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Guidelines for assessing costs and benefits of RET deployment

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PREFACE

DIA-CORE intends to ensure a continuous assessment of the existing policy mechanisms and to establish a fruitful stakeholder dialogue on future policy needs for renewable electricity (RES-E), heating & cooling (RES-H), and transport (RES-T). The core objective of DIA-CORE is to facilitate convergence in RES support across the EU and enhance investments, cooperation and coordination.

This project shall complement the Commission's monitoring activities of Member States (MSs) success in meeting 2020 RES targets and builds on the approaches developed and successfully applied in the other previous IEE projects.

The strong involvement of all relevant stakeholders will enable a more thorough understanding of the variables at play, an identification and prioritization of necessary policy prerequisites. The dissemination strategy lays a special emphasis on reaching European-wide actors and stakeholders, well, beyond the target area region.

PROJECT PARTNERS

N°	Participant Name	Short Name	Country Code
CO1	Fraunhofer Institute for Systems and Innovations Research	Fraunhofer ISI	DE
CB2	Vienna University of Technology, Energy Economics Group	EEG	AT
CB3	Ecofys Netherlands bv	Ecofys	NL
CB4	Eclareon GmbH	eclareon	DE
CB5	National Technical University of Athens	NTUA	GR
CB6	Lithuanian Energy Institute	LEI	LT
CB7	Centre for European Policy Studies	CEPS	BE
CB8	German Institute for Economic Research	DIW	DE
CB9	University of Utrecht	UU	NL
CB10	AXPO Austria	AXPO	AT

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1 Motivation

The increasing deployment of renewable energy technologies (RET) for electricity and power generation has initiated an intensive debate on its associated costs and benefits. To understand the (relevant) extent of costs and benefits of RET use, a comprehensive elaboration and depiction of positive and negative effects of RET deployment is necessary. However, such analyses following a comprehensive approach that includes the most relevant effects have not been realized at EU-level. Costs and benefits of past RET deployment have been estimated for the German market with contribution of Fraunhofer ISI.

Therefore, we plan to realize such a comprehensive approach of assessing costs and benefits for the past development in the EU and to future development scenarios. This report provides the basis for this approach by describing different types of costs and benefits. We suggest a terminology describing the cost and benefit effects and develop a guideline for their assessment. The guidelines draw on experiences made for the German assessment. It should be noted, that the proposed cost and benefit concept is not a cost and benefit analysis typically applied in project assessments[1]. Rather, these guidelines present a framework showing:

- what types of effects arise in line with RET deployment,
- how they can be assessed on an annual basis and
- which information and methodological approach is most appropriate to get an overall/complete picture on costs and benefits of the current RET deployment status.

It is a methodological paper that should make assessments more transparent, harmonize or standardize approaches and partly ambiguously used terminology on costs and benefits and, hence, facilitate discussions on the existing most relevant effects. This paper is structured as follows:

- First, a brief overview of three main cost and benefit categories of RET deployment is given (Chapter 2) ,
- Second, the different effects are identified and described for each category. Their assessment approach is depicted. This includes also a brief sketch of factors that have to be taken into account when assessing the overall effect of RET deployment (Chapter 3 to 5).
- Based on the German example of assessing costs and benefit of RET deployment, the relevant effects that will be assessed for the EU Member States are outlined (Chapter 6).
- Finally, we shortly summarize and conclude in Chapter 7, before we suggest how to implement the developed approach in practice.

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[1] For a description of economic cost benefit analysis (CBA) applied to environmental topics we refer to Hanley & Spash (1993).

Guidelines as "living document"

So far, this guideline for assessing costs and benefits of RET deployment should be seen as a "living document" that evolves over the project lifetime as more and more insights into the character of certain effects as well as data availability and challenges become evident during the practical implementation phase. Therefore, we first suggest an approach by introducing the terminology required from a rather theoretical perspective. Then, we present an example of how to implement such an approach in Germany, before we apply the approach to all other EU Member States. Therefore, we will identify data sources needed to determine the main effects assessed for the EU Member States and estimate costs and benefits of RET deployment. With regard to the practical implementation we foresee to follow a two-step procedure:

First, we calculate and determine all the effects that can be easily estimated, such as additional generation costs.

Second, we include effects requiring more complicated allocation rules.

During the implementation phase ongoing insights will be added to the paper when this experience is available.

2 Overview on the concept: three main categories of costs and benefits

To properly assess impacts of RET deployment the system boundaries must be clearly defined. An unambiguous formulation of the research question is a pre-requisite for the clear definition of the system boundary. Research or policy question should specify which impacts of which RE and technologies on which region, economy and time horizon of RET deployment should be explored.

- The research or **policy question** should make clear which impacts are analyzed, for example, the impact of RE polices or the impact of RET deployment on the economy?
- One further question is the dimension of the effect. Do we focus on economic effects only or should environmental, technological and social effects be included.
- Allocating costs either to a RE-based technology system or to a fossil fuel based system as well as allocating costs to heat and power is not always clear. For example investments in grid or storage capacity are difficult to directly allocate to RE or fossil-based systems. In case of cogeneration of heat and electricity, where two energy sectors are covered and fossil fuels or RE sources could be used. Therefore, the the analyzed **technologies and systems** (heat, electricity) should be (clearly) specified.
- Which **geographic area** is covered by the analysis? The effects in a selected region, in selected countries or worldwide?
- For which part of the economy should the effects be assessed? For example, employment could be assessed for selected sectors or for the overall economy. So it is important to make clear whether **sectoral effects or overall economic effects** are considered.
- Is the analysis restricted to current effects resulting from past and present deployment or will be future RET deployment or impacts also be considered. So the **time horizon** of the analysis must be clearly defined.

When looking at the impacts of RET deployment or RE policies, three main types of effects can be identified (see Figure 1) that occur at three different levels:

- **System-related effects** encompass all benefits and direct and indirect costs of RE-deployment. While direct costs include all the costs that are directly related to electricity or heat generation such as installation, operation and maintenance of RE-technologies, indirect costs are caused by integrating RE into the existing generation system such as grid extension costs, balancing costs, etc. Benefits from RET-use arise e.g. as a result of avoided GHG emissions and air pollutants. The main characteristics of system-related costs and benefits are that they represent **additional costs or benefits of an RE-based generation system compared to a reference system based on a nuclear and fossil fuels.**

Furthermore, system-related effects reflect the **costs** of **input factors** based on market prices (labor, capital, natural resources). Finally, these costs are identified from a system perspective without taking into account any policy-induced payments.

- **Actor-specific effects** focus on costs that accrue for selected economic agents or groups from a micro-economic perspective. They show to what extent the different economic agents have to bear the additional costs or benefit from the additional positive effects – **who pays for RET deployment and who gets money from RET deployment**. These distributional effects are the result of policies that direct how the system-related additional costs or benefits should be **distributed among consumers and producers**. An **aggregation** of the transfers across economic actors or groups is impossible as some agents belong to more than one actor group. For example, private households may be charged by a levy of RET deployment, whilst they could also operate a roof-top PV plant, and may receive a support payment above generation costs leading to profits.
- **Macro-economic effects** are measured at the macro-economic level and comprise gross and net effects in an economy. **Gross effects** refer to the RE sector, i.e. they show the effects in all industries that are directly related to RET activities such as manufacturing, operating, construction, research, etc. They provide information on investments, avoided imports, turn-over, gross employment, etc. and ignore potential negative effects "outside" the RE-related industry. They do not rely on a system comparison (with and without RET deployment). Therefore, these are (positive) sectoral effects, which do not reveal whether the overall effect of RET deployment on the whole economy is positive or negative. To get the real **net effects** (net employment, GDP) of RET deployment – net of all costs – for the overall economy (all sectors), all positive and negative effects of RET deployment should be included. To do this, a macro-economic modeling is required that takes system-related costs and benefits as well as actor-specific effects of RET deployment into account and compares them with a reference situation (scenario or system) without RET use.

The assessment approach of costs and benefits in these guidelines refers to annual effects from current RET deployment. The emphasis is on economic effects or effect that can be quantified in monetary terms, but also social, technological and environmental effects are taken into account where possible. It should be noted that a clear distinction between economic and environmental or social effects is not always clear, as they all could have economic implications. For example emissions as environmental effects have implications on health, which in turn could affect production or income.

Overall it should be become clear that the different costs and benefits reflect only parts of the total impact of RET deployment on the economy. To get the whole picture, all effects at the different levels (system, micro-economic and macro-economic) should be integrated in a comprehensive macro-economic assessment model. This is depicted in Figure 1.

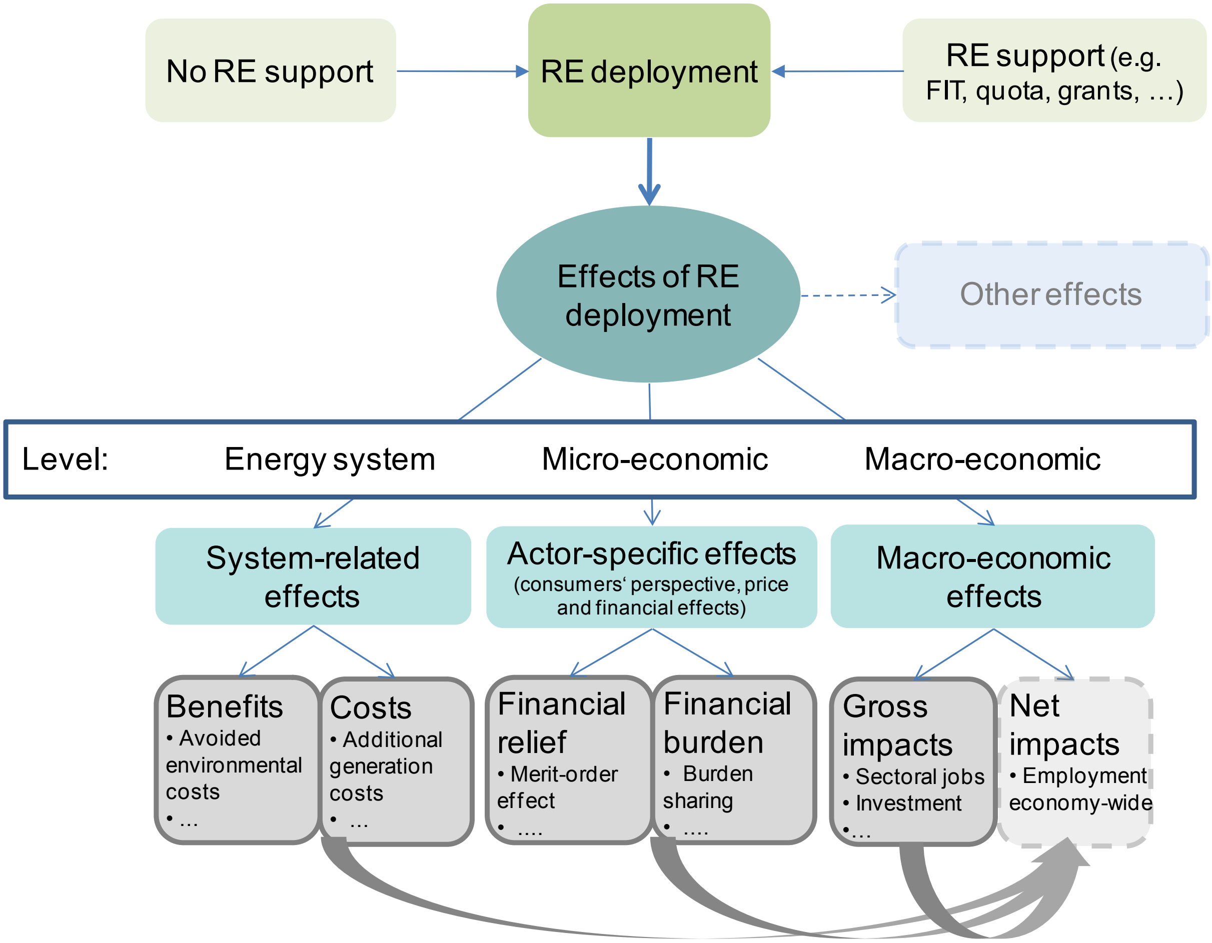

Figure 1: Categories of main effects related to RET deployment

Source: Breitschopf and Diekmann, 2011, adapted

3 System-related effects of RET deployment

This section provides an overview of system-related costs and benefits arising from RET deployment. It identifies diverse system-related effects, provides definitions and explains potential assessment approaches.

The level of the analysis is the **system level.** The term "system" may either refer to the energy sector as a whole, on basis of a final energy sector such as the electricity system or it may be broken down to the technology level. While some costs can be separately depicted at the technology level, for example generation costs for PV power, there are cost categories that are more difficult to assign to a single RET, such as grid infrastructure costs. In this case, the additional costs of an RE electricity system as a whole should be considered. The respective assessment approaches are explained in Chapter 3.1

The system-related effects reflect the **costs of input factors** to enable the system integration of RES and are assessed without taking into account taxes or subsidies or other policy-induced transfer payments for investment or generation. The main principle of determining system-related costs and benefits is quite straight forward: it compares the costs and benefits of two alternative systems:

__System-related effects__ of RET deployment

- *are always based on a comparison of a __nuclear/fossil fuel based system__ with an __RE based system__ and, thus,*
- *are __additional costs__ or __benefits__*
- *reflect the __use of resources__*
- *do __not__ take into account any __policy__ impacts on costs or benefits,*
- *have a system perspective and, hence, are __system specific__ but not policy specific.*

- a system with a significant share of RET (called RET-scenario), typically achieved as a result of policy efforts to trigger the use of RET
- a reference system, which is typically based on nuclear and/or fossil fuels, but which may include a lower share of RET e.g. in a business-as usual case (called reference scenario)

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 business as usual reference scenario (including some RE). In this case, system-related costs and benefits represent **additional** costs or benefits caused by RE policies. In contrast, comparing a RET scenario and a reference scenario without RET depicts/illustrates all costs and benefits associated with RET deployment.

When analyzing the additional costs and benefits, it has to be ensured, that **no double counting** takes place. If, for example, CO2 costs (in terms of CO2 prices) are internalized in the cost calculation (electricity generation costs), then the benefit from avoided CO2 emissions must be reduced by the internalized CO2 costs (see also Breitschopf and Diekmann 2010).

The same principles of avoiding double counting apply to costs related to balancing services required. If **electricity generations costs** already include investment, fuel, operation and maintenance expenditures required to balance and back up the power system, expenditures for balancing cannot be separately accounted for.

Decreasing technology costs partly incur due to learning effects. As technology costs are fully reflected in investment expenditures they are part of the LCOE and reduce the additional generation costs of RET. Therefore, no separate accounting of the effect is required if the focus of the analysis is the current year. If a dynamic perspective is taken, technology costs depending on cumulative deployment (diffusion) should be integrated in calculations of future generation costs.

Similarly, **increasing exports or lead market shares** are additional effects that are captured in the turn-over of manufactures. Provided that they affect GDP or employment, they are considered as macro-economic and not as system-related effects.

3.1 Additional system-related costs

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

- additional direct system-related costs
- additional indirect system-related costs.

With regard to the additional direct system-related costs account it is important to note that direct system-related costs include benefits in terms of avoided costs of conventional generation due to the system perspective adopted. The cost difference between the replaced conventional and the new renewables-based technologies determines whether the final effect is a cost or a benefit. Provided that most RET are still more cost-intensive than most conventional generation technologies, we cover system-related costs or benefits in the cost category.

While the additional direct costs can be assessed at technology level and reflect only the costs arising from generation of heat or power with RET reduced by the avoided costs of conventional generation, additional indirect costs may also include costs that are not directly linked to electricity generation and in some cases cannot be directly allocated to a certain technology. As far as the electricity sector is concerned, these indirect cost components may be required to maintain a stable power system. They include costs such as additional costs for grid infrastructure adjustments etc. Costs may arise in order to integrate increasing shares of non-dispatchable RET into the power system. The different types of additional system-related costs for power generation are depicted in Table 1.

As heat generation is more decentralized, mainly based on non-intermittent RES, 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), indirect additional costs such as additional balancing efforts can be neglected.

Table 1: Additional system 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: (i) the costs of the RE generation technology reduced by the avoided costs of conventional generation (ii) the costs of combinations of RE and conventional generation technologies reduced by the avoided costs of conventional generation
Balancing costs • indirect costs • focus on forecast errors • relevant for electricity	Balancing costs occur due to deviations from schedule of variable RE power plants and the need for operating reserve and intraday adjustments in order to ensure system stability. Balancing services may either increase or decrease the electricity fed-into the grid, provided by positive or negative balancing capacity.
Profile costs • indirect costs • focus on back-up capacity • relevant for electricity	According to Ueckerdt et al. (2013) profile costs occur due to the following effects: • a potential increase of average generation costs of the residual load as a result of RES-induced decrease of utilization of conventional power. • additional 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 times and simultaneous low RES generation • potential curtailment of electricity required in times of overproduction represents another cost component.
Grid costs • indirect costs • relevant for electricity (may also be relevant 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 situation of high grid load.
Transaction costs • indirect costs • relevant for heat and electricity	<u>Market transaction costs</u>: additional forecasting, planning, monitoring, procuring power, establishing trade, contracting, data exchange, etc. <u>Policy implementation costs</u>: administrative cost to implement RE policies or fulfill data provision requirements (accounting, approvals, …)

3.1.1 Additional generation costs

Additional generation costs quantify the change (typically an increase[2]) in heat or electricity generation costs due to an accelerated RET development. The additional generation costs in an RET based system arise from

- either the costs of (often more expensive) RE generation technology that replaces a conventional generation technology or,
- especially in the heat sector, the costs of a combination of RET with a conventional technology that is non-intermittent and permanently available and, thus, ensures the required supply of heat. Combinations are for example solar thermal heat with gas firing, etc.

***Additional generation costs** include all additional costs that arise from the **installation, operation and maintenance** of a facility with the purpose to generate heat or electricity with RET.*

Generation costs are calculated on the basis of levelized costs of electricity or heat (LCOE). Cost components of LCOE include expenditures for investment, fuel, operation and maintenance of the generation plants that are installed to provide energy and not to ensure the stability of the system.

3.1.1.1 Power sector

To assess the generation costs **at the system level,** the LCOE are calculated for each generation plant and weighted according to their respective supplied quantity of power or heat. The difference between the generation costs of the two systems (RET system – reference system) show the additional electricity generation costs at the system level.

Formula 1:

$$adGC_{sys} = \Sigma_{RET} (LCOE_{RET} * Q_{RET}) + \Sigma_{sup} (LCOE_{sup} * Q_{sup}) - \Sigma_{ref} (LCOE_{ref} * Q_{ref})$$

$adGC_{sys}$: additional generation costs at the system level
LCOE: levelized costs of energy[3] in €/kWh
Q: quantity of energy[4] in kWh
sup: conventional generation (plants) that is necessary to provide the required generation capacity in an RE based electricity system
ref: reference system, which is typically based on a higher share of fossil fuel or nuclear based generation technology
RET: renewable energy generation technology

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[2] In principle the additional generation costs can also be negative, i.e. then the generation costs of RET are lower than of fossil based technologies.

[3] Heat or power

[4] Heat or power

At the **technology level,** the LCOE from conventional sources from a reference system are weighted according to its respective share in the energy mix that has been replaced by the respective RET. The difference between the LCOE of RET and its supporting conventional generation technology and the weighted fossil energy mix multiplied by the quantity of RE and of supporting generation gives the additional generation costs per RET. The calculation is as follows:

Formula 2:

$$adGC_{tech} = ((LCOE_{RET} + LCOE_{sup}) - \Sigma_{ref}\,(LCOE_{ref} * weight_{ref})) * (Q_{RET} + Q_{sup})$$

$adGC_{tech}$: additional generation costs at the technology level

The weighting of generation technologies from the reference system reflects an estimated substitution rate, i.e. to what extent RET replace the respective technologies from the reference system. Adding up the additional generation costs per technology shows the additional generation costs at the system level. Data sources for the relevant inputs are depicted in Table 2.

Table 2: Data inputs and sources for generation costs

Data input	Unit	Data sources
Investment expenditures for each technology	€/kW	Schröder et al. (2013); Kost et al. (2012); Prognos (2013); IRENA (2012)
Operation and maintenance for each generation technology: • insurance • operation • maintenance	€/kWh	Schröder et al. (2013); Kost et al. (2012); Prognos (2013); IRENA (2012)
Fuel expenditures	€/J	
Substitution rates • PV • Wind • ….	% of fossil technology $\%_{fossil\ 1} + \%_{fossil2} = 100\%$	
Generation plants per RE installed to compensate for the low capacity factor of RET • PV • Wind	MW conventional /MW RET installed	
Yield:		
• Full load hours per technology	hours	
• Generation per kW	kWh/kW	
• Generation per technology	kWh	
Life time of technologies	years	
Discount rate	% p.a.	

3.1.1.2 Heating sector

The quantification of additional costs arising from using RES in the heating sector is more challenging than in the power sector, as the heating sector is characterized by a large variety of heating systems, and a predominantly decentralized heat generation. The starting point of the assessment at the **technology level** is the quantity of each RES-H generated per RE source or technology and used per building type.

The difference between the LCOE for RET and conventional heating technologies per building type shows the additional generation costs per technology. The calculation is depicted in Formula 3. As one RET for heat replaces different shares of conventional heating technologies (reference technology), a respective reference heating technology mix[5] should be applied. The differentiation into building types allows for a better assessment of the total heating costs.

Formula 3:

$$adGC_{REsys\ tech\ g} = (LCOE_{REsys\ g} - \Sigma_{ref}\ (LCOE_{ref\ g} * s_{ref\ g}) * Q_{REsys\ g}$$

$adGC_{tech}$: additional generation costs at the technology level
LCOE: levelized costs of energy[6] in €/kWh
Q: quantity of energy[7] 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

To assess the additional annual generation costs at the **heating system level**, all expenditures for investments (annuity of investment expenditures), fuel, maintenance and operation for all technologies of an RET based and a non-RET based system are added and compared similar to the calculation shown for power technologies.

3.1.2 Additional balancing costs

Most RES used for generation of **heat** are not variable in their output and available throughout the year, or, they are combined with a generation system that provides heat on a reliable basis at any time. For example, when using solar thermal energy the technology is always linked to non-intermittent energy sources such as gas, oil or biomass. Consequently, in decentralized heating systems costs to ensure permanent and reliable heat generation are already included in the heat generation technology system and, thus, no additional balancing costs incur for RES-H.

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[5] The technology mix reflects a mix of different conventional technologies that are replaced by one single RET.
[6] Heat or power
[7] Heat or power

However, in **power** generation some RES are variable and stochastic in their electricity output. Due to the related difficulties to reliably predict the electricity output they are not fully dispatchable. **Forecasts** on RE-based (mainly wind and solar) power generation are subject to **errors**, which have to be “balanced” in the short term to guarantee that total electricity supply matches the demand profile. To compensate these errors and maintain system stability e.g. by maintaining a stable frequency level, provision of operating reserve is required and involves additional costs. Apart from conventional generation plants, storage of electricity or demand side management are options to provide operating reserves.

***Additional balancing costs** are system-specific and occur due to balancing between withdrawals and injections of power due to deviations from the originally planned schedule.*

- *Balancing services may either increase or decrease the electricity fed-into the grid, provided by positive or negative balancing capacity.*
- *Payment schemes for providing balancing services may be based either on **capacity** or on **generation or a combination of both**.*

It should be kept in mind that each country deals with the implementation of balancing services in a different way. Thus, we face different types and regulation of balancing measures and costs. The variable character of some RE sources such as wind or solar sources makes their integration into the existing energy system challenging and involves additional costs. The European Network of Transmission System Operators for Electricity ENTSO-E differentiates three types of reserve, primary, secondary and tertiary control according to the required speed of response and different reserve needs. Holttinen et al. (2012) provide a categorization of different reserve types and their application.

Costs arising from balancing services for renewable power plants can be assessed if data on forecast errors and the respective cost of the required balancing power is available. Ideally, these values are estimated based on information with high resolution in time (e.g. hourly information), since the price of the 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. Depending on the objective, balancing costs for all renewable power plants in a system may be estimated or the difference in balancing costs between a scenario with higher shares of renewable may be compared to a reference scenario. It should be kept in mind, that data availability or estimations of forecast errors in particular for the future are subject to uncertainties and may complicate the estimation of balancing costs.

3.1.3 Profile costs

According to the definition used by Ueckerdt et al. (2013) "profile costs" cover the economic costs resulting from the variability of RET and are not included in grid and balancing costs. The profile costs may occur due to the following effects:

- a potential increase of average generation costs of the residual load as a result of RES-induced decrease of utilization of conventional power.
- additional capacity (backup 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 times
- potential curtailment of electricity required in times of overproduction represents another cost component.

With regard to the required back-up capacity, it should be noted, that generation capacities must be provided on a long term basis to maintain supply security and avoid system break downs and to meet projected load or peak loads. Costs resulting from additional or back-up capacities needed to provide electricity in times of peak load demand can also be termed "adequacy costs" (see also Ueckerdt et al. 2013). In an energy-only-market RET are feeding-in power at nearly zero marginal cost. Consequently, capacity factors of conventional plants decrease as they are needed less frequently and at least in the short term[8] average and peak time prices decrease.. These effects impair the income situation of all conventional plants including flexible generation facilities with comparatively high variable costs. Special markets – such as capacity markets – are one option to ensure the long term provision of flexible capacities such that capital recovery of these plants is ensured.

To estimate profile costs for an increased share of RES, the residual load – the system load minus non-dispatchable renewable electricity – should be analyzed for extreme situations of the power system with a high feed-in of fluctuating RES in combination with low demand or with low availability of variable RES-E in combination with high demand. For the calculation, it is necessary to know the gap or the oversupply respectively and the frequency of these situations. This can be estimated by means of an electricity market model. To estimate profile costs arising from an increased RET use, we compare two scenarios of the energy system and compare the resulting costs for additionally needed capacity to ensure system adequacy. If no electricity market model is available, generalized results from electricity market models based on the link between capacity factors of installed RET and the share of RET in the system could be used to estimate the share of costs arising from RET. Costs of curtailment can easily be estimated by multiplying the curtailed electricity with the actual electricity market price.

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[8] In the mid to long term the conventional power plant should adapt to the new circumstances: base load plants are expected to become less profitable with increasing shares of renewables and thus will be replaced by more flexible technologies.

3.1.4 Additional grid costs

The use of RES-H hardly requires an extension or reinforcement of the heating grid, as RES-H generation typically is decentralized and located closed to consumption. There is practically no difference of using renewable heat as compared to the use of conventional heating power plants. Further, the existing gas network could be easily used for both, natural gas or methane. Similarly to balancing costs there are hardly any additional grid costs caused by RET-H use.

In opposite to RES-H, the deployment of RES-E may require reinforcement and extension of the grid infrastructure. The physical distance between the location of RE power plants in areas with favourable resource conditions (and load centers, are the major reason for potential bottlenecks in the **transmission grid**. This mismatch calls for extensions or reinforcements.

In addition there may be bottlenecks in **distribution grids,** where too much RES-E from smaller power plants such as PV is (irregularly) fed into the grid and, therefore, might endanger the stability of the voltage level and, hence grid stability at this nodal point. Investments into technical solutions like remote control, interconnectors, or higher voltage cables help to overcome these bottlenecks.

Additional grid costs should encompass only the investments caused by RET deployment and that would not have been occurred in an energy system without RE-use. The grid extension or 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 re-dispatch required to manage situation of high grid load are included in additional grid costs. The detailed estimation of additional grid costs requires a grid model where a scenario with increased RET use is compared to a reference scenario.

Table 3: Data inputs and sources grid extensions

Data input	Unit	Data sources
Investment expenditures for grid infrastructure	€/(kW*km)	
Operation and maintenance:	€/(kW*km*a)	
Life time of grid and components	years	
Discount rate	% p.a.	

3.1.5 Additional transaction costs

Any economic activity entails transaction costs. Transaction costs accrue in two areas:

(i) in the market between actors in the power system (suppliers, demander, grid operator, …) (market transaction costs) and
(ii) at the interface between grid operators and policy/administration (policy implementation costs).

***Additional transaction cost** encompass all costs that arise due to RET induced*

- *market activities and*
- *reporting or monitoring obligations*

Transaction costs among market participants comprise forecasting, planning and monitoring electricity supply and demand, procuring electricity, establishing markets, contracting, exchanging data etc. Since these processes tend to become more complex for variable RES-E, transaction costs could increase with RET deployment. As these costs occur mainly at the level of the transmission system operator (TSO), their assessment relies on data available from the TSO.

To meet the RE policy targets or requirements, **policy implementation cost** arise through monitoring RE-activities (e.g. investments and generation), or reporting requirements or standards in accounting, etc. For example, in Germany grid operators are obliged to assess the RE levy for final consumers in advance to monitor RE power generation or to update the RE plant register. At the same time quadrennial monitoring reports on RET-E deployment are required at the policy level. In RES-H the RE obligation in new buildings must be monitored and controlled as well as special support programs are processed and administered. Therefore, costs occur for grid operators and the government.

Figure 2 depicts the different types of additional cost and show at which aggregation level they could be estimated. If no detailed data is available on additional balancing, grid, transaction costs, etc., or if an energy sector model is available estimates could be made at the system level, where all costs for generation, balancing and grid - investment, fuel, maintenance, operation costs for generation plants, storage facilities, reserve facilities and capacities – are assessed on an annual basis for two different energy systems. The more detailed data on costs etc. is accessible, the better the quality of the assessed costs. But it should be made sure that no double counting or gaps occur when working at different aggregation levels.

In general, it is important to note that interactions between the cost components exist, meaning that the decomposition into the individual components should be seen as an approximation. In this project, we will not analyze the interactions between these additions system cost components. The cost effects of the different cost types are very different, thus Breitschopf et al. (2011) estimate overall grid extension costs in Germany to amount to € 18.5 billion (€14.5 billion for the transmission grid and € 4 billion for distribution grid), whilst cost arising from additional generation costs were estimated to €8 billion only for 2010. A comparison of estimated costs and benefits for Germany is provided in chapter 6.

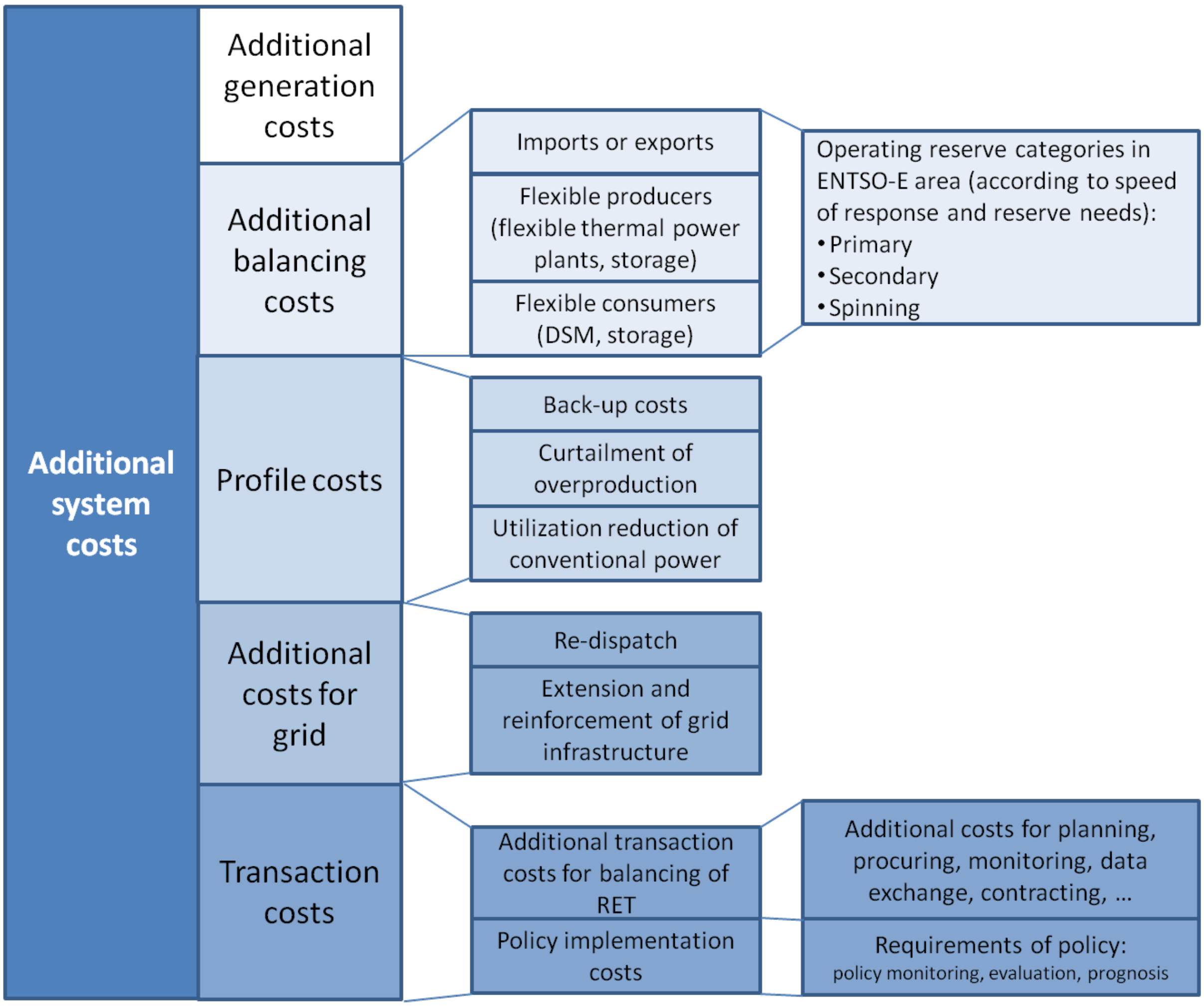

Figure 2: Overview on additional costs

3.1.6 Other costs

There are further negative effects of an RET-based energy system such as the reduction of fishing grounds, detours or deviation of ship routes, emission of noises and lights/flash, irritations for aviation and radar, killing of birds, etc. Most of these effects are external effects as the actor who is causing them typically does not pay for them. Moreover, some are considered as environmental effects, but they cause negative economic impacts through health impacts or foregone revenues or increased expenditures. As data on these effects is hardly available and difficult to account them in monetary terms, these data are not assessed in the analysis.

3.2 Benefits from RET use

The use of RET does not only bring along additional costs but also benefits. As mentioned in the German Renewable Energy Law, positive effects are expected regarding climate change and air pollution, fossil fuel savings, decreasing dependency on fuels imports and technological development leading to lower costs of RET. These are effects that do not occur at the system or technology level only, except for one major benefit of RET deployment that has been quantified so far: the reduction of GHG emissions and air pollutants. The benefit of this reduction is the alleviation of climate change, health issues, biodiversity, land use and material damages.

3.2.1 Avoided emissions of GHG and air pollutants

Avoided emissions of greenhouse gases (GHG) and air pollutants are a major benefit of RET deployment. While GHG emissions have a fundamental impact on climate change and, hence cause long-lasting global effects, emissions of air pollutants cause more short-term local effects.

There have been plenty of studies on emission factors for GHG and air pollutants of generation technologies. The more differentiated the emission factors are at the technology level, the better the estimates on emissions. In some countries emission factors for one technology e.g. coal firing or geothermal heating represents an average value of the existing mix of coal firing technologies or thermal heating technologies, while other studies further differentiate emission factors by the type of coal firing technologies. 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 social costs of carbon is very complex. Thus, existing estimations show a large range of values (from 0 € to more than 200€/t CO_2) that are estimated based on diverse models that take into account effects of GHG on health, consumption, land use, water resources, etc. over a long-term time horizon. Discounting them to the present provides a monetary value for the potential damage of one unit of GHG emitted. Furthermore, discussions arise on whether the marginal damage value of CO2 or the marginal mitigation cost of CO2 should be applied for the monetarization of CO2 emissions. For the current study, a damage value of 80€/t CO2 is assumed which is in line with research results of the German agency for Environment (UBA 2013).

In contrast, damage costs of air pollutants are estimated based on diverse observations, experiments and response functions. They depend to a large degree on where and when they are emitted. Pollutants in densely populated areas cause more damages than in remote areas. Further, the higher the emission location (chimney) the larger the immission zone. As the exact location of the pollution is hardly known, a weighted average of the local damage costs of air pollutants is often used.

To assess the avoided emissions at a **system level**, the generated amount of power or heat per technology and the damage costs should be known. Multiplications of technology specific emission factors with the amount of power generated by that technology and the damage costs lead to the monetary damage of emissions. The difference between the emission costs of an RE based and non RE bases system shows the benefit - monetary effect - of avoided emissions (damages) at the system level.

To assess avoided emissions at the **technology level**, substitution factors are used that show to what extent fossil energies are replaced by RET. Technology-specific emission factors indicate the direct and indirect emissions per kWh generated, the quantity of RE generated as well as the damage cost of emissions are further input factors for the assessment. The calculation is depicted in three steps:

Formula 2: specific avoided emissions ik (spVFik) = Σj (SFij • EFjk – EFik)

EF: emission factor
SF: substitution factor
i: RE
j: reference energies
k: diverse GHG and air pollutants

Formula 3: avoided emissions ik (VEik) = Σi (spVFik • Qi)

Q: quantity of heat or power generated with RE sources
spVF: specific avoided emission

Formula 4: avoided social costsi = Σk (VEik • SKk)

SK: damage costs in Euro/t of GHG and air pollutants
VE: avoided emissions

The assessment of the social costs is the most critical step since there is no unique scientifically accepted “damage value”, but a bundle of approaches and model results giving a large range of values.

Table 4: Data inputs and sources to quantify avoided emissions

Data input	Unit	Data sources
Emission factors for each technology	mg/kWh	
Quantity of power or heat generation per technology	MWh	
Substitution rates (system level)	%	
Damage costs per GHG and air pollutant	€/t	

3.2.2 Other benefits

Besides reduced emissions further positive effects of RET deployment eventually emerge in discussions on the benefits of RET use. Among them the decrease of RET costs in line with the increasing use of RES (although it is the motivation for RE support) as well as energy security aspects such as decreasing dependence on fuel imports.

Some of these positive effects such as **learning by doing** and **economies of scale**[9] however, are captured via prices in the system-related costs. Nevertheless, some studies strive to measure innovative activities by counting patenting activities – but it is difficult to allocate economic values to them and, innovations are not necessarily reflected by patent applications.

A further positive effect, the **spill-over effect** of RET technologies on other technologies or to other economies could be captured by patent citations (technology), co-patents and co-publications (economy) but a monetary quantification of this effect is not feasible, as well.

Energy security[10]: Scarcity of energy sources is reflected by their market price. This means that any supply constraints – be it through political or economic shocks – typically lead to higher fuel prices. The fuel prices are included in the LCOE, but their volatility is not reflected by these prices. Hence, scarcity increases generation costs of fossil based systems, resulting in a decrease of additional generation cost of RET deployment under ceteris paribus.

However, to avoid facing severe supply constraints, storage or stocks of gas or oil are built up in some economies. The costs of these stocks could be seen as some type of insurance costs against shortages. In case these insurance costs are added to fuel prices, they increase generation costs of fossil fuels and reduce the additional generation costs of RE-use. In case these costs are not added to fuel costs but are borne e.g. by the public budget, they should be taken into account as separate system-related effects. If stocks become redundant with increasing RET deployment, these avoided stock or insurance costs can be accounted as benefit.

3.3 Additional costs and benefits – the German case

As Germany has set ambitious RET deployment targets and has reached a large share of RET especially in power but also in heat generation, the costs of RET deployment as well as the deployment of RET is thoroughly monitored and evaluated. To get an understanding for the extent and significance of the diverse effects in monetary terms, the available costs and benefit estimates are depicted in the following table.

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[9] Economies of scale refer to the pure size effect – the larger production capacities, the lower fixed costs of an output unit. Economies of scale do not reflect increases in efficiency.

[10] Security refers here to fuel supply (e.g. import dependency) and not the reliability of the power system. The latter is taken into account by balancing and grid costs.

Table 5: Additional system costs and benefits in the German power generation (2012)

Types	Description	in mio €
Power or heat generation costs	Costs due to higher RET costs	10,330
	Costs for combinations of RE and non-intermittent generation technology	n.a.
Balancing costs	Forecasting errors balanced by operating reserve	53
Profile costs	Back-up costs	n.a.
	Curtailment due to overproduction	n.a.
	Utilization reduction of conventional power	n.a.
Grid infrastructure costs	Enforcement or extension of transmission or distribution grids	460
Transaction costs	Market transaction costs (IT, staff, stock exchange, …)	14
	Policy implementation costs (RE accounting grid, forecast and estimation of RE levy):	180
Benefit	avoided emissions GHG	8,400
	avoided air pollutants	800

4 Actor-specific effects of RET deployment

Actor-specific effects

- *reveals the remaining costs or benefits of RET use after **financial policy support or surcharge schemes** have been taken into account,*
- *from the **perspective of actors** such as firms, households, privileged industries etc. (micro level)*
- *can**not be aggregated**,*
- *do **not** reflect the **use of resources,***
- *are **policy specific.***

Actor-specific effects are distributional effects that depict changes in costs, prices, quantity or quality, induced by policies for different actors. These actor-specific effects may represent beneficial effects for certain actors in the system, while having negative effects for other actor groups. Thus, actor-specific effects reveal the final costs or benefits of RET deployment for selected actors such as private households or firms when policies like the RE act in Germany or other support schemes are in force.

These effects show to what extent the different economic agents or groups have to bear the additional costs or gains - **who pays for RET deployment and who receives money for RET deployment**. The actor-specific effects are the result of policies that determine how the system-related additional costs or benefits should be distributed among consumers and producers. These include **financial effects** and **price effects** that different actors are facing. While some economic actors such as private households are charged by a levy or surcharge to pay for the additional costs of RET deployment, producers or investors of RET-based generation facilities benefit from certain policy design: they receive a tariff or premium for RET and might realize a profit. Distributional effects encompass monetary transfers or payments and non-monetary losses or gains, but do not reflect the actual use of resources for energy provision. The actor-specific effects cannot be expressed as a single aggregated figure, as different actor groups might at the one hand pay for and at the other hand benefit from policy measures to a differing degree.

Based on a classification of distributional effects in economic literature (Fullerton, 2009), the actor-specific effects of RE-policies can be classified into six types (see Breitschopf and Diekmann 2013):

Effects on **consumer surplus**: changes in power prices through surcharges or price increases due to renewable support payments for power lead to an increase of **retail electricity prices** and hence, reduce consumer surplus. Moreover, changes in the generation structure such as an increased use of RET – except biomass technologies - with its close to zero marginal costs leads to a shift of the supply curve, resulting in lower electricity prices at the **wholesale market** and, hence, increase consumer surplus for power suppliers.

Effects on **producer surplus**: tariffs or premiums paid for RE electricity augments total producer surplus of RES-investors. At the individual level some producers benefit more than others as their production and cost conditions differ depending e.g. on the location. Consequently, individually **differing margins** may occur.

Scarcity rents: instead of providing direct RES-support to reduce CO2 emissions in the power sector, caps can be set allowing the emission of a given quantity of CO2 in combination with certificate trading. The prices for these certificates reflect their scarcity, which is the result of supply (cap) and demand for certificates. The latter, in turn, is influenced by the quantity of RE power generation. However, the impact of RET deployment on e.g. the price of a CO2 certificate is beyond the scope of this report.

Capitalization effects: display indirect or consequential effects of RET deployment, which are caused by the installation of RET generation plants. They are reflected in price changes of assets, which are related to RE-based power generation. Examples are changes in the value of land that is eligible for wind power generation, or surfaces (roof tops or land) for solar power. Further examples are the impact on the value of real estate located close to a nuclear or coal firing plant that will be given up. In contrast, the value of real estate is likely to decrease if a wind farm is built. These RET induced changes in asset values cause positive or negative rents for a limited circle of actors, i.e. asset owners. This effect is, however, not further elaborated in this study.

Changes in utility e.g. related to emissions: in- or decreases in emissions of GHG, air pollutants, noise, lights, etc. generates individually differing marginal utilities. The utilities differ across groups ranked by their wealth, gender, age, region, urban-rural households, ethnicity, etc. As there are individual preferences a common measure for these changes in utility is not applicable. Furthermore, the number of affected people varies according to the type of emission. For example, emission of GHG i.e. climate change has a global impact while air pollutants are more local. Although assessment approaches for damage costs of CO2 exist, the actual damage or marginal loss of utility for each individual might significantly deviate from the modeled damage costs. These individually perceived utility changes are distributional effects that will not be further discussed.

Transitional effects and others: in the phase of transition strong distributional but temporary effects occur at all levels – system, micro and macro level. Impacts on technological learning, competitiveness of firms, prices of inputs, demand for inputs, infrastructure, etc. affect individual private households or firms as well as sectors or industries as a whole. In the context of RET, the focus of this study is on public R&D spending where recipients could financially benefit from public support through generation of knowledge and new products.

In the following the distributional effects of RET deployment on costs or benefits of different actors such as firms, private and public households are further discussed by looking at impacts on final prices or costs that affect **consumer and producer surpluses** (see table xx).

Table 6: Overview on distributional effects

Types	Description	Type of effect
Policy costs	Consumer-based burden sharing Public budget-based burden sharing, i.e. resulting policy support costs are financed through the state budget Special exemptions/equalization schemes for selected consumers e.g. energy intensive industries	Financial effect for electricity consumers (consumer surplus)
Merit-order effect	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 (consumer producer surplus)
R&D support	Direct monetary transfer to compensate for costs that cannot be covered because of non-realizable rents (on the short term) due to spill-overs and non-exclusion of uses	Financial effect for technology developers or providers (consumer/producer surplus)

To be precise and identify the diverse effects at the micro level, the analysis distinguishes between direct burdens or supports for consumers and producers, called financial effects and indirect burdens or benefits through changes of the market clearing price, called price effects.

4.1 RE policy support costs

The deployment of RET has been supported by a variety of policy instruments ranging from price or cost-based support to quantity-based support. As the use of RET causes additional costs at the system level, these costs must be borne by someone. How these costs are financed is determined by policy support schemes. Financing of these RET promotion schemes relies on two main financing schemes:

(i) Consumer-based financing
(ii) Budget-based financing[11]

Policy support costs

- *remaining costs of RET deployment that has to be borne by final consumers or public budget.*
- *extent determined by RET support policies*
- *reflect a direct financial /burden or credit*

Policy instruments that are taken into account in this chapter can be distinguished into technology push (public R&D spending) and demand pull instruments (feed-in tariffs and

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[11] Private households and firms will be indirectly affected as public spending for other activities decreases or taxes increase to compensate for RET related expenditures.

premium, quota and certificates or obligations, generation or investment subsidies or tax credits). The latter are discussed here, by depicting their distributional effects according to their source of financing and then according to the type of policy instrument.

4.1.1 Consumer-based financing

Consumer-based financing refers to financing of RET deployment by final consumers without any support from public budgets. As the power and heat sector have different features, the applied policy instruments differ respectively (Table 6).

In the **power sector**, the feed-in tariffs in Germany is a good example for a RE policy instrument financed by the final consumers (households and firms).

The difference between **guaranteed generation prices,** such as **feed-in** tariffs (or premiums) paid to RES-E generators and the market wholesale prices at the respective time plus all additional transaction and balancing costs sum up to the policy support costs. These policy support costs are divided by the total amount of power consumed (less privileged consumption). The resulting surcharge per unit of consumed electricity (€/kWh) is added on top of the electricity price of final consumers. Part of the industry may enjoy privileged consumption. In Germany, policy costs are calculated based on the paid feed-in tariffs, reduced by revenues from sales at market prices, augmented by additional transaction costs and additional balancing costs due to forecast errors.

In a **quota system** 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 costs for certificates equals the additional costs of power generation with RES and the certificate costs are priced in the market price for electricity. Subsequently, final consumers pay for the RET use. To assess the additional costs for consumer, the traded certificate prices could be multiplied by the respective trade volume. This reflects the sum of surcharges paid by consumers. Dividing the sum by electricity consumption displays the average surcharge per unit electricity. To which extent these certificate costs are actually handed through to the different consumer groups - industry and households – cannot be assessed in the framework of this study.

In the **heat sector obligations** like emissions standards or quota w/o certificates are common instruments to induce demand for RET-H. As heat generators and consumers are in many cases identical, the micro-economic additional costs are the same as the system based additional generation costs, if no further support instruments are applied. In case **RET certificates** are traded, the certificate price multiplied by the heat generation plus any other costs that accrue due to trade displays the costs for final consumers. Besides obligations and certificates further support instruments (grants, interest subsidies, tax credits, etc.) exist. They are mainly co-financed by public sources and their credits should be taken into account when assessing agent-specific costs.

Table 7: Overview on consumer-based financing – additional micro-economic costs paid by consumers

Instrument	Power sector	Heat sector
Guaranteed price or price supplement: Feed-tariffs Feed-in premium (with w/o caps)	Difference between tariffs (premium) and whole sale market prices plus all additional balancing and transaction costs.	n.a.
Obligation: Quota with RET certificates Standards (share of RET w/o certificates)	Total amount of certificates (kW) multiplied by their price (per year) n.e.	Total amount of certificates (kW) multiplied by their price (per year) Additional generation costs

4.1.2 Budget-based financing

Budget-based financing refers to financing of RET deployment by government or state budget and can be used to finance feed-in tariffs or premiums, investment grants or tax credits for RE generation or capacities. In contrast, financing of a quota obligation is typically consumer-based.

In the **power sector**, **guaranteed prices** or premium may be completely or partly financed by the public household. In such a case, the same methodological approach as in the case of consumer-based burden sharing should be applied: The additional micro-economic costs should be disclosed in the respective public accounts. Other policy support instruments comprise financial support for investments or support during operation. This can be achieved either by transfer payments from the public households to investors or operators to cover part of the additional generation costs or by tax credits for generation or investments.[12] The monetary volume of both support instruments should be disclosed in the public accounts and annual subsidy reports. The total of subsidies and tax credits provides an estimation for the additional microeconomic costs paid by the public household.

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 public micro-economic costs, the same procedure as for the power sector can be applied. For more details see Table 7.

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[12] Tax credits or subsidies can be granted for own generation and consumption as well as for consumption of third parties.

Table 8: Overview on public budget-based burden sharing – final costs paid by public household/sector

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

4.1.3 Special equalization scheme for industry

Consumer-based burden sharing applies not only for private households but also for any other consumers such as industries and services. The consumer-based burden sharing reflects an interference of the government into the power market. This may strongly impact the energy intensive industries' competitiveness, as the burden for RET deployment in other countries might be lower. In order to reduce the market interference and avoid market distortions, the German government has elaborated a special equalization scheme for the industry. It offers the energy-intensive industries exposed to a strong international competition to pay a reduced RE surcharge. But this in turn leads to domestic market distortions, as not all industries can benefit from this special equalization scheme. This results in an increased burden for the remaining actors. To disclose the effect of this special scheme, the total of the exemptions that is shifted to and finally paid by non-privileged consumers is estimated on a yearly basis.

4.2 Merit order effect and market value

The generation of electricity from RE sources affects the market prices of power as the variable generation costs of most renewable energy power plants (all except biomass power plants) are close to zero. Hence, in an energy-only-market, where the marginal cost of the last operating generation plant sets the market price, the supply curve shifts to the right. This shift is the larger, the more low-variable-cost RET enter the market. Thus, the market entry of RE generation technologies tends to lower market prices.

This price decreasing effect is called merit order effect, as the order of operating power plants changes with increasing RET-share. As this effect depends on the current load profile and available supply it can only be assessed with an energy sector model. The electricity market price of a system with RE and without (a few) RET should be modeled and compared. The difference between the price or traded volume with and w/o RET discloses the merit order effect, either as total (€) or specific effect in €/kWh.

Merit-order effect

- *is a price effect at the power market and, hence, has distributional impacts*

Market value

- *is the "value" of RES-E, realized at market prices when variable RES-E are fed in. The market value of RES-E is an input (factor) for assessing policy costs but not a unique policy effect.*

To do the modeling approach detailed data on costs, capacities, availability, etc. of power plants as well as the load profile and constraints must be taken into account. Moreover, the design of the reference scenario should reflect realistic assumptions on the dispatched generation plants.

Besides the impact on electricity wholesale prices, the "market value" of variable RES may deviate from those of dispatchable technologies. Depending on the time of feed-in, market prices may be higher or lower than on average. Thus, some RET generate power in peak times where market prices are generally higher, whilst other RET feed-in into the grid in times of less demand. In particular the increased value of RET power should be captured in the calculation of policy costs which take into account the difference between the received market price and the paid tariffs. Similarly, in a quota system with functioning certificate markets, the policy costs are the expenditures for certificates. Policy costs or quota systems may be corrected by the difference between market value of RET and the average electricity price.

4.3 R&D support expenditures for RET

Government spending for research, development or demonstration of new technologies is one major support for technology development, knowledge generation, networking, exchange of know-how, etc. In innovation economics it is classified as technology push instrument. As there are spill-over of R&D and no exclusion of competitors from using research results, public support is needed to incentivize research and development. However, R&D supports could be also considered as a distributional effect as it lowers research costs of technology providers and opens windows for temporary rents or profits due to advances in competitiveness. Data on R&D support are for example published by national statistics or ministries (see ISI et al. 2010 and 2013). However, we concentrate on the calculation of effects related to demand-side policies in this report.

5 Macro-economic effects of RET deployment

To get an overall picture of the impact of RET use, the effects at the system and actor level should be integrated into a more overall perspective – the perspective from the macro-economic level. Additional generation costs, grid extensions or surcharges of consumers can be measured at the macro-economic level with different macro-economic indicators, e.g. investments, changes in trade, etc., but typically the overall impact on the economy is expressed in general by changes in GDP or employment.

Macro-economic effects show how and to what degree the use of RET affects the economy either in some selected sectors, e.g. at the RE sector level (sectoral), or in all sectors of the economy (economy wide), i.e. in all industries and services of an economy. In this context, the terms gross (sectoral) and net (economy wide) are commonly used. But when talking about gross and net effects, the definition is not always that clear as there is a large variety of macro-economic impact assessments that range between the pure gross and net effects. To point out the principal differences between gross and net effects, the following definition is applied:

Gross effects

- *take into account the* ***positive effects*** *from investments in RET, operation and maintenance of RET,*
- *do not take into account the* ***negative effects*** *in the conventional energy sector (replacement), of changes in energy prices and income on all other sectors,*
- *show only the effects (direct and indirect jobs) in the* ***RET industry and its upstream industry***
- *is a* ***sectoral*** *impact analysis*

Net effects

- *take into account* ***all positive and negative effects*** *(direct, indirect, induced)*
- *rely on a comparison of two* ***different RET deployment scenarios*** *(no or low*

5.1 Gross/RE-sector effects

Gross effects show the RET induced employment in RE industries and service sectors such as RET manufacturing, or RE project planning, operation of an RE generation facility, etc. and in its related industries. In principle, gross effects are assessed only for RET-based energy systems and do not rely on a comparison of two systems (with and w/o RET use).[13]

As gross impact assessments are related only to industries and service sectors directly involved in RE activities, and as they only look at positive effects in these industries, they are also called sectoral effects at the macro-level. Consequently, gross impact studies are sectoral studies depicting the significance and relevance (share of employment) of the RET in an economy. Several indicators are commonly used to illustrate the RET-deployment induced effects in the RE sector. They comprise investments in RET and turnover of RET manufacturers in the respective sector, avoided imports, jobs in the RE sector (plus upstream industry), value added, etc.

5.1.1 Investment and turnover

Investments into RET are used as a common macro-economic indicator to highlight the significance of RET for economic activities. At the macro-economic level investments in RET generation technologies are the main impulses triggering further economic activities such as manufacturing of RET or intermediate products for RET. The economic activities that are triggered by investments can be measured as turnover of RE related manufacturing and service sectors. It shows the demand for RET, services, equipment or components in the respective manufacturing industries.

To assess the total (new) **investments in RET**, investment expenditures per installed capacity as well as the newly installed capacity per technology is needed. However, investments in RET or services cannot be translated completely to domestic effects, because part of the technology or services could be imported and not all domestically produced technology components are domestically installed. In order to use investment expenditures as an impulse for economic growth (investment impulse), the national RET investment expenditures have to be corrected by the net imports[14]. The calculation is depicted in Formula 5.

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[13] In case employment levels of with-RET and w/o-RET energy systems are compared without taking into account potential price and income effects of RET in other sectors, then two gross effects (sectoral effects) are compared with each other without depicting their impact on the whole economy.

[14] Single parts or components are imported, which represent a share of investment expenditures for an RET.

Formula 5:

$$\text{Investment impulse}_{RET}* = \text{specific investment expenditures}_{RET} * \text{installed capacity}_{RET} - \text{net imports}_{RET}$$

Investment impulses are then split into RET technology components and services and are allocated to the respective sectors**.** The result discloses the **turnover** of manufacturers and service providers in these sectors. Turnover from manufacturing is assessed on the basis of newly installed capacities minus imports plus exports, turnover from operation and maintenance on the basis of generation or cumulated installed capacities. Taking exports into account is especially important for countries with high export shares.

5.1.2 Gross employment (RE Sector)

Gross employment shows how many jobs (in full time equivalents - fte) exist in the sectors that are involved in any RE activities such as manufacturing, project development, re-search, operation, etc. It reveals the significance of the RE sector employment in comparison to total employment. Furthermore, if gross employment is broken down to technology level, the importance and dependence of an economy on the respective technology can be shown.

Gross employment can be assessed by means of different approaches. A very common approach is the use of employment factors, which relies on labor coefficients indicating full time equivalent jobs needed per MW installed (manufacturing, construction, installation) or per MWh generated (operation and maintenance). Simple multiplication of these coefficients with additionally installed capacities and generation, and some adjustments for regional or technological factors and ex/imports lead to gross employment figures that show the number of direct jobs.

A more complex assessment approach uses for example input-output tables. In this approach investment expenditures (export/import adjusted) of RET are divided into components and cost shares, which are in turn allocated to the respective economic sectors. They are used as impulse (input) in the input-output model to assess changes in industry production and services due to RET-use. A multiplication of the output changes with labor coefficients displays the number of jobs created due to RET deployment.

5.1.3 Imports or exports of fossil fuels and technology

Avoided imports of fossil fuels due to RET deployment reflect a macro-economic figure that highlights the decrease of import dependency and geopolitical risks of energy supply. It should be noticed, however, that a decrease of imports might not necessarily entail a positive economic impact per se. In case imports are replaced by products that are “more expensive” per unit energy, consumers might face a loss in their consumer surplus.

It is difficult to translate the value of a decreased import dependency into monetary terms. One option is to look at the risk of price fluctuations and shortages of certain fuels (geopolitical risks). Both might decrease in line with decreasing fossil fuels imports. The reduced risk may lead to lower requirements for storage capacity for example for gas and thus reduce infrastructure-related costs. These reduced "security" costs could be counted as "benefit" at the system level, but again its monetary quantification is a challenging task. (see Lehr 2011)

The economic effects of increases in **technology exports** are captured by or reflected in production, turn-over, value added or gross employment data. Subsequently, trade or export of RET is a macro-economic indicator, which enters macro-economic modeling and might have a large impact on value added but the exports itself allows no conclusions on the actual "net" benefits.

Data on trade is available in the UN Comtrade database (trade classification HS for wind: HS 850231).

5.2 Net effects

Overall macro-economic impacts of RET deployment in all sectors of the economy can be measured by changes in GDP or net employment. This assessment implies the development of two scenarios, e.g. RET scenario and reference. All positive as well as negative effects of RET deployment should be included (see Table 9) to get a real overall picture of the RET effects.

To estimate net impacts of RET development on GDP or employment macro-economic modeling under different scenarios is required. Thereby, a comparison of the different scenarios shows the net impacts. To model the net effects all costs and benefits at the system-level as well as the different charges and reliefs of economic agents at the micro-level must be included. However, implementing a macro-economic modeling is not in the scope of this project. Table 1 depicts the main effects that should be included in the modeling approach of a net impact assessment.

Table 9: Overview of positive and negative effects that should be taken into account when modeling net effects of RET deployment

Positive effects → job increases	**Negative effects → job losses**
increase in investment in RET (RE industry and upstream industry)	displaced investment in conventional generation technology (CE industry and upstream industry)
increase in O&M in RE generation (RE industry and upstream industry)	displaced O&M in conventional power generation (CE industry and upstream industry)
increase in fuel demand (biomass) (RE industry and upstream industry)	decrease in fossil fuel demand (CE industry and upstream industry)
increase in trade of RE technology and fuel (biomass) (RE industry and upstream industry)	decrease in trade of conventional technology and fossil fuels (CE industry and upstream industry)
higher household income from employment in RE industry	lower household income from employment in CE industry
decreased electricity price for households and industry due to merit-order effect, CO_2 pricing, etc*	increased electricity price for households (budget effect) and industry (cost effect) due to additional generation cost of RE-based power generation

Source: Breitschopf et al. 2013

6 Costs and benefits of RET in Germany

The preceding chapters have illustrated the diverse effects of RET deployment have suggested a methodological approach of how to assess the involved costs and benefits in the most appropriate way. Further, data and data sources needed for the assessment have been indicated for some countries. In our case, we mainly refer to data from Germany, as RET deployment and the economic analysis of its effects and availability of data is the most advanced so far.

In Germany, detailed assessments of historic RET deployment effects have been conducted for the power sector, while in the heating sector and transportation the analysis have been limited to a few selected effects. To illustrate the order of magnitude of these effects, some aggregated data for Germany are depicted in Table 10. The effects show costs and benefits of past and present RE use. In the case of Germany it becomes clear, that the largest costs arise from additional generation costs at the system level and that these costs are mainly paid/borne by consumers through the RE-surcharge. At the macro-economic level, investments and the number of jobs has increased in the RE sector while there is no comprehensive information available about the present net economic effect on employment.[15]

Table 10: Overview on costs and benefits in Germany (2012)

Level	type of effect	power	heat	transport
System level	Additional generation costs	10.3	2.7	2.4
	Grid costs	0.46		
	Balancing costs	0.16		
	Avoided emissions	9.2	1.2	0.1
Micro level	Surcharge (policy cost)	14.2	1.6	
	Tax credits/taxation			
	Special equalization scheme	2.5	-	-
	Merit-order	4.9	-	-
	R&D (heat and power)	0.8		
Macro-economic level	Investment (heat and power)	19.5		n.a.
	Turnover (heat and power	21.9		n.a.
	Gross employment (heat and power)	377,800		n.a.
	Avoided imports	3.9	4.9	1.2.
	Net employment	n.a.	n.a.	n.a.

Source: ISI et al. 2013

Overall, these effects displayed in Table 10 disclose the magnitude of the different effects as well as the main burdens and offer a good basis for discussions on social and distributional (side) aspect of the RET deployment. For the EU Member States it is

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[15] Assessments on prospective net employment impacts are available for 2020 and 2030.

suggested to analyze the most relevant effects regarding their magnitude/impact and societal/political significance. Moreover, costs that might significantly increase with a higher share of RET should also be indicated as the time horizon of the EU Member States' assessment covers the time horizon up to 2020 and potentially 2030.

7 Implementing the suggested approach

In this paper we have described and explained the different types of effects associated to the development of RET. The analysis has shown that a complete estimation of costs and benefits represents a challenging task. We have differentiated the different effects – positive or negative – according to the level these effects are relevant for – the energy system level, the micro-economic level or the macro-economic level. Thus, we refer to system-related effects for effects occurring at the energy system level include, to actor-specific effects or distributional effects for effects occurring at a micro-economic level reflect and finally to macro-economic effects for effects throughout the whole economy.

The estimation of the different cost and benefit components is partly challenging and requires the application of modeling tools. Provided that not all of the effects may be allocated directly to an individual RET, the comparison against a reference system may be required. Thus, additional system-related costs including additional generation, balancing and grid costs are costs at the system level, which cannot be assessed for each technology separately, but typically requires a system comparison. Actor-specific effects include distributional effects where money flows from one actor such as the supplier to the consumer or the other way around. These financial or price effects include the merit order effect, where electricity prices decrease as a result of increased low-variable cost RET feed-in. Finally macro-economic effects include the investment and turnover induced by RET deployment, employment effects as well as imports and exports.

In the context of DIA-CORE, we plan to apply a cost-benefit assessment of RET deployment to all EU countries. Therefore, we distinguish between two dimensions:

- Assessing costs and benefits for RET development that has already occurred – assuming a historic perspective
- Assessing costs and benefits for RET development for potential future development pathways – assuming a forward-looking perspective.

In particular some of the identified effects, such as the need for balancing services, are subject to considerable uncertainties regarding their future development. Thus, it is challenging to estimate how the quality of variable RES-E forecasts will evolve in the future.

Regarding the implementation to assessing future costs and benefits we will use the GreenX model and where required complement the analysis with other complementary modeling tools such as the power system model *HiREPS* (High Resolution Power System Model) and the *GreenX+* market model. Given that some of the effects are challenging to represent, we foresee to realize a two-step approach. In a first step we will assess the effects where a straight-forward approach is possible, whilst effects that are more difficult to determine will be analyzed in a second step.

The first steps of assessing costs and benefits for future RET deployment – mainly based on the GreenX model – are the following:

- Additional generation costs: These costs are based on investment, operation and maintenance expenditures of the individual technologies
- Policy support costs: In the modeling analysis we will not analyze economic impacts of differences between private and public burden sharing.
- Avoided emissions of greenhouse gas emissions
- Investment expenditures in RET

In a second step we will include effects that require more detailed analyses and potentially additional modeling tools:

- Additional balancing & profile costs will gain in significance with increasing RES-shares. This cost assessment calls for more detailed data and modeling adaptations and adjustments and will therefore be assessed at a later stage of the WP/project.
- Grid costs.
- Avoided emissions of air pollutants will be estimated in the second step.
- The Merit Order Effect will be analyzed in the second stage, provided that it requires the application of an electricity market model.
- The turnover will be modeled at a later stage and will be based on input from other projects (EmployRES for exports and imports)
- Gross employment effects will be approximated relying on other studies such modeling these effects in more detail as EmployRES. In DIA-CORE it will not be possible to estimate gross employment effects with the modeling tools available.

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