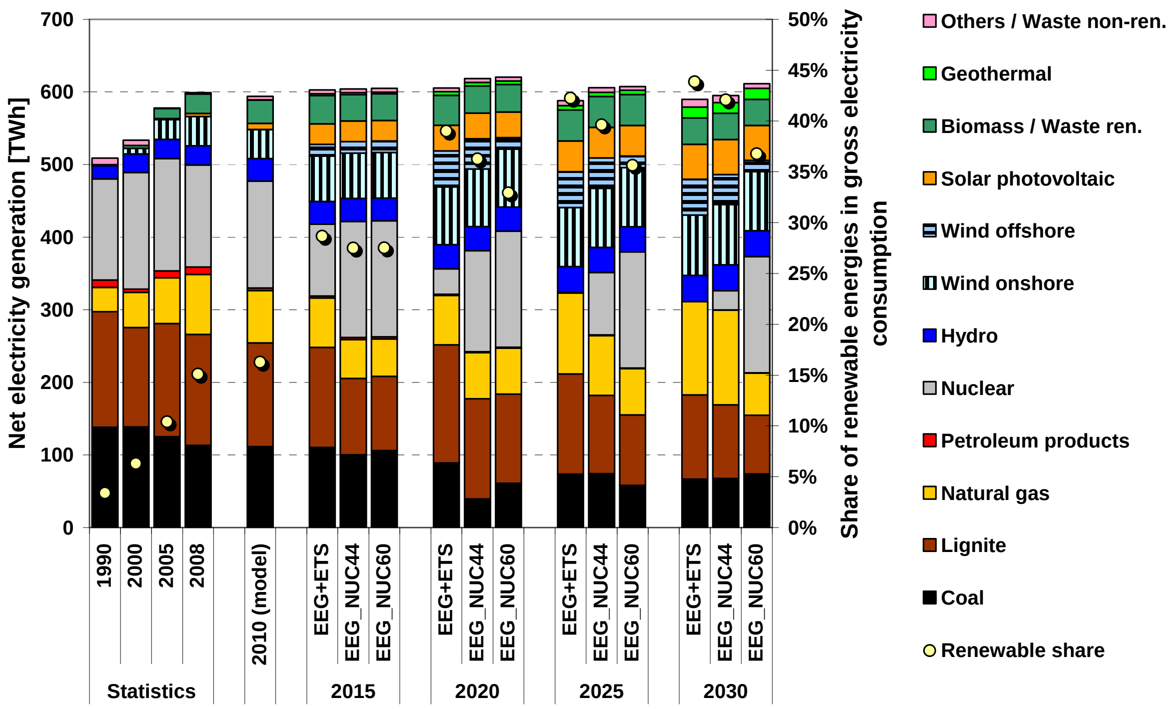


Figure 3: Net electricity generation in Germany with different operation times of nuclear power plants: phase out until 2022 (EEG+ETS), 44 years (EEG_NUC44), and 60 years (EEG_NUC60)

In the case of an extension of operation times of nuclear energy in Germany to 60 years (scenario EEG_NUC60), the renewable electricity production is still increased substantially in the projected period with the help of the feed-in tariff system. The generation from offshore wind and from biomass is, however, clearly reduced in comparison to the scenario EEG+ETS with nuclear phase out until 2022. Renewable energies account for 223 TWh or 37 % of gross electricity consumption in this scenario in 2030. Thus, the model results indicate that very long operation times of nuclear power plants of 60 years might have a slightly dampening effect on renewable electricity generation in Germany, whereas no such effects can be observed in the case of operation times of nuclear power plants of 44 years.

3.4. Comparison with a quota system

As an alterative to the feed-in tariff system, the implementation of a fixed quota system could be considered for the promotion of renewable energies in electricity generation. In order to compare these two different support measures from an energy system perspective, an additional scenario RE_quota is introduced that contains, in addition to the EU Emissions Trading System, an overall quota on the renewable power generation that yields the same shares of renewable energy in total gross electricity consumption in each model period as the scenario EEG+ETS. Hence, whereas the EEG establishes a technology-specific promotion scheme, the quota system leads to a uniform support for the generation of all renewable energy sources and technologies.

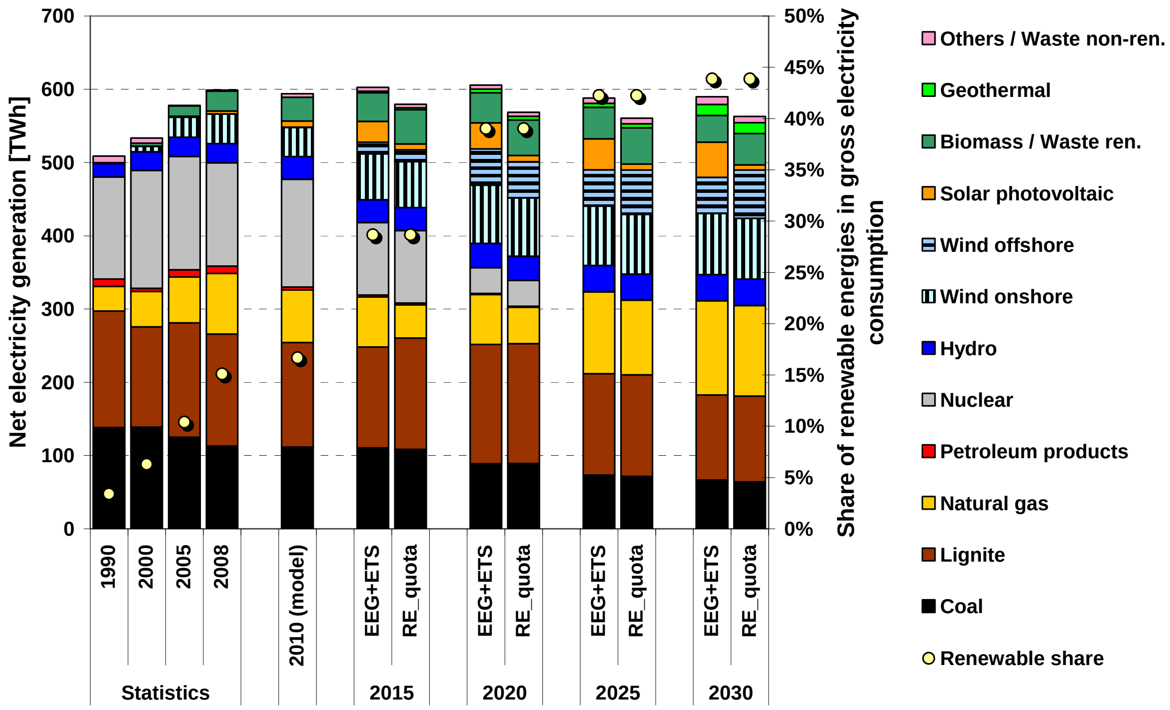


Figure 4: Net electricity generation in Germany in the scenarios with EEG and ETS (EEG+ETS) and with a quota system for renewable electricity (RE_quota)

Since in a quota system always the most cost efficient technology will be applied, the structure of the electricity generation from renewable energies in the scenario RE_quota differs clearly from the one in the scenario EEG+ETS. Technologies with higher generation costs (especially photovoltaics and certain types of biomass), that receive higher EEG tariffs and are therefore expanded in the scenario EEG+ETS, are now replaced with less costly technologies (here primarily offshore wind) (Figure 4). This leads to a reduction of the heterogeneity of electricity generation from renewable sources: in 2030, wind energy contributes with 62 % to the total renewable electricity production in the scenario RE_quota, compared to 51 % in the scenario EEG+ETS.

The results in Figure 4 also show that total electricity consumption, and consequently also electricity generation, is substantially lower with a quota system than with the feed-in tariff scheme. This is due to a higher electricity price level in the scenario RE_quota: residential electricity prices exceed those in the scenario EEG+ETS by 2.5 €-cents$_{2007}$/kWh in 2020 and 1.4 €-cents$_{2007}$/kWh in 2030. An even higher price difference between the two scenarios exists for the energy-intensive industry branches. While in the EEG scheme these industries benefited from a substantially lower EEG apportionment, no special arrangements have been modelled in the quota system.

At first glance, it seems difficult to understand, why consumers are faced with a higher cost burden in a system that automatically favours the most cost efficient generation technologies. Here, however, a differentiation has to be made between the additional capital expenditures of the renewable electricity production on the one hand, and the support expenditures (i.e. the transfer costs for the consumers related to the support system) (Ragwitz et al. 2007). Whereas a quota system surely exhibits lower capital expenditures for the expansion of renewable electricity, the feed-in tariff system is associated with lower support expenditures due to its technology-specific support which causes a reduction in the producer surplus. In the quota system the certificate price, which all renewable electricity generators receive uniformly, is fixed by the marginal production unit, i.e. the last (and most expensive) renewable production unit that is necessary to fulfil the quota. This certificate price is probably lower than the highest tariff within the feed-in tariff system, as the most expensive renewable technologies are not used. In the tariff system, however, tariffs are differentiate between technologies and energy sources leading, in total, to lower support expenditures than the uniform quota system. It has to be noted, yet, that this advantage of the feed-in tariff system is only maintained if the tariffs are periodically adjusted to the competitive situation of the different technologies such that overfunding is avoided.

Additional insights may be obtained when looking at the energy system costs. In all model periods, the energy system costs are slightly lower for the scenario with the quota system highlighting the cost efficiency of this support scheme. It has to be pointed out, however, that the differences in energy system costs between the scenario EEG+ETS and the scenario RE_quota are marginal (around 1 %).

4. Conclusion

The aim of the paper was to analyse the long-term impacts of the German feed-in tariff system for renewable electricity using the energy system model TIMES-D. It has been shown, that the contribution of renewable energy sources to electricity generation rises substantially when both the feed-in tariffs and the EU Emission Trading System are implemented. This also causes a marked increase in EEG payments and the EEG apportionment. When the merit order effect of the renewable electricity generation is taken into consideration, the additional burden of the EEG on electricity consumers turns out to be a lot less significant. Consequently, the impact of the feed-in tariff system on power consumption is, on the whole, relatively small.

Additional scenario calculations indicate that the strong expansion of renewable electricity in Germany is not the most cost efficient CO_2 mitigation measure. Furthermore, the extension of the operation times of the existing German nuclear power plants does not seem to have a marked effect on the development of the renewable electricity production. The adoption of a fixed quota system for renewable electricity would favour the investment in the most cost-efficient renewable technologies resulting in a stronger expansion of offshore wind at the expense of solar photovoltaics and biomass as well as slightly lower energy system costs than in the case of the tariff scheme. At the same time, the electricity price level is substantially higher when using the uniform quota system than with the technology-specific feed-in tariff system.

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