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A concept to assess the costs and benefits of renewable energy use and distributional effects among actors: The example of Germany

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Abstract

This paper describes a concept for the detailed assessment of the costs and benefits of renewable energy technologies deployment. A first quantitative impact assessment of German renewable energy technologies use is conducted from a historical perspective based on this comprehensive method. It includes costs and benefits at three different levels – energy system, micro- and macro-economic. The findings suggest that, at the system level, the generation costs in the electricity and heat sector are partly compensated by positive effects mainly from avoided emissions due to the use of renewable energy technologies in the electricity and heat sector. On the electricity market, small power consumers bear a very large share of the policy costs, while others might even profit from renewable energy technologies use. However, a comprehensive assessment that accounts for all the different negative and positive effects in the long term, including distributional effects, is more challenging. The concept applied here allows a differentiated comparison of a wide range of effects including aggregated costs and benefits as well as how these are distributed across different economic actors.

Keywords

Renewable energy deployment, costs and benefits, impact assessment

Introduction

The EU is moving towards a low-carbon economy based on the deployment of renewable energy technologies (RET) sources, a process that entails several positive effects: it lowers the EU's dependency on imported fossil fuels, makes the energy supply more sustainable,

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and fosters technological innovation and employment across EU countries. The EU's renewable energy directive constitutes an important step towards decarbonization with its binding target of 20% of gross final energy consumption from RET by 2020. The annual progress reports show a significant increase in the installed capacities of renewable electricity generation, especially wind and PV. Some countries, Germany among them, are even expected to exceed their national 2020 RET target, while others have a slow deployment rate (Renewable energy progress Report 2015; EC Com (2015) 293 final, June 2015). RET targets have since been set for 2030 – but in contrast to the 2020 targets, the EU-target has not been allocated at Member State level. Given that the overall RET governance is still to be decided, an intensive debate is now taking place, requiring a comprehensive and detailed analysis of the associated costs and benefits.

In this context, this paper aims to provide a comprehensive approach to assessing the costs and benefits of RET-development that is able to consider a wide variety of impacts at different levels. The approach provides a basis for conducting impact assessments and comparing effects between EU countries using different RET support policies. Thus, the objective is to develop a uniform and standardized concept that takes into account the diversity of RET policies. In addition, the paper indicates the data needed to conduct the impact analysis and depicts the costs and benefits of RET deployment at different levels while avoiding double counting or mixing effects. However, it is not a conventional cost-benefit analysis integrating all effects into one assessment, but a concept to identify and quantify the diverse impacts of RET policies at different levels. Ultimately, using this concept, the properly assessed costs and benefits of RET deployment provide a good basis for policy recommendations. The concept will be illustrated and implemented using the example of Germany.

The overall goal is to support policy makers in their decision-making processes concerning future RE policy designs. Therefore, the first step is to define the scope of the analysis: Which geographic area and time period does the assessment cover? Which RET are included? Which RET support policies are included? Which actors and levels are included?

The paper is structured as follows.

First, we provide a brief literature review of diverse assessments of the costs and benefits of RET use. Then, we describe the developed methodological approach depicting the types of costs and benefits and describing how to assess them. Before we draw conclusion for policy makers, we carry out an exemplary assessment of the different effects for Germany.

Literature review of the costs and benefits of RET use

Economic analyses of projects usually rely on a conventional cost-benefit analysis including the net social benefits of projects, while neglecting price and other distributional and economic effects. This is not a problem as long as projects are marginal, i.e. as long as they hardly affect relative prices or growth.[1] However, increasing RET deployment and RET targets in the EU are no longer marginal but are now decisive and crucial. This development is having significant effects on the energy system, the market and the whole economy and calls for a comprehensive impact assessment of RET deployment that goes beyond a conventional cost-benefit analysis to differentiate between impact levels, actors and interdependencies.

Regarding the impact of RET deployment on costs and benefits at the energy system level, ISI et al.[2] and Breitschopf et al.[3] differentiate between the direct and indirect generation costs of RET use. The latter refer to the integration of RET into the energy system.

These integration costs are identified by Hirth[4] as additional costs of RET deployment due to balancing electricity, profiling generation capacities and grid enforcements or extensions. These costs accrue because renewable electricity is variable, uncertain and location-dependent. The authors also point out that the market value of renewable electricity differs from the average price for electricity. Novacheck and Johnson[5] focus more on generation costs and include changes of the generation mix in the power system in their model. They argue that the increase in PV generation capacity will lead to a reduced need for conventional capacities, and will displace the variable costs of conventional generation, and thus impact the energy system.

Krozer[6] looks at the micro-economic level and the impact of RET use on consumer prices in the EU by comparing observed electricity prices with simulated prices. His findings suggest that deploying RET leads to a net relief of final energy consumers. The impact of RET on market electricity prices is confirmed by other studies such as Sensfuß et al.,[7] Tveten et al.,[8] Cludius et al.,[9] and Burgos-Payán et al.[10] They all report an impact of RET on the merit order of the power market. The change in the merit order results in a decrease of the wholesale market price. This price impact together with special levy and exemption schemes entail distributional effects at the consumer level. While energy-intensive industries, e.g. in Germany, France, the Netherlands, Denmark, etc., are not obliged to pay the full RET levy,[11] households enjoy no such privileges and therefore have to shoulder a larger share of the costs than privileged industries. A similar distributional effect is also reported by Farrell and Lyons[12] for Ireland and by Cludius et al.[9] for Australia, who state that larger consumers such as industries are more likely to benefit from decreased wholesale market prices than households.

There are many studies examining the impacts of RET deployment on national economies. Some[10,13–15] focus on the employment effects caused by construction, manufacture and installation of RET in these (RET) sectors and partly ignore the effects on upstream industries and others. Other studies extend the scope of analysis and include effects in upstream sectors[16] and in sectors beyond the RET sectors as well.[17–19] To assess the overall macro-economic impact properly, all the negative and positive, direct, indirect and induced effects of RET deployment have to be included.[20] While direct and indirect effects occur in the RET sector and its upstream industries, further effects are induced due to changes in production costs, income and hence consumption. There is a special focus on decreasing the import dependency on fossil fuels (see, e.g. Santamaría and Azqueta[16] and Ortega et al.[21]) or electricity,[5] which is supposed to improve energy security. However, none of the authors quantifies the additional energy supply security gained from RET deployment. Moreover, technology cost decreases due to growing RET capacity installments is another important element of macro-economic analyses. Experience or learning curves are one option that can be used to illustrate the impacts of RET deployment on technology costs.[17]

Many authors such as Santamaría and Azqueta,[16] Farrell and Lyons,[12] Burgos-Payán et al.,[10] and Ortega et al.[21] stress on the positive environmental impact of RET deployment. Although emission data are available, the analyses are limited by the lack of accepted monetary values for avoided damages or costs. As Barbose et al.[22] state, there are hardly any detailed and comprehensive estimates of broader social benefits beyond the metric quantification of the avoided emissions.

Regarding the overall concept or framework for assessing costs and benefits, JRC[23] provided a very detailed and comprehensive illustration of the potential effects of wind power on society. The study refrained from elaborating a detailed methodology, or an assessment, but serves as a good framework and basis for elaborating suitable approaches. Similarly, based on previous studies of ISI et al.,[2] IRENA and CEM[14] suggest splitting the effects of RET use into four main categories: macro-economic, distributional, system-related and additional effects.

The methodological concept

This paper enhances the methodological concept depicted in Breitschopf and Held[24] and IRENA and CEM[14] by adding a stepwise consideration of the impacts triggered by RET policies. As shown in Figure 1, RET policies form the starting point, since these are critical determinants for decisions to invest in RET. These investments in RET affect the energy system and induce changes in the generation mix, operation and electricity transmission. Subsequently, prices on the wholesale and retail markets might be affected. The financing mechanism of policies determines how the costs and benefits caused by RES support impact different actors. This implies that the policy scheme allocates costs and benefits among consumers, investors or generators which, in turn, has an impact on the whole economy. Typically, increasing energy prices lead to increasing consumer expenditure for energy and decreasing expenditure for other goods. As a consequence, any change in energy price affects the whole economy (referred to as "induced effects"). At the macro level, the impact of RET deployment is captured by aggregated figures, e.g. changes in GDP. However, in order to assess the impacts at the micro level, detailed information on the distribution of the burden is required. Therefore, to properly understand and assess the costs and benefits of RET deployment, the method applied here differentiates between three levels:

- Energy system (system-related costs and benefits)
- Micro-economic level (actor-related costs and benefits as well as price occurring at the micro level)
- Macro-economic level (economy-wide costs and benefits)

While some effects such as costs, levies or employment due to RET deployment are clearly attributable to the energy system, market, or economy, other effects are not. The latter include technological and structural changes as well as energy security aspects (see left-hand and right-hand side of Figure 1). Technological and structural changes occur at all levels, e.g. changes in market structures or technologies. They all entail price (cost) changes. Similarly, energy security aspects occur across all levels. Energy security is a broadly used term that is described by a set of different attributes[25] such as efficiency, productivity, technological reliability and diversity at the system level. At the micro-level, energy security can be captured by the affordability of energy and the competitiveness of industries, while import dependency and price volatilities address macro-economic aspects of energy security. Therefore, technological changes and energy security are considered cross-level effects that affect the national economy and can be partially depicted at the different levels. But they cannot be assessed as one single all-encompassing effect.

The cost-benefit concept relies on two principles: additionality and no double-counting.

With regard to "additionality," it compares the costs and benefits of two energy systems, markets or macro-economic scenarios:

- a scenario with an increased share of RET

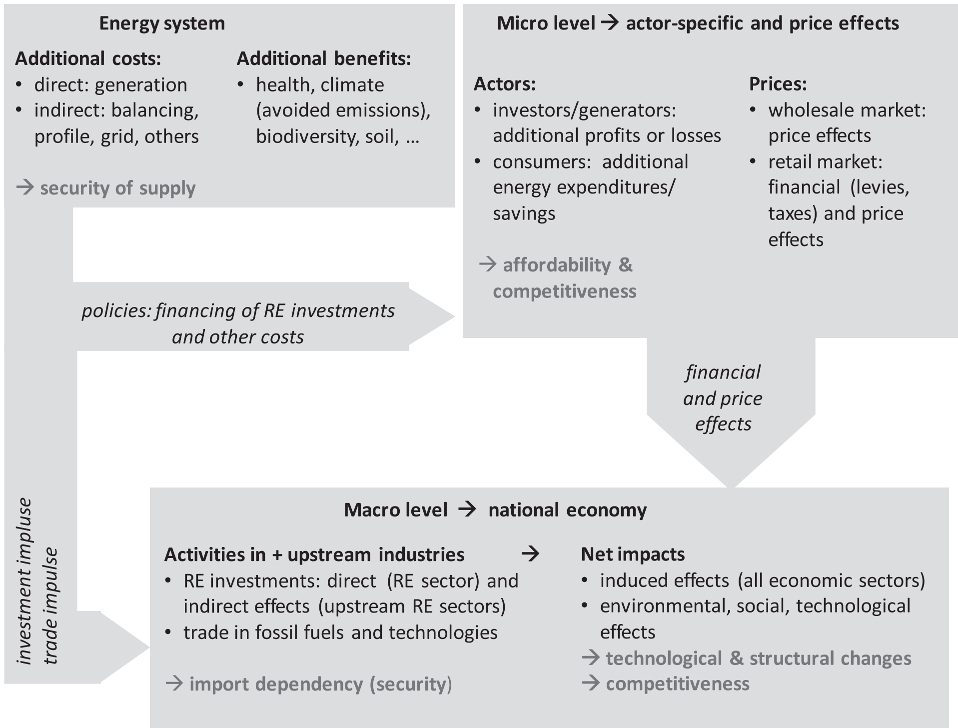

Figure 1. Levels of impact related to RET deployment. Source: own depiction.

- a reference scenario, which typically includes nuclear and/or fossil fuels and possibly no or only a low share of RET.

The "additionality" shows the additional costs or benefits due to RET deployment. The design of the scenarios is flexible and depends on the research question. For example, analyzing the effect of policy-induced RET deployment requires a comparison of the RET scenario with a reference scenario that includes all RET which are not induced by policies. In contrast, comparing a RET scenario and a reference scenario without any RET depicts all the costs and benefits associated with RET deployment.

"No double-counting" means that it has to be ensured that no double counting takes place, if additional costs and benefits are analyzed. For example, if $\mathbf{CO_2}$ prices are internalized in the generation cost calculation, the benefit from avoided CO_2 emissions must be reduced by these internalized CO_2 costs (see also Breitschopf and Diekmann[26]).

The same principles apply to costs related to balancing and system back-up services. If electricity generation costs already include expenditures that are required to balance and backup the power system, expenditures for balancing cannot be included as a separate position in cost accounting at the system level.

Normally, future technology costs are fully reflected in future capital expenditures (investments) and, under a dynamic perspective, they are assessed using cumulated installed generation capacities. Therefore, no separate accounting of the effect is required at the macro level.

Similarly, decreasing fuel imports, increasing exports or lead market shares are additional effects that are captured by their prices and quantities and reflected in the fixed and variable costs of electricity generation as well as in the turnover of manufacturers and service providers. Therefore, at the system level, they are incorporated in the additional generation costs (prices, quantities, risks). As decreasing imports or increasing exports affect the value added, GDP and employment, they are also considered macro-economic effects and will be captured by future growth or employment.

Energy system

Additional direct costs

- Effects on the energy system encompass all the direct and indirect costs and benefits of RET deployment within the system boundaries. While direct costs include all the costs that are directly related to electricity or heat generation, such as installation, operation and maintenance of RET, indirect costs are caused by integrating RET into the existing generation system and include grid extension costs, balancing costs, profiling etc. Benefits from RET use arise, e.g. as a result of avoided GHG emissions and air pollutants. Overall, the effects at the system level do not take into account any policy-induced payments.

The types of additional system costs that occur at the system level depend on the design of the energy system and can differ from system to system. Additional system costs can be roughly differentiated into two types:

- additional direct costs at the system level
- additional indirect costs at the system level.

The different types of additional costs for power generation are listed in Table 1.

The additional direct costs are the difference in generation costs (power or heat) between an RET scenario and a reference scenario. The generation costs are calculated as the levelized cost of energy (LCOE). LCOE are the sum of discounted operation and maintenance and investment expenditures over the lifetime, divided by the sum of discounted yields over the lifetime, and are based on investment, operation and maintenance expenditures. As conventional and renewable generation technologies display different expenditure structures, e.g. high upfront costs for RET versus high expenditures for operation and maintenance of conventional generation, the choice of the discount rate strongly influences the LCOE, and hence, the magnitude of the additional direct costs.

In the power sector, LCOE are calculated for each generation plant. The sum of LCOE, weighted according to the supplied quantity of power, yields the total direct costs. The difference between the generation costs of the two systems (RET system – reference system) shows the total additional electricity generation costs at the system level (equation 1)

$$adGCsys = \sum_{RET}(LCOE_{RET} * Q_{RET}) + \sum_{sup}(LCOE_{sup} * Q_{sup}) - \sum_{ref}(LCOE_{ref} * Q_{ref}) \quad (1)$$

adGCsys: additional generation costs at the system level
LCOE: levelized costs of heat or power, in €/kWh
Q: quantity of heat or power, in kWh
sup: conventional generation (plants) needed to provide the required generation capacity in a RET-based electricity system

ref: reference system, which is typically based on a higher share of fossil fuel – or nuclear-based generation technology and includes no RET or at least no policy-induced RET deployment
RET: renewable energy generation technology

RE in the heating sector cover a large variety of heating systems in different buildings and predominantly decentralized heat generation. The difference between the LCOE for renewable heating technologies (RET-H) and conventional heating technologies per building type shows the additional generation costs per technology. The calculation is given in equation (2). As one RET-H might replace different shares of conventional heating technologies (reference technology), a respective reference heating technology mix (The technology mix reflects a mix of different conventional technologies that are replaced by one single RET.) should be applied. The differentiation into building types enables a better assessment of the total heating costs.[27] To assess the additional annual generation costs at the heating system level, all expenditures for investments (annuity of investment expenditures), fuel,

Table 1. Additional costs in power generation.

Types of additional system cost	*Description*
Power or heat generation costs • direct costs • relevant for heat and electricity	Costs arising from electricity and heat generation: • the costs of the renewable generation technology minus the avoided costs of conventional generation
Balancing costs • indirect costs • focus on forecast errors • relevant for electricity	Balancing costs occur due to deviations of variable renewable power plants and the need for operating reserve and intraday adjustments in order to ensure system stability. Balancing services provided by positive or negative balancing capacity may increase or decrease the electricity fed into the grid.
Profile costs • indirect costs • focus on back-up capacity • relevant for electricity	According to Ueckerdt et al.,[28] profile costs occur due to the following effects: • a potential increase in the average generation costs of the residual load as a result of RET-induced decrease of conventional power utilization. • Additional capacity of dispatchable technologies required due to the lower capacity credit of non-dispatchable RET such as wind or solar in order to cover electricity demand at peak times with simultaneous low RET generation. • Potential curtailment of electricity required in times of overproduction represents another cost component.
Grid costs • indirect costs • relevant for electricity (potentially for biogas grid in the heating sector)	Reinforcement or extension of transmission or distribution grids as well as congestion management including re-dispatch required to manage high grid loads.
Transaction costs • indirect costs • relevant for heat and electricity	Market transaction costs: additional forecasting, planning, monitoring, procuring power, establishing trade, contracting, data exchange, etc. Policy implementation costs: administrative cost to implement RET policies or fulfill data provision requirements (accounting, approvals,. . .)

maintenance and operation for all technologies of an RET-based and a non-RET-based system are summed up and compared, similar to the calculation shown for power technologies.

$$adGC_{REsys\ tech} = \sum_{g}[(LCOE_{REsys\ g} - \sum_{ref}(LCOE_{ref\ g} * s_{ref\ g})) * Q_{REsys\ g}] \quad (2)$$

adGCtech: additional generation costs at the technology level
LCOE: levelized costs of heat or power, in €/kWh
Q: quantity of heat or power, in kWh by each RET and g
s: share of fossil-based energy that is replaced by the respective RET
ref: reference heating technology, e.g. a fossil fuel-based generation technology
g: building type (single family home, flats, service and producing sector buildings)
REsys: renewable energy generation technology plus its accompanying conventional heating technology if there is a combination of technologies

Additional indirect costs. Additional indirect costs may arise, for example, from integrating large shares of non-dispatchable RET into the power system. These include costs that are not directly linked to electricity generation and, in some cases, cannot be directly allocated to a certain generation technology. But they accrue due to the necessity to maintain a stable power system.

As heat generation is more decentralized, either based on non-intermittent RET or combined with non-intermittent energy sources (e.g. gas and solar thermal) and often located close to demand sites (choice of sites is less dependent on resource availability), there are only low additional indirect costs, e.g. if the district heating network is extended due to RET use.

Balancing costs. In power generation, some RES are variable and stochastic in their electricity output and, thus, are not fully dispatchable. Forecasts of wind and solar power generation are subject to errors, which have to be "balanced" in the short term to guarantee that the total electricity supply matches the demand profile. To compensate these errors, operating reserve has to be provided involving additional costs. Apart from conventional generation plants, electricity storage or demand-side management are other options to provide operating reserves. Costs arising from balancing services for renewable power plants can be assessed if data are available on forecast errors and the respective cost of the required balancing power. Ideally, these values are estimated based on information with high time resolution (e.g. hourly information), since the price of balancing power depends on the individual load situation. Thus, the use of a modeling tool is suggested in order to estimate the price of the required balancing power in the respective load situation.

Profile costs. According to the definition used by Ueckerdt et al.,[28] "profile costs" are the economic costs resulting from the variability of RET and not included in grid and balancing costs. Profile costs occur due to the following effects:

- a potential increase in the average generation cost of the residual load as a result of the RET-induced decrease of conventional power utilization.
- Additional capacity (back-up capacity) of dispatchable technologies required due to the lower capacity credit of non-dispatchable RES such as wind or solar to cover electricity demand at peak periods.

- Potential curtailment of electricity required in times of overproduction is another cost component.

To estimate the profile costs arising from increased RET use, again, the costs for additionally needed capacity to ensure system stability are compared between a RET scenario and a reference scenario. If no electricity market model is available, generalized results from electricity market models based on the link between the capacity factors of installed RET and the share of RET in the system can be used to estimate the share of costs arising from RET. Curtailment costs can be easily estimated by multiplying the curtailed electricity by the current electricity market price.

Additional grid costs. Additional grid costs encompass only the investments that are caused by RET deployment and that would not have occurred in an energy system without RE use. The grid extension and reinforcement costs are calculated as the annualized investment over the lifetime of the grid infrastructure and the discounted annual operation and maintenance costs. In addition, congestion management including the re-dispatch required to manage high grid loads is included here. A detailed estimation of additional grid costs requires a grid model in which a scenario with increased RET use is compared to a reference scenario.

Transaction costs. In line with increasing RET use, market transactions also increase as more data, information, coordination and contracting is required. Besides market transactions, there are policy-induced transactions to meet administrative requirements and monitor activities. Thus, transaction costs comprise costs for additional transactions among market participants and policy implementation costs due to RET deployment.

Other costs. There are further negative effects of an RET-based energy system such as the reduction of fishing grounds, shipping detours or deviations, noise emissions and lights/flashes, irritation for aviation and radar, bird fatalities etc. As data on these effects are hardly available and they are difficult to account for in monetary terms, they are not assessed in this analysis.

Additional benefits

Beside the positive effects on the environment and air pollution of using RET rather than fossil fuels, society also benefits from decreasing the dependency on fuel imports and from technology development. However, these effects are partly captured by expenditures or other macro-economic effects, and are not further discussed as system-related costs or benefits.

Avoided emissions of greenhouse gases (GHG) and air pollutants are major benefits of RET deployment. While GHG emissions cause long-lasting global effects, emissions of air pollutants have more short-term local impacts.

In the literature, emission factors are determined with a varying level of detail. Whilst some studies define factors at technology level, covering, e.g. coal firing as an average value of existing technologies,[29] other studies further differentiate emission factors by the type of coal firing technology, and are rather demanding regarding data requirements. Direct emission factors reflect the emissions of fuel use (generation), while indirect emission factors represent the emissions related to the provision of the technology or fuel. Ideally, both factors should be included.

The monetarization of emissions in terms of the social costs of carbon is very complex. Thus, existing estimations based on diverse models show a large range of values (from 0 € to more than 200€/t CO_2) and take into account effects of GHG on health, consumption, land use, water resources, etc. over a long-time horizon. Discounting them to the present provides a monetary value for the potential damage of one unit of GHG emitted. Furthermore, there are discussions about whether the marginal damage value of CO_2 or the marginal mitigation cost of CO_2 should be applied when monetarizing CO_2 emissions. Ideally, these should be identical in a perfect market.

The damage costs of air pollutants are estimated based on diverse observations, experiments and response functions. To a large degree they depend on where and when they are emitted. Pollutants in densely populated areas cause more damage than in sparsely populated ones. As the exact point source of the pollution is rarely known, a weighted average is often used of the local damage costs of air pollutants.

Micro-level

Effects at the micro-level are the result of policies that determine how the additional costs or benefits at the system level should be distributed among consumers, producers and investors. These effects are also called actor-level or distributional effects.[2,24] They include financial effects or price effects that different actors face, but in contrast to system-related effects, these do not reflect the real use of resources. Price effects (Table 2: Merit-order effect) occur at the micro-level and affect the wholesale price of electricity. They occur due to changes in the merit order of electricity production leading to a lower price and increase the consumer surplus and decrease the producer surplus of conventional electricity producers. Price effects may be passed through to retail markets (electricity component of the retail price (Table 2)). If a quota obligation is used to promote RET, higher costs of renewable electricity are usually passed on to consumers through market prices. Financial effects (Table 2: policy costs) are the direct burden or support for consumers and producers as a result of RET policies. While burdens are "money outflows from consumers' pockets", supports are "money inflows into the generators/investors' pockets". These are referred to as "policy costs" and comprise payments by the public or consumers due to RET support. For example, in Germany or France, industries and households pay a levy to help finance RET support policies. In many countries, selected final energy consumers enjoy a privileged levy (special exemption schemes). Alternatively, the RET levy can be financed from the public budget, as was the case in the Netherlands until 2012.

The market-related effects cannot be expressed as a single aggregated figure, as some actors might pay for but also benefit from policy measures to a differing degree. Finally, financial and price effects do not really reflect the actual use of resources for energy provision; instead, they are the result of policy design and the chosen financing mechanism.

Policy costs for consumers and the state budget. The policy costs in the electricity sector, i.e. the total additional burden, is calculated as the difference between the remuneration, such as feed-in tariffs paid to generators of renewable electricity (or market prices plus premiums or certificate prices), and the market wholesale prices realized for renewable electricity at the respective time multiplied by the generated quantity of renewable electricity plus all additional transaction and balancing costs (see equation 3).

$$\text{Policy costs} = \Sigma_{RE}(REMUN_{RE} * Q_{RE} - \Sigma_t(P_t * Q_{t\,\mathrm{RET}})) + \text{other additional costs or revenues} \quad (3)$$

$REMUN$: feed-in tariff for each RET and respective year, or sum of electricity price and certificate price, or sum of electricity price and premium.
t: time (hourly)
RET: renewable energy technology
Q: quantity renewable power sold in time t
P: market price in time t

The policy costs in the heat sector paid by the heat generator (equal to investor) are calculated as the difference between the additional generation costs for heat generation minus the annuity of the total financial public support (over the lifetime of the heat system; see equation 4)).

$$Add.\ burden\ heat = adGC_{REsys\ tech} - \text{ annuity of financial support} \quad (4)$$

$adGC_{REsys\ tech}$: additional generation costs of a RET system at the technology level

Consumer-based financing. Consumer-based financing refers to the financing of RET deployment by final energy consumers without any support from public budgets. As the

Table 2. Effects on actors in the market.

Types	*Description*	*Type of effect*
Policy costs (retail market)	Consumer-based burden-sharing through feed-in schemes Special exemptions/equalization schemes for selected consumers e.g. energy-intensive industries	Financial effect for electricity consumers → through levies, taxes and exemptions on retail price (shift of financial effect or burden between different types of consumers) state budget
	Public budget-based burden-sharing, i.e. resulting policy support costs are financed through the state budget Consumer-based burden-sharing through RET obligations or standards	Price effect for consumers → energy price component of retail price
Merit-order effect (wholesale market)	Change of market prices due to changes in the merit order of the power supply (changes in the order of the generation portfolio).	Price effect for power market participants on wholesale price
Transfer payment, premium	Grants, subsidies, premiums, tariffs or PPA with certificates for RET generation paid to investors or producers	Financial effect paid by consumers or state budget to RET investors/ generators

power and heat sectors have different features, the applied policy instruments differ (Table 3). In the power sector, the feed-in tariff scheme in Germany is a good example of an RET policy instrument financed by final energy consumers (households and firms).

The levies in feed-in schemes are determined either by the difference between the feed-in tariff and the actual market value of power (€/kWh), or by the premium. Some parts of industry may enjoy a privileged levy. The reasoning behind this is that energy-intensive industries' competitiveness may suffer under increasing energy prices. The German government has elaborated a special equalization scheme for energy-intensive industries facing strong international competition. They pay a reduced RET surcharge. But this, in turn, leads to domestic market distortions, as not all industries benefit under this scheme. And the relief of privileged consumers increases the burden on the remaining, non-privileged actors.

In a quota system (RET obligation or portfolio standards), in which RET certificates are traded, the additional costs of RET deployment for actors are reflected in the certificate prices. In a functioning market, the cost of certificates equals the additional costs of renewable generation, and the certificate costs are included in the market price for electricity. Ultimately, final energy consumers pay for RET use. To assess the additional costs for consumers, the traded certificate prices could be multiplied by the respective trade volume. This reflects the sum of surcharges paid by consumers.

In the heat sector, obligations like emissions standards or quotas w/o certificates are commonly used instruments to induce demand for RET-H. In case RET certificates are traded, the certificate price multiplied by the heat generation plus any other costs that accrue due to trade reflect the costs for final energy consumers. Other support instruments (grants, interest subsidies, tax credits, etc.) also exist. They are mainly co-financed from public sources and their credits should be taken into account when assessing policy costs. As heat generators and consumers are in many cases identical, costs equal burdens if no further support instruments are applied. Burdens are smaller than system-related costs if public financial support is provided.

Public budget-based financing. Public budget-based financing refers to the financing of RET deployment from government or state budgets. Regardless of the type of policy scheme – feed-in tariffs or premiums, investment grants or tax credits for RE generation or

Table 3. Overview of consumer-based financing – financial effects for final energy consumers.

Instrument	*Power sector*	*Heat sector*
Guaranteed price or price supplement: Feed-in tariffs Feed-in premium (with and w/o caps)	Difference between tariffs (premium) and wholesale market prices plus all additional balancing and transaction costs.	Not applied
Obligation: Quota with RET certificates	Total number of certificates (kW) multiplied by their price (per year)	Total number of certificates (kW) multiplied by their price (per year)
Standards (share of RET w/o certificates)	Not applied	Additional generation costs

capacities – this represents government interference in the market. In contrast, the financing of a quota obligation is typically consumer-based.

In the power sector, guaranteed prices or premiums may be completely or partly financed by the public budget. In such a case, the same methodological approach should be applied as in the case of consumer-based burden-sharing: The additional price costs or financial effects should be disclosed in the respective public accounts. Other policy support instruments comprise financial support for investments or operation (Tax credits or subsidies can be granted for own generation and consumption as well as for consumption of third parties.). The total monetary volume is an estimate for policy costs and should be disclosed in the public accounts and annual subsidy reports.

In the heat sector, publicly financed investments or generation via subsidies or tax credits are common measures to support RET use. To assess these additional financial effects, the same procedure can be applied as in the power sector. See Table 4 for more details.

Price and financial effects for producers

Merit order in the wholesale market. The generation of electricity from renewable sources affects the market price of power as the variable generation costs of most renewable energy power plants are close to zero (with the exception of biomass power plants). Hence, in an energy-only-market, where the marginal cost of the last operating generation plant sets the market price, the very low marginal costs of additional renewable-based electricity generation shifts the supply curve to the right and lowers wholesale market prices. This

Table 4. Overview of public budget-based burden-sharing – financial effect.

Instrument	*Power sector*	*Heat sector*
Guaranteed price or price supplement: Feed-in tariffs Feed-in premium (with or w/o caps)	Public budget for support scheme should include: difference between tariffs (premium) and wholesale market prices plus all additional balancing and transaction costs.	not applied
Obligation: Quota with RET certificates Standards (share of RET w/o certificates)	not applied	not applied
Grants or subsidies	Public budget for grants	Public budget for grants
Investment grants Interest/repayment subsidies	Public budget for subsidies: based on foregone revenue from capital (interest rate) or directly paid subsidies	Public budget for subsidies: based on foregone revenue from capital (interest rate) or directly paid subsidies
Tax credits	Public accounting of lost tax revenues	Public accounting of lost tax revenues
Generation tax credit Investment tax credit		

price-decreasing effect is called the merit-order effect. As this effect depends on the current load profile and available supply mix, it should be assessed using an energy sector model that compares the resulting wholesale market price of a RET scenario with that of a reference scenario. Thus, the merit-order effect reduces the supplier surplus of conventional electricity generators, and increases the consumer surplus of electricity utilities. Passed through to final electricity consumers, it affects the electricity retail price as well.

Effects on investors. Depending on the policy scheme, RET policies could ensure revenues, e.g. through feed-in tariffs, or reduce the expenditures of investors on renewable generation technologies, e.g. through grants, or tax credits to ensure investors a certain return. There are no additional profits due to RET deployment or RET policy if a similar investment in a conventional or non-policy-supported technology would have led to the same profit. To assess the impact of RET policies on projects' returns, a cash flow analysis could be applied, which provides either the net present value (NPV) or the internal rate of return (IRR) of an RET and an alternative investment. Assuming discounting factors that reflect the real opportunity costs of capital (same risk level), the NPV of an RET investment reflects the total benefit of RET projects compared to alternative investments. However, strictly applying the "additionality" principle calls for comparing the NPVs or IRRs of an investment in RET with the corresponding alternative investment in conventional generation technologies instead of using the opportunity costs of capital. But as data on these investments are rarely available, the opportunity costs of capital can be considered a "reference case".

National economy

To obtain a general picture of the impact of RET use, the effects at the system level and micro-level should be integrated into a more overall perspective at the macro-economic level. A distinction is made between gross and net effects. Whilst gross effects are restricted to the renewable sector, net effects consider economy-wide effects. The problem of gross effects is that they do not respect the additionality principle, if a reference scenario cannot be determined. To fully account for the additionality principle, a comparison of two scenarios is required, where effects in the RET industries (direct), upstream industries (indirect) and beyond these industries (induced effects) are included. This is often called net impact assessment, and respects the additionality principle. Given that the estimation of net effects requires comprehensive macro-economic modeling, gross effects are commonly used as an indicator to assess the significance of RET-use for the overall economy and employment effects. Beyond economic effects, there are also environmental, technical and health aspects affected by RET use that entail further economic effects. However, they are difficult to include in a model and we do not consider them in this analysis. A more detailed description of these effects is given in JRC.[23]

Effects in the RET sector (gross effects). Sectoral effects, also qualified as gross effects, show the effects in all industries directly related to RET activities such as manufacturing, operating, construction, research, etc. Strictly speaking, sectoral effects do not show additional effects. They show the RET-induced employment in RET industries and service sectors and related industries. They are assessed only for RET-based energy systems and do not rely on comparing an economy with to one without RET (If the employment levels of an energy system with-RET and one w/o-RET are compared without taking into account the potential price and income effects of RET in other sectors, then two gross effects (sectoral effects) are compared without depicting their impact on the economy as a whole.).[14,20] Thus, they ignore potential negative effects and effects ''outside'' the RET-related industry. Therefore, these effects are purely (positive) RET sector effects.

A relatively simple and common approach to assess sectoral employment – direct impact – is to apply employment factors per unit installed or per operated generation capacity.[14] A more complex approach is depicted in IEA-RETD,[30] which describes how to apply input-output tables to assess direct and indirect job creation due to RET deployment.

Reduced imports of fossil fuels due to RET deployment imply decreasing import dependency and energy supply exposure to geopolitical risks. It should be noted, however, that a decrease of imports does not necessarily entail a positive economic impact per se. If imports are replaced by products that are ''more expensive'' per unit of energy, there may be negative economic impacts for consumers.

It is difficult to express a decreased import dependency in monetary terms. One possibility is to look at price fluctuations and shortages of certain fuels (geopolitical risks). These might decrease in line with decreasing fossil fuel imports. The reduced risk could lead to lower requirements for storage capacity, e.g. gas, and thus reduce infrastructure-related costs. These reduced ''security'' costs could be counted as ''benefits'' at the system level, but again they are difficult to quantify in monetary terms.

The economic effects of increases in technology exports are captured by or reflected in production, turn-over, value added and gross employment across RET manufacturing industries. RET trade or RET export is a macro-economic indicator, which can be used in macro-economic modeling and might have a large impact on value added, but the volume of exports does not allow conclusions about the actual ''net'' benefits.

Net impact assessment – economy and beyond. To pinpoint the real economy-wide effects (net employment impact, net GDP growth) of RET deployment – net of all costs – for the overall economy (all sectors), all the positive and negative effects of RET deployment should be included. This requires macro-economic modeling that takes system-related costs into account as the main economic drivers as well as the financial and price effects at the micro-economic level and compares them to a reference situation (scenario or system) without RET use. The macro-economic (net) approach integrates all the system- and actor-related effects into one assessment. In order to model net effects, all the costs and benefits at the system-level must be included as well as the different charges and reliefs of economic agents at the market level. Table 5 depicts the main effects that are considered crucial for assessing net impacts. Moreover, the model produces more accurate aggregated results, i.e. impact on economic growth measured by changes in GDP or net employment, if the distributional effects are more differentiated. The net impact assessment (see Table 5) delivers an overall picture of the economic RET effects. In addition to distributional effects, impacts on competitiveness (changes in prices of domestic versus global products (relative prices)) as well as energy security aspects (price volatilities (market), storage costs and system enforcements) widen the perspective from a regional to national and international framework.

Case study: effects of RET use in Germany

In this section, we implement the concept outlined above, and assess the costs and benefits of historical RET use based on the case of Germany. We apply the proposed structure,

Table 5. Overview of positive and negative effects that should be taken into account when modeling the net effects of RET deployment.

Positive effects → job increases	*Negative effects → job losses*
Increase in investment in RET (RET industry and upstream industry)	Displaced investment in conventional generation technology (CE industry and upstream industry)
Increase in O&M in renewable generation (RET industry and upstream industry)	Displaced O&M in conventional power generation (CE industry and upstream industry)
Increase in fuel demand (biomass) (RET industry and upstream industry)	Decrease in fossil fuel demand (CE industry and upstream industry)
Increase in trade of RET and fuel (biomass) (RET industry and upstream industry)	Decrease in trade of conventional technology and fossil fuels (CE industry and upstream industry)
Higher household income from employment in RET industry	lower household income from employment in CE industry
Decreased electricity price for households and industry due to merit-order effect	Increased electricity price for households (budget effect) and industry (cost effect) due to additional generation cost of renewables-based power generation

Source: Breitschopf et al.[20]

analyzing impacts at distinct levels – i.e. at energy system, micro-economic and national economy level.

Energy system

Additional costs. In Germany, the total additional costs for renewable power and renewable heat amounted to about € 12.1 billion and € 2.2 billion in 2014, respectively.[13]

Regarding balancing costs, the TSOs provide data on forecast errors in Germany. The respective market electricity prices for compensating these errors are assessed based on the costs for electricity reserves. In 2014, the balancing costs amounted to almost € 190 million.[13] These costs include the expenditures of direct market participants as well as those of TSOs for balancing forecast errors due to RET-based electricity generation. These costs have declined over time due to increasing market integration and learning effects.

Data on profile costs are not available in Germany, because, up to now, no back-up capacity is explicitly provided. Short-term supply security (grid) is provided by balancing capacities, while the Federal Network Agency in Germany is responsible for permitting shutdown or operation of power generation plants. This affects electricity supply in the long term. Curtailment costs can either be accounted for under direct costs (generation costs of two systems) or indirect costs (profile).

In Germany, data on investments in grid projects are derived from the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway. Based on these data, investments are identified that are related to RET deployment. The total additional grid investment is then calculated as an annuity over the lifetime of these investments. For 2014, the estimated annual additional costs for investments in the transmission grid amounted to more than € 720 million.[13]

Transaction costs comprise the transaction costs of market participants and the policy implementation costs due to RET deployment. They are not available on an annual basis. The estimation for Germany in 2008 shows additional costs of around € 30 million.[2]

Most RET used to generate heat are not variable in their output and are available throughout the year, or they are combined with a generation system (and included in additional generation costs) that provides reliable heat at any time. Thus, no additional balancing costs are incurred for RET-H.

The use of RET-H hardly ever requires extension or reinforcement of the heating grid, as RET-H generation is typically decentralized and located close to its consumption point. The existing gas network could be easily used for both natural gas and methane. Similar to balancing costs, there are hardly any additional grid costs caused by RET-H use.

Table 6 shows the total additional costs and benefits at the system level for heat and power. An interesting aspect is the additional costs per unit generated renewable heat or power. Figure 2 displays the additional generation and integration costs of power and heat per generated RET. It highlights several interesting aspects:

(i) Additional indirect costs are still low compared to direct costs in the electricity sector. (ii) The investments and variable costs of heat and power differ due to the different product types and technology mix for generation. Further, the implementation of energy efficiency

Table 6. Overview of costs and benefits in Germany in 2014.

Level	*Type of effect, in billion euros*	*Power*	*Heat*
Energy system	Additional direct costs	12.1	2.2
	Additional indirect costs:	0.7	1.3
	Grid costs	0.2	
	Balancing costs	10.2	
	Avoided emissions		

Source: ISI et al.[13]

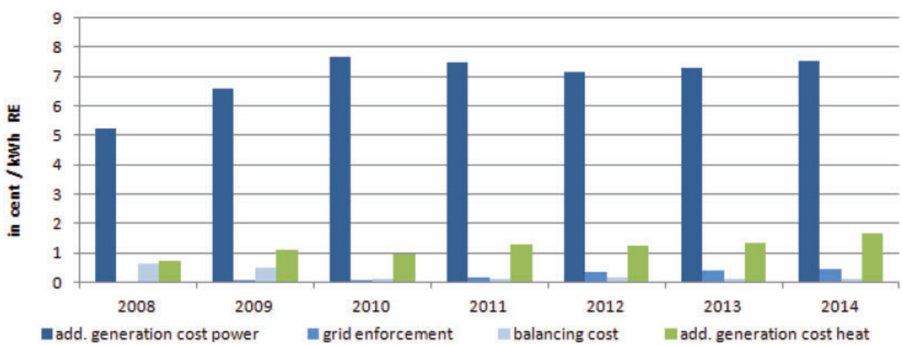

Figure 2. Development of additional costs per generated unit of power or heat in Germany.
Source: own depiction, based on ISI et al.[13] Note: technology-specific data are not available for all costs.

measures, e.g. insulation of buildings, long (re)investment cycles and self-sufficiency or supply in the heat sector, may keep investments in RET and hence generation costs (still) low. (iii) Between 2009 and 2011, temporary high growth of the relatively expensive RET solar power (AGEE-Stat (BMWi))[31] drove total system costs upwards.

Additional benefits. The most critical step is assessing the social costs of GHG because there is no scientifically accepted "damage value," but rather a variety of approaches and model results giving a large range of values. For the current study, a damage value of 80€/t CO_2 is assumed, which is in line with research results of the German Environment Agency.[29]

To assess avoided emissions, substitution factors are used that show to what extent fossil energies are replaced by RET. Further input factors for the assessment include technology-specific emission factors that indicate the direct and indirect emissions per kWh generated, the quantity of RET generated and the damage cost of emissions.[29] The calculation is described in detail in Breitschopf and Held,[24] and includes three steps: estimation of specific avoided emissions, multiplication by generated RET volume and by marginal damage costs.

The avoided emissions for Germany are dominated by avoided emissions of GHG in the power sector, while the effect on air pollutant emissions is minor (see Figure 3). Certificate prices for CO_2 are not included here, i.e. internalized external costs (CO_2 prices) are not subtracted from the total (gross) avoided damages.[26] The benefits are highly sensitive to the assumed damage costs of CO_2 (e.g. 20€/t CO_2 would result in total benefits of about € 2.4 billion).

Comparing the benefits of avoided emissions with additional costs (Figure 4) reveals that the benefits from using RET per unit of additional costs are higher in the power sector. This emphasizes the importance of implementing energy efficiency measures in buildings, preferably in combination with RET-based heating. Although avoided damage costs represent a crucial benefit, they are not the only positive effect of RET use. Further positive, dynamic effects are decreased import dependency and technology costs, which are captured by decreasing future prices.

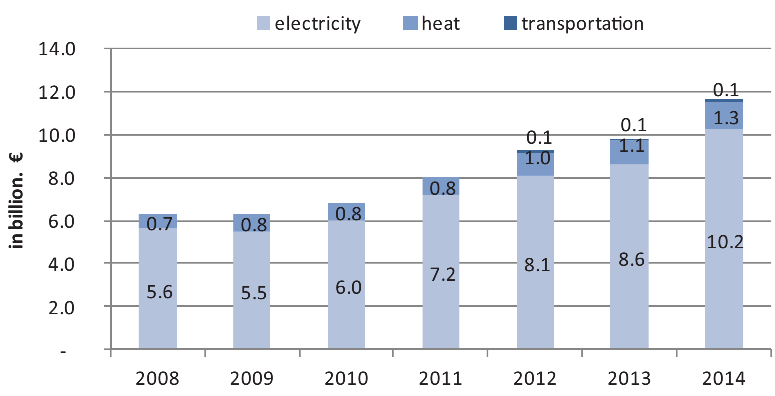

Figure 3. Avoided damage costs in Germany due to RET deployment.
Source: ISI et al.[13] based on UBA[29] and BMWi.[31]

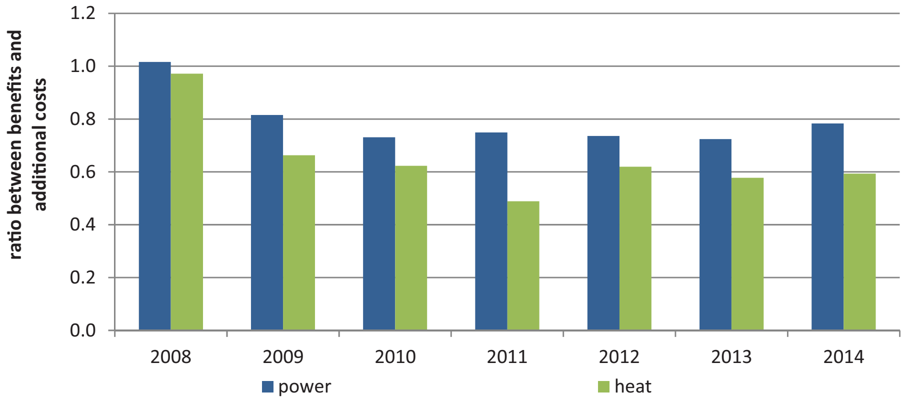

Figure 4. Benefits from avoided emissions in relation to additional costs in Germany.
Source. Own depiction, based on ISI et al.[13] Please note that assuming a lower damage cost for GHG yields lower ratios.

Micro-level

Policy costs for consumers. In Germany, the annual policy costs in the electricity sector are calculated based on the annual feed-in tariffs paid to generators (€ 21 billion), minus the annual revenues from RET power sales at market prices and other revenues (€ 2.1 billion), plus additional annual costs (forecast errors, transaction costs of about € 0.1 billion) (Data from ÜNB[32]). The estimated policy costs amount to about € 19 billion. The non-privileged RET levy is calculated by dividing the policy costs by the total amount of power consumed (minus privileged consumption). The RET levy paid by non-privileged final electricity consumers was about 6.2 ct/kWh in 2014, while a privileged consumer paid less than 1 ct/kWh. Curtailment costs are included here.

To disclose the effect of the exemption rule to the RET levy (special equalization scheme) in the electricity sector, the cost burdens are shifted to non-privileged consumers and are estimated on a yearly basis. This reveals a volume of about € 5 billion for 2014.[13] However, besides the special equalization scheme for the RET levy in Germany, there are other additional exemptions, e.g. exemptions from the levy for combined heat and power generation, for off-shore plants and reduced grid fees, tax privileges for the electricity and energy tax, and exemptions from levies for self-generated power and, finally, a compensation payment for CO_2-induced increases in energy costs (ETS compensation). The sum of all these privileges results in an estimated overall relief of more than 12 billion euros (community taxes are excluded) for energy-intensive industries, in which the RET levy accounts for a large part. This cost burden was shifted to non-privileged electricity consumers in 2014 (Figure 5).

Regarding the RET-heat sector, policy costs (additional burdens when heating with RET) and costs (additional costs) are equal, if no public support is offered. In Germany, the market incentive program offers a grant for investments in renewable heat generation. As Figure 6 shows, the additional generation costs at system level minus the annuity of the financial support (public support) reflect the remaining burden, namely the policy costs for consumers in the heat sector. These amounted to about € 2 billion (2014) in Germany.[13]

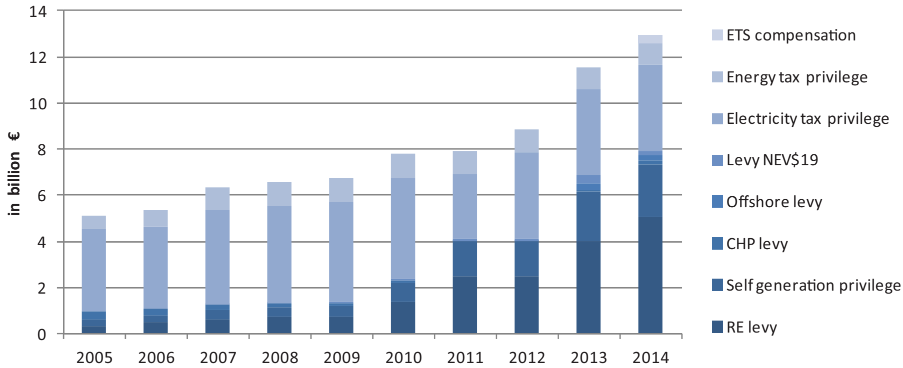

Figure 5. Relief of privileged energy-intensive industries and services.
Source: own calculation based on diverse databases.

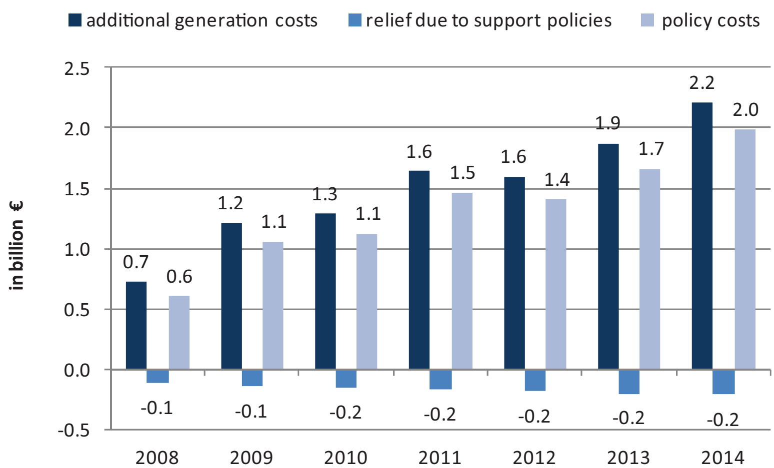

Figure 6. System-based heat cost, annuity of financial support and remaining burden.
Source: ISI et al.[13]

To capture the merit-order effect, the electricity wholesale price is modeled for a market with and one without RET, and the resulting prices are compared. The difference between the price and traded volume with and w/o RET discloses the merit-order effect, either as a total (€) or a specific effect in €/MWh. Figure 7 shows the total merit-order effect of the RET policy in Germany (€ 3 billion) and in the neighboring regional market areas, where it is at least as large as in Germany;[33] the specific price effect for the German market is around 0.6 ct/kwh (2014).

Effects for investors. The LCOE was assessed for PV installations based on generalized assumptions about investment and operation expenditures as well as yields. It is assumed that all investors are also operators. The assessed period covers installations between 2000 and 2012, and includes the opportunity costs of capital based on the average interest rate for saving certificates (5 years) in Germany, reflecting a low-risk investment.

Figure 8 illustrates how profits from PV power generation have evolved in Germany (before tax). The assessment is based on the difference between the actual generated power and LCOE and the guaranteed feed-in tariff in the respective installation year. The opportunity costs show the cost of an alternative investment. The question remains whether the opportunity costs sufficiently reflect the cost of a foregone alternative investment in fossil-based generation. But as returns on fossil-based investments are unknown, we can

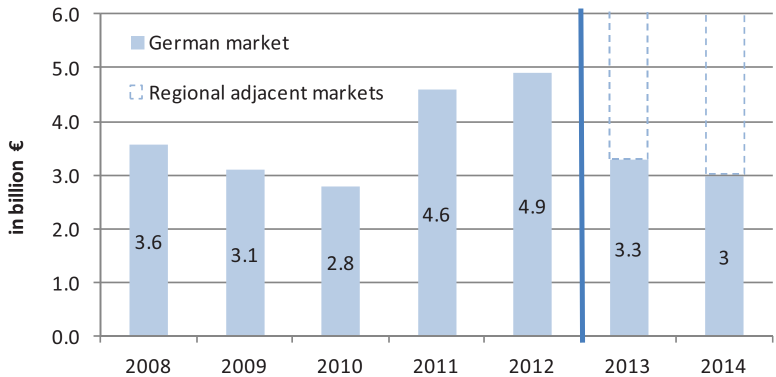

Figure 7. Merit-order effect in Germany and adjacent markets.
Source: based on Sensfuß.[33] Note: The share of RET in electricity generation as well as cross-border power flows have increased considerably. Therefore, RET deployment also affects neighboring markets. Since 2013, the impact on neighboring markets has been modeled and depicted separately.

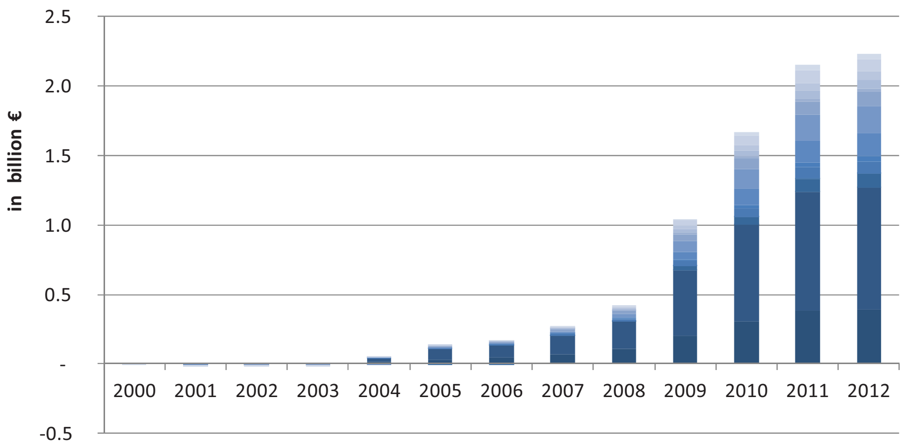

Figure 8. Profits from PV generation in Germany.
Source: Breitschopf et al.[3]

only apply the principle of opportunity costs for an analogous low-risk investment. Similar calculations for wind power report a profit of about € 700 million in 2012 for Germany.[3]

Summary of micro-level effects. Looking more closely at the retail market for electricity reveals some negative effects for non-privileged consumers. First of all, they pay a higher RET levy than privileged consumers. Second, the pass-through of the price effect to small final energy consumers may be limited or deferred, while large consumers, already paying a privileged RET levy (retail market), can also benefit from the price effect on the wholesale market.

Figure 9 depicts the evolution of policy costs and price effects on the German wholesale electricity market and compares them with policy costs. While additional generation costs have grown relatively steadily over time, policy cost increases vary, reflecting their dependence on the electricity market price in Germany under a feed-in tariff. Theoretically, the price effect plus the additional generation costs should equal the policy costs. But as the power market extends beyond Germany's borders, domestic RET deployment reduces market prices on foreign power markets as well. This merit-order effect on non-domestic markets should be added to the domestic price effect.

The price effect on foreign markets has interesting implications. If no electricity exports were possible, increasing RET deployment would reduce domestic wholesale market prices even more and, hence, further increase policy costs. As a consequence, non-privileged consumers would have to pay an even higher RET levy (retail price), while large electricity consumers could enjoy even lower wholesale prices. Overall, even though it can be argued that German consumers ''finance'' the decrease in electricity prices in adjacent electricity markets, increasing electricity exports are still beneficial for non-privileged consumers' budgets, as they prevent further increases of the RET-levy under a feed-in tariff system.

The burdens or reliefs of final energy consumers and generators are summarized in Table 7. It shows the magnitude of additional payments for final energy consumers due to RET use, the relief for energy-intensive industries, the price effect on the domestic wholesale market and the profits of power generators from wind and PV.

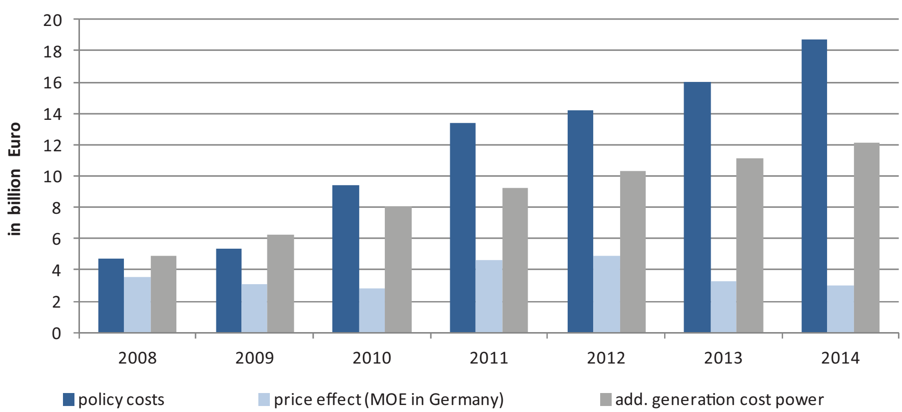

Figure 9. Development of additional generation costs, policy costs for consumers and merit-order effect. Source: own depiction, based on ISI et al.[13] and others.

Table 7. Overview of additional burdens and reliefs in Germany (2014).

Level	*Type of Effect, in Billion Euros*	*Power*	*Heat*
Micro-economic	Policy costs	18.7	2.0
	Special equalization scheme (RET act)	5.1	–
	Merit order (wholesale price in Germany)	3.0	–
	Additional profits (PV and wind in 2012)	2.9	

Source: ISI et al.,[13] Sensfuß[33] and Breitschopf et al.[3]

National economy

In Germany, jobs and turnover in RET-related industries and services as well as investment in RET and avoided imports of fossil fuels are estimated on an annual basis. The reduced imports of fossil fuels in Germany were assessed at about € 3.9 billion for power and € 4 million for heat generation in 2014, based on the methodological approach described by Lehr.[34] Normally, changes in imports/exports are included in macro-economic models.

The data on gross employment suggest that RET deployment has triggered significant growth in RET-related sectors in Germany amounting to 371,400 jobs in 2013.[35] However, negative effects, e.g. high energy prices or displacement effects of conventional generation, could affect the economy and offset the positive effects of RET deployment. This underpins the importance of assessing and discussing the effects of RET deployment at different levels: system, micro-economic and national economy.

Net impact assessments up to 2030 have been conducted for Germany in the framework of different (research) projects. The results are based on projections of future prices, consumption patterns, imports/exports and RET developments, and show impacts on growth and employment.[17,19,35] The study results include direct, indirect and induced effects and report (slightly) positive net impacts of RET deployment on the national economy. However, socio-economic impacts have not been included so far.

Conclusions

In this paper, we develop a new uniform and standardized concept to assess the costs and benefits of RET-development in a comprehensive way. The developed concept has a wide-ranging analytical framework, which helps to identify the different effects of policies, such as burdens and pass-through mechanisms to final energy consumers. The impacts of RET are classified on three levels: the energy system, the micro-level and the macro-economic level. While the assessment at the system level mainly comprises direct and indirect additional costs and benefits of RET-development, the micro-level examines the supplementary expenditures or revenues of the different actors and price effects. Finally, we capture the impacts of RET-use on the national economy from a macro-economic perspective.

The case example of assessing the costs, benefits and distributional effects of past RES-use in Germany showed that the indirect costs in the power sector resulting from the integration of large shares of non-dispatchable RET only amount to 7% of total system costs (direct and indirect costs). Costs due to investment in generation technologies account for the largest share in total costs: € 12.1 billion in 2014. Effects occurring on the micro-level show that the special equalization scheme leads to savings of roughly € 5 billion in 2014 for energy-intensive industry, whilst the merit-order effect leads to a cumulated reduction in wholesale electricity prices of € 3 billion on the German wholesale electricity market. When looking at the evolution of system costs and policy support costs, the case example reveals a stronger increase in policy costs. This can be explained by the decreasing electricity market prices in Germany and temporary strong growth in relatively "expensive" RET.

With regard to the energy system level, it should be considered that the specific generation costs strongly depend on the assumptions made for the calculations. Thus, the comparison between costs and benefits is highly influenced by the selected discount rate. In particular, the costs of technologies with high capital costs increase with higher discount rates. The choice of the discount rate depends e.g. on the risk exposure of an investment and it typically varies between investor types, technologies and countries.

Determining the effects at the micro-level requires a sound knowledge of the different policy designs and access to detailed data on policy financing. Impacts on the competitiveness of industries and household budgets represent knock-on effects of energy price changes at the micro-economic level which trigger changes at the macro-economic level. Macro-economic analyses account for these effects by including product price changes and a trade module, or changes in household consumption. However, a separate depiction of impacts on competitiveness neglects other positive drivers such as growing investments or exports.

At the macro-level, simple analyses provide insights into sectoral (gross) effects, while assessing net benefits requires a comprehensive macro-economic model. Socio-economic impacts have not yet been quantified in a comprehensive way (except for avoided emissions) as this requires assumptions and detailed assessments of multiple (input) parameters.

In principle, the proposed concept can be applied to other Member States, but data availability may prove a challenge. Before conducting a comprehensive impact assessment, sufficient data of good quality is a necessary precondition. In Germany, for example, data collection and monitoring RET policies' impacts were anchored in the RET acts and started in the early phases of RET deployment. However, the case study also revealed that there are still data availability issues for some of the effects in Germany.

Finally, it should be taken into account that the proposed concept follows a static approach and does not consider potential costs and benefits expected for future developments.

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