How to Assess Investment Needs and Gaps in Relation to National Climate and Energy Policy Targets?
A Manual - and a Case Study for Germany

A report by
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ACRONYMS

AGEE	Arbeitsgruppe Erneuerbare Energien Statistik
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle
BAU	Business-as-usual
BCG	Boston Consulting Group
BMWI	Bundesministerium für Wirtschaft
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
CCS	Carbon Capture and Storage
CEIM	Climate and Energy Investments Map
CIC	Climate Investment Capacity
CRP	Capital Raising Plans
CZ	Czech Republic (Country Code)
DH	District Heat
EC	European Commission
EE	Energy Efficiency
EUKI	Europäische Klimainitiative
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt(s)
IEA	International Energy Agency
INGA	Investment Needs and Gap Analysis
IKEM	Institut für Klimaschutz, Energie und Mobilität
IRENA	International Renewable Energy Agency
KfW	Kreditanstalt für Wiederaufbau
LV	Latvia (Country Code)
MAP	Market Incentive Programme
NECPs	National Energy and Climate Plans
OECD	Organization for Economic Co-operation and Development
RE	Renewable Energy
PV	Photovoltaic
R&D	Research and Development
TFEC	Total Final Energy Consumption
TWh	Terawatt hour(s)

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Executive Summary

Background and Rationale

The Study *"Assessment of investment needs and gaps in relation to the 2030 climate and energy targets of Germany"* is part of the EUKI project "Climate Investment Capacity: climate finance dynamics & structure to financing the 2030 targets". The EUKI project has three main and interlinked components. First, the design of a climate and energy investment map for Germany (CEIM), which has been provided by IKEM. Second, and based on CEIM results, the development of Energy and Climate Investment Needs and Gap Analyses (INGA) – which is presented in this report. Finally, results from INGA and CEIM will be used to deduct Capital Raising Plans (CRPs) in the third phase of the project.

This report addresses the central question **"How to identify and assess the investment needs and gaps (INGA) for the climate and energy transition?"** by providing a review of existing models and studies. Investment needs assessments are relevant to make long-term investment related decisions, both for the public and private sector. This is particularly the case when market failures and public goods require policy intervention to achieve a socially optimal level and allocation of capital. Investment needs assessments produce insights that can be instrumental in evaluating, legitimizing and motivating respective choices by private and policy decision makers.

This structured review provides a key element for the main purpose of this project, namely the strengthening of the understanding and skills of the project's target group, i.e. decision-makers at ministries, public banks, and operators of public financial support schemes who are responsible for tackling the investment challenge of meeting 2030 energy and climate targets in Czechia (CZ) and Latvia (LV). Our report enables them to develop a better understanding of how to capture the 2030 investment challenge and the related investment needs; how to assess them; and what to pay attention to when interpreting the results of such assessments. While this review of the "German case" by itself enables governments to solve the task of assessing investment needs, it provides an excellent basis for starting discussions and interactions with decision makers, desk officers, analysts, and stakeholders. It also informs more generally about how to tackle this task and how governments (in particular) can be supported in this endeavour.

The introduction (chapter 1) is followed by a discussion of the rational and the analytical framework (chapter 2). In chapter 3, we discuss the range of models that are used to analyse investment needs, their key elements and key factors, assumptions, and choices driving their results and outputs. Then we turn from the general discussion to a presentation of specific insights for Germany, providing an overview of the most recent studies analysing climate investment needs in Germany and discuss the analytical approaches and models used (chapter 4). In chapter 5, we illustrate the analysis in practice and exemplify prototypes for assessing investment needs in two sectors: energy efficiency investments in buildings (section 5.1) and renewable energy investments in the energy sector (section 5.2).

Main conclusions

To make the best use of model outputs representing, in our case, investment needs related figures, it is important to understand their underlying drivers. Across the different studies which model Germany's investment needs to reach climate targets in 2030 or 2050, figures range from EUR 24.9 billion to EUR 58.5 billion annually. The wide range is determined by discrepancies in scenarios, and in underlying models and assumptions. This illustrates the importance of understanding the differing frameworks in investment needs assessment studies.

Estimates of investment needs depend on assumptions that are taken along the course of the modelling-process. Some are more important than others, some are more controversial than others and some may not be obvious in the face of the (necessarily) complex modelling framework required for sophisticated estimates. Examples include price assumptions for fuels, carbon credits, technologies, model boundaries, macroeconomic expectations on economic growth and size of population.

Moreover, it is crucial to understand modelled target scenarios and in particular what is and what is not included in the baseline (i.e., the business as usual or reference case), since investment needs are commonly stated as *additional* costs *on top* of the reference case. When comparing different investment needs figures, one should appreciate the modelled policy scenarios but also take the differing time frames (e.g., 2030 vs. 2050), reference years, metrics (e.g., incremental costs vs. full costs, which is especially important for energy efficiency investments in the buildings sector), and sectoral scopes (e.g., renewable energy investments in the power sector or across all sectors, including heating) into account.

Technical Conclusions from the model review

1. Business-as-usual (BAU) and the choice of scenarios influence the estimated investment needs.

Climate and energy targets are the starting point of INGAs. They are determined politically and defined in national climate and energy transition commitments. They are not necessarily outcomes of assessment studies. Hence, under the same emissions target, different pathways and scenarios are analysed. They can affect in different ways the unfolding of the energy transition resulting in different energy demand, supply, and technologies. Accordingly, investment needs to achieve climate and energy 2030 targets will vary across scenarios.

2. Models differ in their assessment of investment.

Concerning the sector and subsector of interest, it is important paying close attention to the modelling framework. A macroeconomic model, for instance, potentially lacks the required degree of precision on a sectoral level as they mostly just overlook energy markets functioning mechanisms, whereas a specific focus on the energy system is required to provide robust results through taking demand- and supply-side factors into account.

When it comes to technology analyses, substitution cost curves are accurate and easy-to-use instruments that allow users to identify the least costly options to achieve climate and energy targets. Caution is required when the substitution cost curves have a limited emissions abatement scope. Indeed, on the one hand, GHG emissions derive from a wide range of economic activities that are not always accounted for; on the other hand, there are emissions resulting from activities (e.g. agriculture) that are also greenhouse gases but not included in measures such as total final energy consumption (TFEC). Large potential lies in those sectors that are seldom included in investment needs assessments. Accordingly, especially in countries where those economic activities contribute to a large share of GHG emissions (e.g., agriculture in Latvia contributes ca. 4% to GDP but was responsible for 23.6% of total GHG emissions in 2016[1]) investment needs assessments shall have a comprehensive scope.

3. Investment Needs Assessments are Sensitive to the Underlying Assumptions. Assumptions like the price estimates on fuel, technology, interest rates, learning rates, capacity and deployment pathways, and so forth, affect the investment needs projections for the climate and energy transition.

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[1] According to Latvia's draft NECP (2019), see: https://ec.europa.eu/energy/sites/ener/files/documents/latvia_draftnecp_en.pdf

Such assumptions can inflate or constrain the estimated investment needs and, in turn, the deployment of the focal technologies. Furthermore, regulatory and policy assumptions also play a relevant role in the deployment of new technologies. Elements such as disruptive technological innovations or extreme climate events are naturally difficult to account for, nevertheless, they might well affect future investments. Therefore, it is important to account for unexpected events and design appropriate risk management strategies.

4. The Two Sector Studies Confirm the Relevance of Scenario Choices and Parameter Assumptions. In the buildings sector, assessing the buildings stock is of primary relevance, and is, combined with renovation and reconstruction rates, the starting point of INGAs. Then different technology options, relative costs and benefits can be assessed for the calculation of the net present value of future investments that would allow to achieve climate and energy targets. Indeed, they have a large effect on investment need estimates. As the result of differing parameter and model framework assumptions, the annual estimated (additional) investment needs of our considered studies vary from 2.1 to 29.3 billion EUR. However, large parts of the discrepancies can easily be explained.

In the case of renewable energy (RE) deployment, short-term demand and supply dynamics are important to have optimal renewable power flexibility and costs and (related) investment decisions. Higher granularity for large temporal resolution and coverage of operational constrains is necessary to model renewable energies deployment. Long-term energy market models are often inadequate to calculate revenue streams for renewable energy projects. As with the building case, different assumptions on costs, technology options, their (relative) costs and benefits have a large effect on investment needs. In line with the studies on the building sector, estimated results differ significantly: three considered studies provide figures ranging from 4.4 to 12.8 billion EUR per year.

1. Introduction

1.1. Climate Investment Capacity (CIC): Climate Finance Dynamics & Structure for Financing the 2030 Targets – Short Project Overview

The governance regime of the EU Energy Union requires EU member states to develop national energy and climate plans (NECPs). To achieve the objectives and targets defined in these reports significant private capital will need to be mobilized.

Against this backdrop, the project aims to strengthen capacity of the public sector in Czechia and Latvia, gearing and adapting the decision makers' knowledge and know-how to the country challenges with help of the implementing partners. Using a learning-by-doing approach, the partners will co-operate with the target group to jointly develop prototypes of (i) climate & energy investment maps to track public finance and private investment flows, (ii) investment gap & need analyses to reach 2030 climate and energy targets, and (iii) capital raising plans to close the investment gap. The work will focus on at least two sectors up to the target group preference and data availability. The project will therefore illustrate the potential and the means for the 2030 agenda to mobilize sustainable investment.

Germany will in this context serve as an example, where a full development of the climate and energy investment maps and investment needs assessments prototypes, in the first project phase (until the first quarter of 2019), will provide detailed insights (data and methodological challenges, etc.) to inform their development in Czechia and Latvia. The climate and energy investment maps and the investment gap and needs analyses in these two countries will build on a review of the relevant German experience, which, as a frontrunner, provides a good example and is characterized by a minimum level of data availability required for this kind of analysis.

1.2. Assessment of Investment Needs and Gaps in Relation to 2030 Climate and Energy Targets: Contribution to Activity 1.3 and 1.4 (Output indicator O.1)

This report discusses how investment needs and gaps analysis (INGA) can be used, and provides a key element for strengthening the understanding and skills of the project's target group (i.e. colleagues at ministries, public banks and operators of public financial support schemes) that will be involved in tackling the investment challenge of meeting 2030 energy and climate targets in Czechia and Latvia. On the basis of our report it will be possible to develop a better understanding of how to capture the 2030 investment challenge and the related investment needs; how to assess them; and what to pay attention to when interpreting the results of such assessments.

In line with this objective, this report provides an introduction to the rationale and framework of analysis for investment needs assessments, a review of literature relevant to assess those needs and a critical discussion of existing approaches as to their added benefits, constraints, and applicability in the context of national climate and energy targets. A review of relevant German studies is conducted to summarize our current understanding of investment needs in relation to Germany's 2030 (and 2050) climate and energy targets. In line with the preferences of our major target groups in Czechia and Latvia, revealed through our interviews/personal discussions and workshops in Prague and Riga, we developed prototypes (i.e. a detailed account of "how to analyse the investment challenge" for two sectors, namely buildings (with a focus on energy efficiency) and electricity supply (with a focus on renewable energy). Learning from the German experience, this analysis has the primary aim to support the development of capacity in Czechia and Latvia to carry out INGA in relation to their 2030 targets.

1.3. Background

EU energy union governance and national energy and climate plans (NECPs)

Europe faces a significant investment challenge: meeting the targets of the 'Clean Energy for All Europeans' package will require around EUR 11.2 trillion of largely private capital to be raised until 2030 (EU High-Level Expert Group on Sustainable Finance, 2018). Accordingly, the Investment Plan for Europe calls for smarter use of financial resources, removing obstacles to investment and providing visibility and technical assistance to investment projects. To serve this objective, European Member States are preparing National Energy and Climate Plans (NECPs) to describe their approach to contribute to the 2030 Energy Union objectives.

Germany's energy and climate policy context

In Germany, climate and energy transition targets are outlined in the German Climate Action Plan 2050 (BMU, 2016), where intermediate country-wide and sector-specific GHG emission reduction targets are set for 2030 as compared to their 1990 level, following the Energy Concept (BMWi and BMU, 2010), the Energiewende Law (GoG, 2011), and the Paris Agreement[2] (see Table 1). While Germany has hence been working on its climate and energy transition for some time already (see CEIM Report), considerable additional investments are still necessary to achieve national targets (BMWi, 2018a).

Table 1 - Country-wide and sector-specific GHG emission reduction targets for Germany in 2030 as compared to their 1990 level. Source: Climate Action Plan 2050 (BMU 2016).

Sectors	Germany
Energy	- 61 to - 62%
Buildings	- 66 to - 67%
Transport	- 40 to - 42%
Industry	- 49 to - 51%
Agriculture	- 31 to - 34%
Other	- 87%
Total	- 55 to - 56%

The annual monitoring report of the energy transition, which is carried out by a commission on behalf of the German government (coordinated by the German Ministry for Economic Affairs and Energy) provides for a detailed review of the policy framework, some assessment of its effectiveness and an analysis of key indicators in relation to Germany's energy and climate targets. **Our central question for this report is as follows: How to identify and assess the investment needs for the climate and energy transition?**

Subordinate questions are:

- How are such assessments carried out and by whom?
- Which analytical tools are used for such assessments?

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[2] The policy context for buildings and renewable energy will be discussed in more detail in Chapter 5.

- What are the key issues one has to pay attention to in relation to the different models and studies?

Addressing these questions, the report consists of six chapters. Following this introduction, Chapter 2 introduces the methodological framework to identify the investment needs for the achievement of energy and climate targets. Chapter 3 presents different models, modelling frameworks and actual studies on which we can draw to assess investment needs, sectors and technological potential to contribute to the achievement of the targets. Chapter 4 provides results from a review of German studies that assess investment needs to achieve national targets. Chapter 5 applies the framework to analysing investment needs for two prototypes for two sectors in Germany, presenting a detailed overview of models that can be used to assess renewable energy and energy efficiency investment needs of the energy and buildings sectors. Furthermore, sector-specific studies are analysed. Chapter 6 discusses the main results and relevant insights and concludes.

2. Rationale and Framework of Analysis

Climate and energy investment needs can be defined as the amount of capital necessary to achieve climate and energy targets. Within the time horizon of interest, new investments and technologies have to be deployed, and existing infrastructure (notably buildings) have to be up-dated or renovated across sectors to capture the potential of energy markets, energy-consuming sectors, and major emitters of GHG to contribute to achieving the targets. The rationale of this report is to explain how to better understand the role of investments as one dimension of the climate and energy transition and as important means for reaching the targets. It goes without saying that successfully reaching the NECP objectives does depend on a range of measures and activities, most notably behavioural changes, which do not necessarily require any investment. In that sense investment need estimates should not be seen as independent or alternative targets, but as an additional dimension we need to understand, address, and monitor on our way to reaching climate and energy objectives.

2.1. Building Blocks to Identify the Investment Needs

A sound understanding of future economic activities (e.g. production, population growth, and other socioeconomic variables) is crucial for identifying investment need - just like related energy demand (i.e., energy efficiency across sectors), energy supply and transformation capacity (i.e., energy sector developments), together with the costs of the technologies that influence the transition of relevant sectors (e.g. the opportunity cost of capital). After comparing investment needs estimates with current and historical[3] as well as projected climate and energy investments levels, investment gaps can be identified - i.e. the order of magnitude of additional private and public capital that must be raised to achieve the targets.

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[3] as provided through the development of the climate and energy investment maps, CEIM, in a parallel report prepared as part of this project

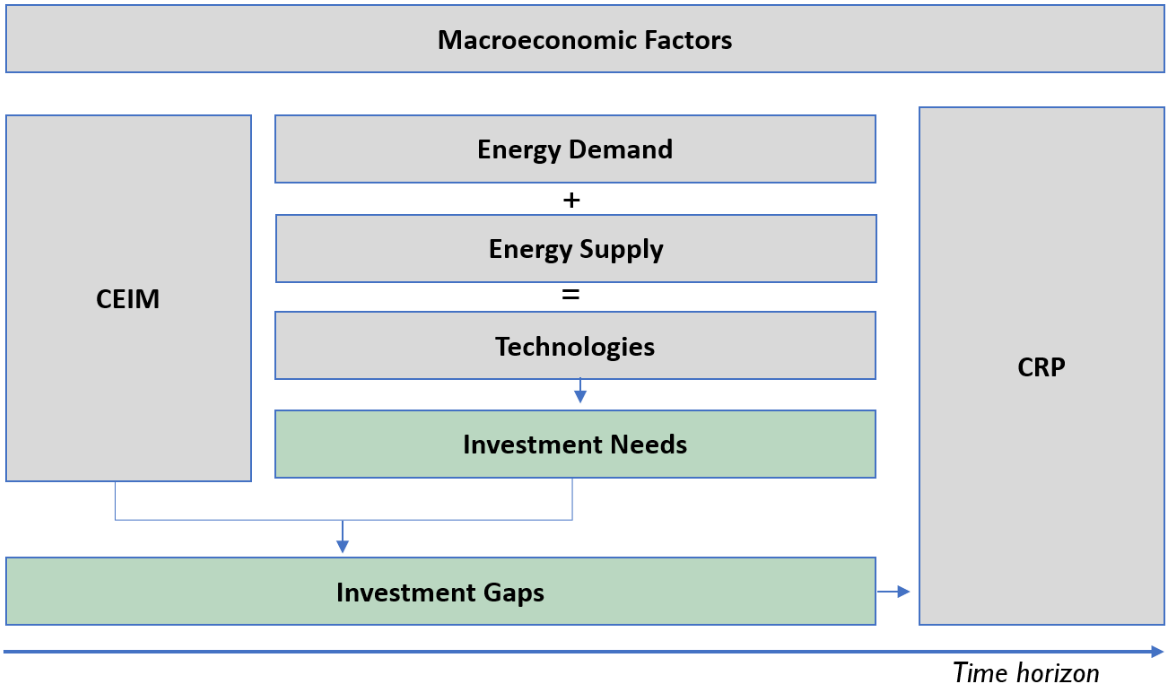

Figure 1- Building Blocks to Assess Investment Needs.

Figure 1 depicts the building blocks and their respective relationships, and introduces a time dimension to guide the reader through the overall work stream of the overall EUKI CIC2030 project. Starting from documenting the status quo via Capital and Energy Investments Maps (CEIMs) to assessing investment needs and gaps through INGAs, and then further on to the definition of Capital Raising Plans (CRPs) to address the need to stimulate the necessary investments.

In the following we discuss the key building blocks and factors that need to be considered - namely “Macroeconomic Factors”, “Energy Demand”, “Energy Supply” and “Technologies (see Figure 1) - to thoroughly assess “Investment Needs”.

Macroeconomic Factors

The basic starting point for an investment needs study are the socioeconomic factors that define the overall activity of an economy. One common way of characterising these is through the following set of six macroeconomic factors/dimensions:

- **Population** – Population growth estimates are crucial to assess both the demand of goods and services within an economy (indirect energy demand) and the number of people that will consume energy (direct energy demand) at a given point in time. The World Population Prospects published by the UN Department of Economic and Social Affairs are the population forecasts most widely used to produce economic projections (United Nations 2017).
- **Economic Activity and Economic Growth** - Gross Domestic Product (GDP)– The GDP is the value of goods and services produced in a country. As such, GDP growth figures are key for energy demand and consumption estimates as long as economic growth and energy demand have not been entirely decoupled. Examples of GDP forecasts are those provided by the IMF and the World Bank (internationally), for Germany this is done most prominently by the bi-annual “Gemeinschaftsprognose” (the joint forecast) of five economic research institutes

(currently DIW, ifo, IfW, IWH and RWI[4]); and for the EU (and its member states) by the European Commission in its quarterly economic forecast[5].

- **Innovation and Productivity** – Productivity is a proxy for economic efficiency. Productivity is generally measured as output relative to input and in the case of labour productivity, for example, is measured as unit labour cost. In developed economies, productivity improvements tend to reflect the improvements in efficiency and quality of output rather than increases in the quantity relative to inputs.
- **Innovation and Technological Learning Curves** – Technology and cost developments determine the energy needs of the sectors of an economy. Furthermore, they can influence also the productivity of relevant economic sectors. Low-carbon technologies have the potential to decrease the carbon intensity of energy production while energy efficient technologies have the potential to decrease energy demand. As the market for those technologies grows and cost of production decreases, also investment costs decrease. The shape of technology learning curves is a highly unpredictable yet crucial factor for determining investment needs for the energy and climate transition. Information on learning curves and cost predictions can be either taken exogenously from the literature or determined endogenously through bottom-up research (see Chapter 3 for more details).
- **Energy and Climate Policies** – Climate and energy transition policies define the regulatory setting within which the energy demand and supply will develop in the time horizon of reference. Such policies affect GDP and productivity and can improve the predictability of technology and cost learning curves when they define support instruments for the achievement of policy targets.
- **Natural Resources** – The availability of natural resources is the first factor that drives the price of energy commodities before transformation (coal, gas, oil production) and raw materials to produce new technologies (e.g. lithium for energy storage batteries). Similarly, the availability of land/ocean to use for the deployment of renewable energy resources (e.g. wind parks) or the best weather conditions to install them (e.g. sun to produce electricity through PV panels) are key to identify the potential deployment of a certain technology.

Identifying these factors is the basis to assess investment needs within a certain time horizon. Macroeconomic models are the instrument used for forecasting key economic factors (as discussed above) as they allow to simulate how different markets[6] interact and unfold over time and between countries[7]. Such models provide inputs to and help defining important boundary conditions for sector-level studies, which take these outputs as so called "exogenous" inputs (i.e. factors and data that are used by the more focused sectoral model but are not generated by this model). This combination of macro-models and sector models is often driven by the need to analyse sectors in more detail than would be feasible to implement in the macro model.

Energy Demand

Energy demand is directly related to the activity of an economy, the production of goods and services (internally consumed or exported), the technologies available to produce them, and the related costs of production, including the price of electricity and fuels. On the one hand, the socioeconomic factors identified above are used to estimate the expected output (e.g. quantity of steel produced) of energy using sectors (e.g. manufacturing). On the other hand, the energy efficiency parameters of

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[4] See: http://gemeinschaftsdiagnose.de/

[5] https://ec.europa.eu/info/business-economy-euro/economic-performance-and-forecasts/economic-forecasts_en

[6] Subject to the models' specific scope and objective, this includes more or less explicitly financial markets, labour markets, product markets etc.

[7] The geographical scope also varies and depends on the model configuration; also identical models can be set up, for specific purposes and to answer specific policy questions, to either explicitly model certain individual countries or to aggregate them, for example into groups like EU vs. rest of the world.

technologies used in manufacturing (e.g. electric arc furnaces versus blast oxygen furnaces for steel production), are combined with expected energy prices to forecast the specific final energy demand within every sector (e.g. how many hours are the different technologies used in, say, the steel sector, are expected to operate and hence consume energy) and total final energy consumption (TFEC).

Energy Supply

Directly using the load curves deriving from energy demand forecasts or after interactions with energy demand modules, energy supply can be derived with energy (sector/market/system) models. In particular, they allow to estimate the quantity of energy transformed into electricity and heat, from primary energy resources to final energy supply, and the expected price. Energy supply modules also identify the share of fossil fuels (natural gas, oil, coal and related) and renewable energy (RE) sources in the energy mix, their costs and the cost of carbon emission allowances. According to the technology deployed or available for deployment in the energy sector, the capacity, emissions-intensity, and efficiency of the energy sector varies.

Trade can be included in the model, i.e. treated endogenously. This allows to take into account primary energy and final electricity exports and imports, and to estimate carbon leakage risks from asymmetrically priced carbon emissions between differently regulated markets. Also in this case, supply-side technologies are important factors, which influence the total cost of energy production (including the cost of primary energy sources, operation and maintenance costs and GHG emission allowances)[8].

Technologies

Technologies adopted on the supply and demand sides define the efficiency of energy production and consumption, and the amount of greenhouse gas (GHG) emissions released in the atmosphere by the respective production processes. The use of low-carbon and energy-efficient technologies is crucial for achieving energy and climate targets. The cost of deploying such technologies to the extent necessary for compliance with climate or energy saving targets, varies (over time) according to technology learning curves (JRC, 2012). Technology curves and cost projections are, indeed, pivotal in the estimation of investment needs for the energy and climate transition.

Summary

The underlying economic forecasts under which investment needs figures are estimated, and the respective assumptions and resulting socioeconomic variables (population growth, GDP growth, innovation and similar factors) are reflected in the building block "Macroeconomic Factors", while elements such as disruptive technological innovations or extreme climate events are generally not properly accounted for. Regarding climate change, global warming and its impacts on the economy, this is a short coming which should be addressed by future macro-models, especially considering the significant progress in simulating and predicting the development of these factors. This is important as the assumptions and choices behind macro-forecasts affect the estimation of investment needs and the design of capital raising strategies, both indirectly as inputs to the modelling of investment needs (see Figure 1) and directly by outlining the socioeconomic context for the CRPs.

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[8] Carbon leakage risk depends on the technologies that are deployed in the different trading countries and the resulting costs of production.

2.2. Investment Needs for the Achievement of Climate and Energy Targets

Climate and energy 2030 targets can not only be considered as constraints (or boundary conditions) that need to be met, taking into consideration the underlying economic scenarios. Depending on the modelling framework used, different climate targets and technological learning assumptions, as implemented in an economy-wide model, have an impact on the key factors discussed above (i.e. prices, GDP, energy demand). Thereby they are influencing for example electricity prices, energy intensive product prices, and through the respective elasticities (i.e., “links” between demand and supply functions), energy consumption and emissions (which in turn influence electricity and carbon prices) in the modelling framework.

Such climate and energy targets are not necessarily the socially optimal outcome of an assessment, but are determined politically and defined in national climate and energy transition commitments (national strategies, EU or national legislation or, in our case, the governance regime of the EU energy union and the corresponding NECPs).

As a first and foremost guiding factor determining the investment needs of a country undergoing its climate and energy transition, climate and energy targets are the starting point for INGAs. Then, the scope of analysis is defined in terms of sectoral coverage and (at the sub-sector level) the relevant (energy generating, energy consuming, and GHG emitting) economic activities and corresponding technologies. Overall, regardless of the specific transition pathways of the different sectors, two types of lever can be used to achieve GHG emissions reduction targets within the time horizon of interest (2030):

1) Energy efficiency levers, determining productivity of energy generation (supply side), and efficiency of final energy use (demand side)
2) Decarbonization of energy production (supply side) levers.

Hence, in order to achieve a given emissions target, the amount of renewable energy sources that needs to be deployed under a 2030 scenario with efficient energy-consuming sectors (Scenario 1) is lower than that of a scenario with less efficient energy-consuming sectors (Scenario 2) and highly energy-intensive demand-side technologies (Scenario 3). Figure 2 depicts such hypothetical scenarios, under which emissions targets for 2030 can be achieved through different combinations of energy efficiency and renewable energy (RE) deployments, implying different degrees of decarbonization of energy demand and supply respectively – and, concerning our overarching research question, also implying different kinds of investments (roughly speaking “energy efficiency and renewables as complements”). Even though energy efficiency is important, one should keep in mind that in the long run every unit of energy demand must be met by renewables.

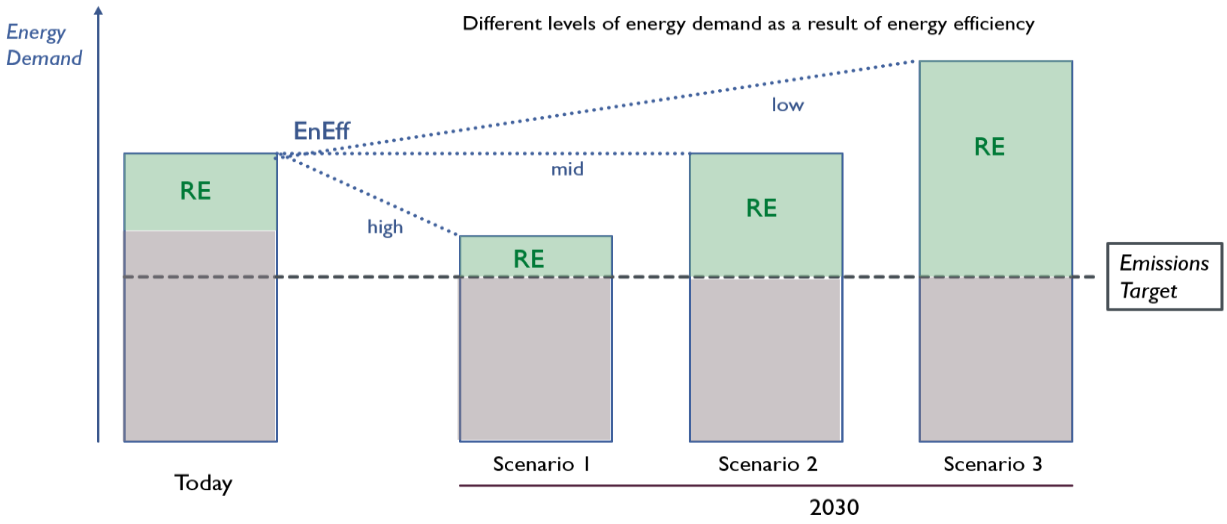

Figure 2 – Purely illustrative graphical representation of the combined role of energy savings and decarbonisation measures for achieving emission reductions of final energy consumption.

As in the example above, usually studies present a baseline scenario[9] and one or more low-carbon scenarios which are characterised by different combinations of technologies (driven by differences in assumptions, for example as regards the availability and cost of Carbon Capture and Storage (CCS) technologies; or the degree of electrification of major emitting manufacturing processes or transport). Making these assumptions visible and comparing scenarios allows to understand differences across pathways and related potential outcomes. Following the hypothetical case in Figure 2 above, under the same emissions target, scenarios 1, 2 and 3 would affect the unfolding of the energy transition in different ways, resulting in different levels and compositions of energy demand, energy supply, and technologies. Accordingly, investment needs to achieve climate and energy 2030 targets would also vary across scenarios.

3. Models to Assess Investment Needs

Different types of models can be used to assess the investment needs in relation to climate and energy targets. The choice of the model depends on the objective of its users and scope of the analysis, i.e. focus on macroeconomic factors, demand side or supply side factors, or the opportunity cost of investing in new technologies versus business-as-usual (BAU) technologies, for example. In turn, investment needs are estimated according to the assumptions and inputs of the model framework adopted and are also influenced by the availability and accuracy of the data required for running the model.

Following the order of the table below (Table 2**Error! Reference source not found.**), the chapter presents a series of models used in the literature, assessing investments needs for the energy and climate transition. This overview is not and does not aim at being comprehensive but is supposed to capture the range of relevant models "in use" and exemplifies key elements of different analytical frameworks.

This will provide the reader with an understanding of the different relevant types of models, which building block(s) they address in the overall framework for finally deriving investment needs, how they

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[9] A baseline scenario mostly refers to a business-as-usual (BAU) pathway which assumes – depending on the model setup – no or only modest increases in political efforts.

relate to each other, and how they contribute to the identification of the relevant investment strategies. We will focus the attention on the specific output features of every model.

Table 2 - Studies Overview

Study	**Building bocks**			**Model-specific output features**
	Socioeconomic factors	**Energy markets**	**Technologies & Innovation needs**	
OECD (2017)	Yoda model + Oxford GE model	Oxford GE model	Exogenous	SR and LR economic growth, potential output. GEM enables sector-level analysis.
IEA (2017)	Exogenous	World Energy Model (WEM)	REmap	Energy flows by fuel, investment needs and costs, carbon dioxide (CO2) and other energy related GHG emissions, and end-user prices.
IRENA (2015)	Exogenous	Exogenous	REmap	Supply substitution cost curve. Current cost of technologies (no LR).
DENA (2018)	Exogenous	DIMENSION +	Exogenous	GHG emissions per sector.
BCG (2018)	VIEW Model by Prognos	Different models by Prognos	Bottom Up Substitution Cost Curve	Sectoral cost-efficient and low carbon technologies related investment needs.
Frauenhofer-ISE (2015)	Exogenous	REMod-D	Exogenous (e.g. expansion capacities of technologies)	System composition including cost analysis.
Prognos et. al. (2018)	ISI Macro Model	Exogenous	Cost-Benefit Tool (UBA)	Primary effects (direct economic and environmental impacts, investment); Secondary effects (e.g. employment)
European Commission (2017)	All the economy is modelled endogenously			Investment needs figures and detailed assessment of relative economic impacts.

3.1. Macroeconomic Models

We start the literature review with the macroeconomic models used to perform the simulations of the OECD (2017) study titled *"Investing in Climate, Investing in Growth"*. The two models adopt different approaches and use different data series.

3.1.1. The Yoda Model

The Yoda model is an OECD in-house semi-structural macroeconomic model for selected G20 countries. It includes country-specific structural features as well as international dimensions. Major advanced economies, major emerging-market economies and the rest of the world are connected through trade volume linkages (i.e. the exchanges happening between countries and resulting prices). The model depends on the current state of economies (their position in the business cycle). The main equation of the model is the economic growth equation, which depends on potential growth, real interest rates and discretionary fiscal policy – i.e. forecasted production (GDP) levels, prices and trade expectations, and national fiscal policies.

In order to identify climate transition investment needs, the model includes:

- innovation, which captures the increase in R&D spending
    - necessary to reach a 2°C scenario (leading to 55% reduction of GHG emissions), and
    - equivalent to 0.1% GDP (leading to a 66% reduction of GHG emissions);
- the regulatory setting, which captures the effects of the regulatory framework on the costs of the transition.

Potential damages from climate change are not taken into account, which, particularly for longer projection time horizons, is problematic, regardless of the specific question the models are used to answer, as projections of the economic impact of climate change are high and distributed heterogeneously across regions and economic sectors (see for example IPCC 2018)[10]. Furthermore, also factors such as political decisions, social acceptance, and institutional factors, which play an important role in the real world, are not incorporated in the model. This is the case for every macroeconomic model since those elements are difficult to capture at the necessarily aggregate level of analysis.

3.1.2. The Oxford Global Economic Model

The Oxford Global Economic Model is widely used for macro-economic modelling (e.g. in OECD, IMF, World Bank studies), with a special focus on trade and financial interlinkages. The main equation of the model defines potential output – i.e. forecasted production (GDP) level – as determined by demand side factors in the short run and supply-side factors in the long run. In a 2030 scenario, the long-run (potential) output is determined by a standard[11] production function using capital flows, interest rates, technological progress, labour supply, trade volumes, exchange rates, and commodity prices as inputs. In the OECD (2017), the long-run output equation has been revised to include also an explicit effect of public capital[12] on potential output. The model allows for sector-level analyses since aggregate output and employment are split into twelve high-level sectors. These include the energy sector which is treated in a more detailed manner, ensuring consistency between energy prices and supply/demand balances.

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[10] https://www.ipcc.ch/sr15/

[11] Cobb-Douglas

[12] Public capital is the stock of government-owned assets that are used as means for productivity (i.e. government money and physical infrastructure).

3.1.3. Discussion

As explained above, macroeconomic models can be used to forecast the economic activity of a country and perform simulations relative to some counterfactual or baseline set of macroeconomic factors (e.g. different population growth rates, labour supply, production capacity). They outline the socioeconomic factors that determine the economic activity of a country, its sectors and subsectors. The level of detail of the estimates varies according to the scope of the model and the granularity allowed[13]. Despite that, the degree of precision with which a macroeconomic model can estimate climate and energy transition investment needs is limited. Macroeconomic models "overlook" energy markets specific functioning mechanisms and related outcomes. A specific focus on energy markets is necessary to model electricity and heat demand and supply interactions in a way suitable to identify where and how much investments are needed for the low-carbon transition.

3.2. Energy System and Market Models

Energy system models estimate electricity consumption and production quantity, quality and price at a certain point in time. Demand and supply dynamics – determining the quantity of energy exchanged – are endogenous to the models; consumption and production technologies – which define the efficiency and carbon content of the electricity in the market – are exogenous to the model while crucial to determine the quality of electricity exchanged (i.e. the carbon content of the energy produced). Finally, energy quantity and price (including the price of related GHG emissions allowances) is forecasted for a specific time horizon and given specific constraints. This allows the users of energy system models to identify the amount of investments necessary to achieve energy and climate targets and the specific areas where those investments are necessary. Furthermore, they allow to account for electricity demand, demand side changes, assess cross-sectorial linkages, and sector coupling. On the contrary, energy market models focus on energy supply, assessing production decisions in a granular way, while taking demand side parameters as exogenous. Energy market models are also highly relevant to model investment decisions. Thanks to the large number of information factored in such models, they can provide detailed estimates of the price of electricity and related services. Together with investments models, energy market models allow to identify the capacity mix that a country needs and the resulting investment or decommissioning decisions.

3.2.1. The World Energy Model

The World Energy Model is an iterative energy supply and demand model run, recalibrated, and improved every year by the International Energy Agency (IEA). It estimates electricity consumption and prices that link the final energy demand and production. The main output of interest is the amount of investments sufficient for meeting the projected demand, whereas the main exogenous assumptions are economic growth, demographics, and technological developments.

Demand modules

As first step, socioeconomic variables are estimated econometrically for each sector based on historical values (e.g. steel production in industry or household size in dwellings). They drive the economic activity of each sector (e.g. use of machineries in industry or appliances ownership in dwellings) and, thereby, influence the demand of energy services within every sector. A wide range of technologies are included in the model to satisfy every energy service (e.g. production capacity in

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[13] An analogy may help to explain this important trade-off: if you want to draw a map of the world, you will only be able to capture major rivers, cities or mountain ranges. A map of Germany would already allow you to include more detail. It is pretty similar for models. If for example I want to be more detailed in terms of my sectoral disaggregation and expand my number of sectors from 12 to 13, I am not just adding one element but the interaction of this one additional sector with the other 12 sectors times all countries I am including in my model. So "just one more sector, dude!" becomes 1*12*50 (or so) additional things/equations/links.

industry or refrigeration capacity in dwellings) in an efficient way and at the least cost. The resulting demand for primary energy is used as input for the supply modules.

Supply Modules

The supply modules estimate the production of fossil fuels that is stimulated under a given price trajectory. The modules take the costs of different production technology options and the respective capacity constraints into account. Until a given price is not sufficient to cover global demand, the energy demand and price are recalculated and fed back into the supply modules, in an iterative way. Eventually, the model identifies an equilibrium price, resulting from the balance of the demand and supply of energy. Fossil fuels prices will vary according to cost and capacity assumptions considered in the model. Hence, price paths and investment needs vary across scenarios.

On this basis, energy balances can be compiled at regional levels and respective GHG emissions can be calculated through the use of emission factors.

3.2.2. DIMENSION+

The *Dimension+* model allows to run simulations of European energy markets. It permits to minimize energy costs in the short- and long-term across all sectors within the European energy market, using a detailed spatial and temporal dimension. Furthermore, the model considers electricity, gas, and heat networks, as well as costs for the expansion of the sector – allowing to investigate in details the potential development of the power system until 2030 or beyond, and related investment needs.

The model, owned and operated by Ewi[14], has been used for example in the DENA (2018) study to optimize investments and dispatch decisions for the German power plant park.

3.2.3. RemoD-D

The RemoD-D (Renewable Energies Model - Germany) is a simulation and optimization model, capable of developing entire transformation paths. The basic functionality of the model builds upon a cost-based structural optimization of the German energy system in which CO2 emissions do not exceed a target value. The model works on an hourly level and guarantees that the energy balance of the system is always met. The model requires weather data and parameters on technology and the economy as inputs. Besides capital expenses and CO2 emissions, it provides hourly time series on the energy demand as well as a dimensioning of power and heat generation.

The model has been applied for example in *"What will the Energy Transformation Cost? – Pathways for Transforming the German Energy System by 2050"* by Fraunhofer-ISE (2015).

3.2.4. Discussion

Energy system models, such as the World Energy Model, can be adopted to identify climate and energy transition pathways to achieve respective national targets. They allow to identify the quantity, quality, and price of energy that result from demand and supply interactions under different scenarios. The World Energy Model includes a wide range of technologies that permit to serve energy demand in different ways and to test variations in structure, policy, or technology across scenarios.

Energy market models, such as *Dimension+*, can be adopted to investigate the potential development of the power system in detail. Using a detailed spatial and temporal disaggregation, they allow to

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[14] The model brochure can be found here: https://www.ewi.research-scenarios.de/en/models/dimension/ .

minimize the costs of energy in the short- and long-term and to optimize investments and dispatch decisions[15].

A crucial element for the assessment of investment needs is the cost of technologies. The technology costs contained in the models described above are generally characterized by learning rates (from the literature, mostly derived empirically) and the degree of market penetration of the technologies. While the first is exogenous, the latter is endogenously determined according to the demand of energy and the degree of ambition of decarbonization policies. In turn, the share of technologies deployed is determined in different parts of the model on the basis of their specific costs – which include investment costs, operating and maintenance costs, fuel costs, and in some cases costs for emitting CO2.

Despite this attempt to capture important technology features, it is important to note that the profitability of those technologies in the future cannot be predicted through energy market models alone. This is due to several reasons:

- such models estimate smooth fossil fuel price trajectories, that do not reflect the volatile and cyclical patterns usually followed by prices in the real world[16];
- the information contained in the models is not disaggregated at the technology level to an extent that is sufficient to identify different technology options.

Overall, given endogenously determined socioeconomic factors and endogenously identified technology options, energy models allow to weigh and choose the least cost and most efficient technologies that satisfy the activity needs of economic sectors of a country or region.

In the previous section we have seen how macroeconomic scenarios are identified; in this section we have looked at the functioning of energy system and market models; in the next section we step into a further level of disaggregation, at the bottom of the investment need question – i.e. the cost of transforming the existing and evolving energy system (the baseline scenario) by expanding low-carbon technologies for the production and use of energy across sectors.

3.3. (Bottom-up) Technology Models

The analytical frameworks described so far use pre-defined sets of technology options in their models which are weighted according to demand needs and supply capacity. These technology options are derived from technology assessments and are selected through substitution cost analyses (i.e. substituting existing, less efficient and more carbon intensive technologies with low-carbon options). These are exploratory bottom-up studies, typically carried out through sector-specific investigations and technology-level evaluations. The data collected are then aggregated to understand the potential role that each technology can play for the achievement of energy and climate transition objectives. The result is usually a technology substitution cost curve which shows the cost difference of replacing conventional energy technologies with low-carbon (renewable)alternatives.

3.3.1. The REmap Model

The REmap (Renewable Energy Map) from IRENA (2014) is an example of a technology substitution model. It allows to estimate the cost of substituting conventional technologies expected to be in place

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[15] While investment decisions are related to long-term energy supply planning, dispatch decisions are those related to the short-term management of energy flows along the grid. Energy flows need to be regulated in a way that energy supply and demand are always balanced. Dispatch decisions are critical to guarantee the safety and continuity of the service provided.

[16] Commodity prices are characterised by a trajectory with a more or less variable frequency. They are subject to cycles, long-term trends and short-term volatility (Erdem and Ünalmis, 2016).

in 2030 in the reference case[17] with renewable energy (RE) technologies that can produce the same amount of energy. The technology cost-supply curve calculated for Germany by IRENA (2015) is shown in Figure 3.

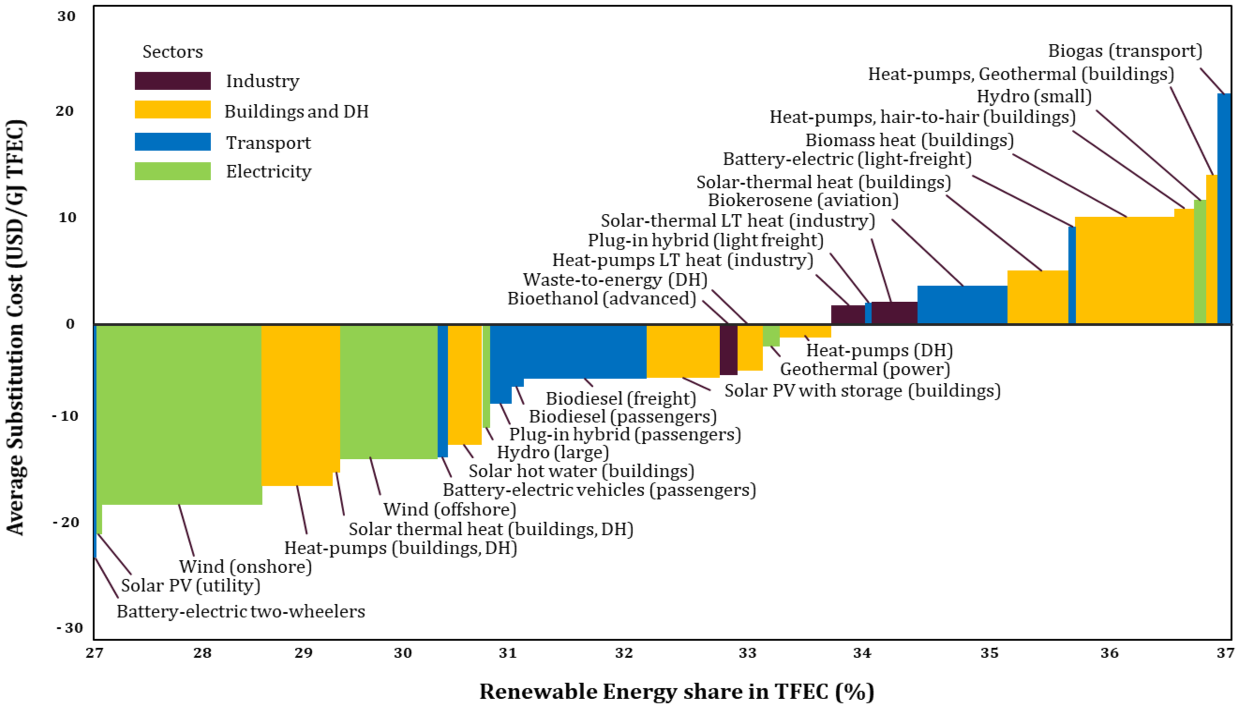

Figure 3 - REmap cost supply curve for Germany. Source: IRENA (2015)

The x-axis shows the share of renewable energy in total final energy consumption (TFEC). It is expected to increase to 30% in 2030 (under Reference Case Scenario) and to over 37% (under REmap Scenario) through higher uptake of renewable technologies in end-use sectors.

The energy demand (TFEC) is typically exogenous to such models and, in this case, derived from the IEA World Energy Model. Further assumptions include emissions targets, climate and energy policies, energy import/export figures, and technologies at disposal in the time horizon of interest (2030). These assumptions are crucial to draw scenarios of interest against which investment needs to achieve climate and energy (2030) targets can be estimated.

The average substitution cost of the low carbon/renewable energy technologies is shown on the y-axis of the graph. In other words, it represents the unitary cost of the additional clean energy capacity that is necessary to achieve the renewable energy deployment level projected in the REmap Scenario.

Each block depicted in the graph shows the contribution of a specific technology, of a specific energy-use sector, to the renewable energy target. Its height indicates the substitution cost of the technology while its breadth represents the capacity of each technology to provide (and substitute) a certain share of the TFEC of the economy. Accordingly, the main inputs of the model are:

- **capital cost projections,** which decrease at a certain learning rates (derived from the mostly empirical literature) which is a function of the installed capacity or market penetration of that technology (i.e. in simple words: the more of a technology has been installed, the more all involved actors have learned and the cheaper it is);

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[17] The Reference Case accounts for planned policies and expected market developments for the energy sector of a given country (Germany) as of 2014. RE options (REmap Scenario) reflect changes agreed through mid-2015 in Germany, hence, foresee additional renewable energy deployment to achieve 2030 decarbonization targets.

- **operation and maintenance cost projection**s, as identified again empirically, for example from available national databases of RE projects;
- **technological performance and capacity constraints,** i.e. the conversion efficiency of a technology and the maximum capacity allowed for deployment in the model (onshore wind energy capacity could for example be constrained by available land area eligible for wind power construction).

Consequently, the cost of a technology can be calculated as product of these three inputs, plus the cost of fuel or electricity used by the technology. Similarly, the substitution cost for a renewable energy technology is defined comparing the overall costs that are necessary to generate one unit of energy with that technology and the costs that are necessary to generate the same unit of energy with a non-renewable technology.

The analysis of technologies substitution costs can also include other cost figures such as energy taxes, fossil fuel subsidies, the cost of carbon allowances or monetary incentives for low-carbon and energy-efficient technologies. Furthermore, different costs of capital can be used. IRENA (2015) adopts the local cost of capital (e.g. 6% for Germany) for national studies and a standard discount rate (10%) for cross-country comparisons. As Chapter 4 shows, the two costs of capital generate very different outcomes.

3.3.2. BCG Bottom-Up Cost Derivation

Like the Remap model, the BCG bottom-up cost derivation, as applied in BCG and Prognos (2018), is an example of combining energy-market and economic models with a technology substitution model. Three scenarios have been developed: (1) BAU, (2) scenario reducing 80% emissions until 2050 (reference year: 1990), (3) scenario reducing 95% emissions until 2050 (reference year: 1990). For each scenario (2) and (3) two different world frameworks have further been included, one “lack of global ambition” (only few European nations with ambitious climate measures) and one “global climate protection” (high ambitious worldwide).

The study was compiled over the course of the year 2017, with close to 70 companies and associations as well as a board of renowned economists involved in more than 40 workshops. To calculate economic dynamics the PROGNOS VIEW model was used, which considers 42 countries and 90% of global economic activities. The energy market has been modelled for each sector (industry, transport, households) using bottom-up approaches. During the modelling process, GHG reduction measurements were prioritized with respect to economic abatement costs, thereby combining different technologies in order to deduct the most economic cost-efficient path to achieve Germany’s climate goals for 2050.

With regards to technologies only those have been considered that are in a mature stage or that – under reasonable assumptions – will have a mature status in the near future. Game-changing technologies were not considered (e.g. technologies for the hydrogen economy). Some technologies paths have been set exogenously, given the assumptions that Germany will phase-out nuclear technology, and that Carbon-Capture-and-Storage (CCS) technologies will not be well received by large parts of the population.

The main output of the methodology adopted by BCG is represented by the avoidance costs that can be realized through the substitution of carbon-intensive with low-carbon technologies. To calculate the avoidance costs of energy efficiency measures, investment costs have been determined in comparison to a less efficient technology and then offset with the associated energy savings. When the energy costs saved using an energy efficient technology (compared to a less efficient technology) would also over-compensate for the cost of capital resulting from the increase in investment, a negative cost is connected to the focal technology; otherwise, a positive cost is attributed to the technology. For instance, in the industry sector, replacing a variety of cross-cutting technologies at the end of their lifecycle with the most efficient models has been estimated to have avoided costs in the range of €180/t CO2to €40/t CO2.

The results' ranges identified in the analysis depend on a set of exogenous variables, including energy prices, taxes, carbon allowance prices, and production growth (GDP). Changes in these variables affect the results – hence, also causes different investment needs estimates.

Important exogenous variables that determine the results (total investment needs) are among others: (1) population growth, (2) energy prices, (3) price for EUAs.

With regards to costs the study differentiates between (1) business costs and (2) governmental costs. For the government, taxes and subsidies excluded, discount rates are lower (2% versus 8% from a business perspective) and energy prices higher (13 ct/kWh vs. 3 ct/kWh for energy-intensive companies). Hence, since the business perspective often does not coincide with the governmental/public perspective, as companies have higher cost of capital and may have to pay lower energy costs through derogations, the negative avoidance costs of many low-carbon technologies may actually be positive for businesses that have high costs of capital and/or benefit from derogations/advantages linked to the price of energy consumed.

Overall, the BCG approach has the advantage of being a recently published study with a stringent concept done by renowned institutions (i.e. BCG and Prognos AG). On the negative side lies the fact that the study is available only in German (short summary in English) and that sensitivity analyses are not included except one sensitivity regarding different energy prices.

3.3.3. Prognos Cost-Benefit Analysis

Prognos et. al. (2018) use a cost-benefit analysis to assess (governmental) costs of environmental policies, e.g. policies that aim to reduce CO2 emissions, noise, and air pollution, as well as very hands-on policies like a law that obliges German car owners to use winter tyres in the 1th and 4th quarter of the year. The analysis builds upon an excel tool developed by the UBA (Porsch et. al., 2015).

Therefore, policy makers and other stakeholders interested in policy dialogues can assess and quantify economic and environmental impacts of environmental policy measures. The approach can be used to sharpen political arguments for environmental policy.

The approach considers two cost-benefit areas:

(1) Quantification of environmental damages saved by the implementation of environmental policies, e.g. reduced CO2-emissions by introduction of CO2 tax;
(2) Economic impacts on the total economy, like employment effects, growth effects (using input-output tables), but also secondary effects like less public health expenses (due to less accidents, less air pollution, etc).

Prices to calculate economic costs and benefits of certain environmental measure are defined based on (external) studies and recommendations. In 2015, its year of publication, the tool used for example the following figures on environmental costs to calculate economic benefits of policies aiming at reducing CO2-emissions: CO2: 80 EUR/tonne, CH4: 2,000 EUR/tonne, N2O: 23,840 EUR/tonne.

As the approach translates policy measures into governmental economic cost and benefits (using the same unit, in this case EUR) it is possible to aggregate cost and benefits and compare net values with benchmarks. For instance, the study uses the above-mentioned winter tyres law and concludes that the net economic effect dominates. On the one hand, the laws have additional environmental costs, due to increased use of fuel and additional air pollution (in sum 15.4 Mio. €). On the other hand, the law generates positive economic effects, like additional value added for mineral oil industry, additional employment (and thereby social security contribution), and less health costs, as new tyres lead to less car accidents (in sum 238 Mio. EUR).

Overall the cost-benefit approach has the advantage of being a standard tool used for many years to calculate economic values, e.g. for environmental services. While some argue that environmental values should not be expressed in monetary terms, this method helps to assess and compare new policy initiatives, thereby helping to structure economic discussions and decisions. On the other hand, one should not forget limitations, like the high sensitivity of assumed (shadow) prices for goods where there is typically no market price available and boundaries regarding other considered secondary effects.

3.3.4. Discussion

Substitution cost curves are detailed and easy-to-use instruments that allow users to identify the least cost options to achieve climate and energy targets. The choice of cost figures and measurements, learning rates, capacity and deployment assumptions, strongly affects the investment needs projections for the climate and energy transition. Such assumptions can inflate or reduce the estimated investment needs and the corresponding deployment and mix of technologies.

Caution is important when the substitution cost curves have limited emissions abatement scope. Indeed, on the one hand, GHG emissions stem from a wide range of economic activities that are not always accounted for; on the other hand, there are GHG emissions resulting from activities (e.g. agriculture) that are not energy related and hence not reflected by metrics such as final energy consumption. GHG emission abatement potential in those sectors, which are often excluded in the extant literature on investment needs assessments, can be significant.

The example of wind power and the electricity sector

Zooming into the electricity sector and, in particular, the generation of power from onshore wind, it is possible to identify the elements that are going to drive investment needs estimates and affect the deployment of onshore wind technologies.

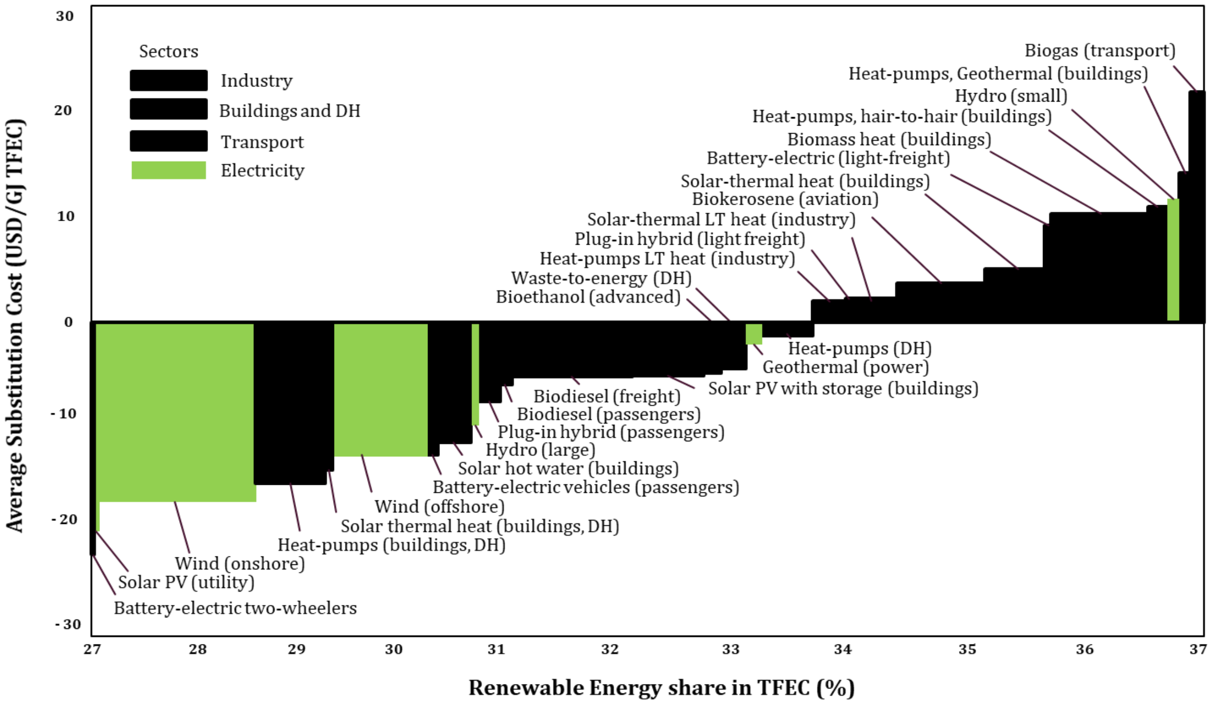

Figure 4 - REmap cost supply curve for Germany - Energy sector. Source: Based on IRENA (2015).

Under the REmap Scenario, the cumulative value of installed capacity of wind onshore in 2030 is expected to be equal to 72.3 GW and 160 TWh. It reflects the rate of deployment for onshore wind (2.5 GW per year) of the reformed Renewable Energy Act (*Erneuerbare-Energien-Gesetz*). This normative choice has a large impact on the shape of the substitution cost curve. Indeed, assuming a larger deployment rate for onshore wind, would result in higher estimates of final installed capacity. In turn, investment cost estimates would be lower to an extent that is proportional to the relative learning curves (technology learning rates represent the cost savings that are gained in proportion to deployment levels). Hence, the estimated overall final investment costs of onshore wind technologies would decrease as well. Similar considerations hold for other factors included in the model, as well as for the other technologies positioned along the curve – meaning that investment needs forecasts are consistently dependent on the sensitivity of predictions to the assumptions of the model.

In parallel to these considerations, it must be noted that the substitution cost of wind offshore is negative, i.e. it is cheaper to produce one unit of energy through wind offshore plants than through conventional power plants. However, this does not mean that the opportunity cost of investing in offshore wind energy is also negative. Indeed, the same amount of capital can be invested in an indefinite number of projects that may have higher internal rates of returns. Furthermore, according to the type of investors (e.g. municipalities or steel companies) the opportunity cost of investing in new low-carbon technologies varies, while differences in and uncertainty about the further evolution of the policy framework (in particular those policies directly related to renewable energy support) can have significant effects on the financing costs (see for example May, 2017; May et al. 2017).

3.4. Integrated Assessment and Modelling Frameworks

The previous studies do not tell the whole climate story. They do not capture agriculture, forestry, fishery and other sectors that also use fuels and electricity, thereby emitting GHG emissions. One of the most comprehensive analytical frameworks to date that endogenously models large parts of the economy is the one adopted by the European Commission (2017) to produce its impact assessments. The EC's modelling framework is depicted in Figure 5.

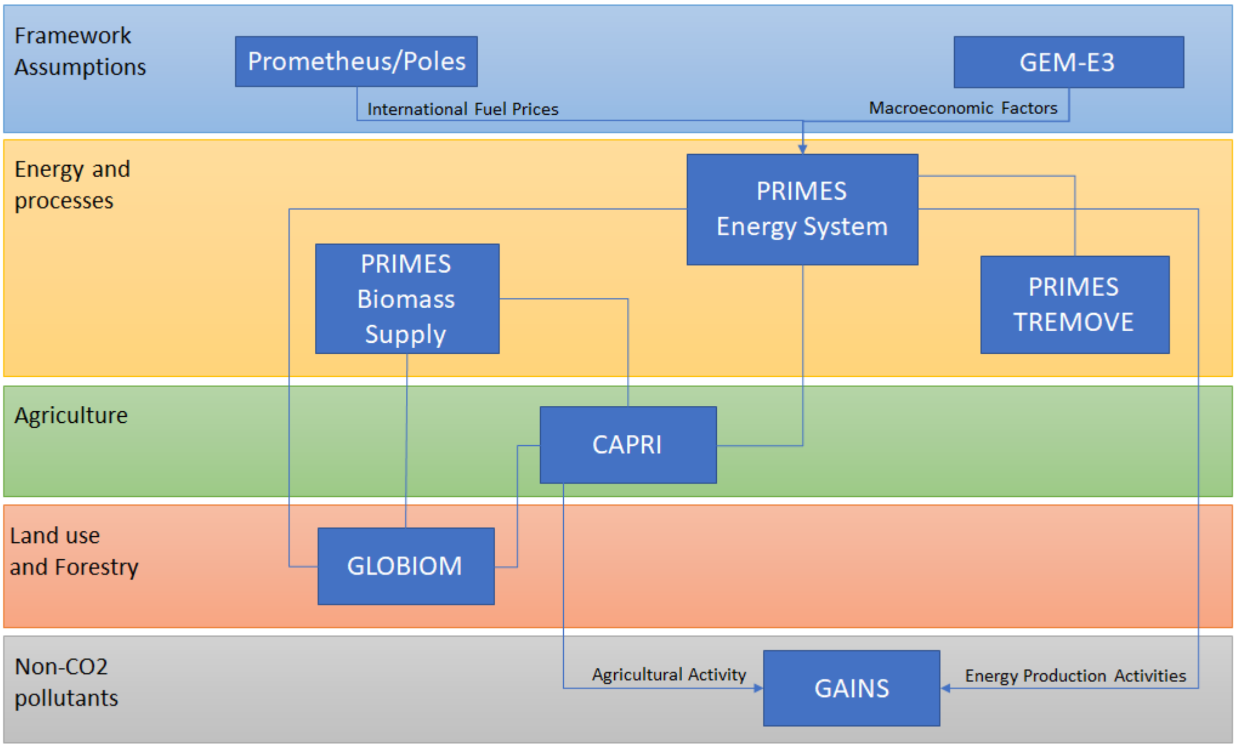

Figure 5 – The European Commission's modelling framework - Source: EC (2017)

The framework combines and interlinks ten different economic models. The European energy system is modelled through the PRIMES[18] model, which provides projections of energy demand, supply, prices, future related investments, as well as related GHG emissions. The model can be either applied on a national level for single European countries or the European energy sector as a whole. PRIMES is a behavioural microeconomic model that incorporates engineering and energy system aspects. It is designed to provide long term energy system projections and system restructuring. Hence, it balances demand and supply through prices, and it endogenously models both demand-side and supply-side investment decisions. The databases that are used by PRIMES to run its bottom-up calculations on energy efficiency and renewable potential include DLR, GREN-X and several others. Furthermore, it takes marginal abatement cost curves for non-CO2 greenhouse gases from GAINS and sends energy projections to GAINS in order to evaluate impacts on atmospheric pollution.

Furthermore, PRIMES is linked to GEM-E3, from which it takes projections of economic activity by sector, country and GDP. On the other hand, energy projections can be sent from PRIMES to GEM-E3. This allows to carry out closed-loop macroeconomic impact assessment studies. PRIMES is also linked to the global energy models – PROMETHEUS or POLES – that provide projections of world fossil fuel prices, while it sends biomass supply projections to CAPRI and GLOBIOM to evaluate land use and LULUCF impacts.

Despite the level of precision and granularity of the models adopted to estimate investment needs, the underlying assumptions still play a crucial role.

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[18] https://ec.europa.eu/clima/sites/clima/files/strategies/analysis/models/docs/primes_model_2013-2014_en.pdf

4. Key Findings from the Review of Climate and Energy Investment Needs Studies for Germany

4.1. Discussion of Key Assumptions and Sensitivities

We would like to start this review of existing studies about investment needs in Germany with a qualitative discussion about the sensitivities of the outputs and results generated from the previously identified models. The output of each model depends, first of all, on the model inputs and underlying assumptions. Examples are economic or population growth projections from which energy demand is derived which is then, eventually, used for estimating investment needs. It is important to note that different models give different weight to different factors or use different underlying datasets or projections.

The choice and configuration of scenarios are the second source of sensitivity for a given model output. Scenarios are coherent sets of assumptions that describe the context (in our case the climate and energy policies), define the timeframe (in our case 2030 or 2050), and are generally used to illustrate the development of selected indicators (e.g. investment cost) against a baseline or reference scenario.

The differentiation between the “two sources” (i.e., model inputs and assumptions vs. scenario configuration) is not clear cut and assumptions on, for example, the evolution of technology costs can be made “in the model” or “in the scenarios” (for example running scenarios with a strong role of carbon capture and storage versus a scenario without CCS). Regardless at which stage of the modelling-course the assumptions are made, we need to be aware of them. Table 3 presents a detailed overview of the elements just described, which should be considered before we move on to the review of investment needs studies conducted for Germany.

Table 3 - Characterization of the models and key sensitivities.

Models	Main sensitivities & assumptions	Inputs	Outputs
Yoda Model	- Population growth - Country-specific structural features - Current state of the economies (business cycle position) - Interest rates - Fiscal policy and general regulatory setting - R&D spending	- Historical trade volumes and trade linkages among countries - Current state of the economies (business cycle position) - Real interest rates - Regulatory policies	- Potential economic growth - Production levels, prices and trade expectations - Real interest rates - Economic growth
Oxford Global Economic Model	- Population growth - Country-specific structural features - General regulatory setting - Effect of public capital on potential output	- Historical trade and financial interlinkages - Demand-side factors (population growth, demand of goods and services) - Supply-side factors (capital flows, interest rates, technological progress, labour supply, trade volumes, exchange rates and commodity prices)	- Potential production output of economies - Supply/demand balances by industry - Markets equilibrium quantities and prices
World Energy Model (WEM)	- Economic growth - Population growth - Technological developments - GHG emissions permits cost - Infrastructures development	- Energy markets data - Capacity and cost of energy production technologies - Historical socio-economic data - Capacity and cost of demand-side technologies - Emissions intensity of technologies	- Total final energy demand by sector - Total final energy consumption (TFEC) by sector - Electricity production - Energy flows by fuel - Electricity and fossil fuel equilibrium prices - End-user prices - Energy balances and quantity of GHG emissions

Models	Main sensitivities & assumptions	Inputs	Outputs
REmap	- Consumption growth (TFEC by sector) - Energy prices - Technological performance and capacity constraints - Capital cost projections - GHG emissions permits cost	- Capacity and cost of demand-side technologies - Emissions intensity of technologies - TFEC by sector - Capital cost projections	- Technology substitution potential - Technology substitution cost - Investment needs to achieve TFEC objectives - Quantity of GHG emissions
DIMENSION +	- Electricity networks and energy balance requirements - Economic growth (energy demand) - Political circumstances - Variation in political frameworks	- Detailed energy markets data (granular information on electricity demand, generation capacities, renewable energy profiles and the corresponding grid infrastructure) - Electricity, gas and heat networks - Capacity and cost of energy production technologies, grids and storage units	- Total system costs - Energy quantities (primary, secondary, final) - Generation capacities and mix - Power-to-X generation and capacity - GHG emission - Optimal grid expansion - Investments in energy production technologies and storage units
RemoD-D	- Electricity networks and energy balance requirements - Economic growth (energy demand) - GHG reduction targets (determines the whole modelling process) - Interaction between the sectors electricity, heat, mobility and industry	- Boundary Conditions (e.g. CO2 target, scenario data) - Weather Data - Technology Parameters (existing stock, efficiency) - Economic parameters (technology cost projection, fossil fuel price etc.)	- Key Output: A cost-optimized development of national energy systems, including: - Total system costs (capital and operating expenses, fuel) - Hourly time series of plant and storage operation and energy demand - Dimensioning of power and heat generation and energy conversion - CO2 Emissions - Market share per technology

Models	Main sensitivities & assumptions	Inputs	Outputs
BCG Bottom-up Cost Derivation	- Technology development - Model boundaries - Population growth - Production growth - Energy prices - GHG emissions permits costs	- Technologies - Energy prices - Energy efficiency technologies learning curves and costs	- Avoidance costs of energy efficiency measures - Investment costs of energy efficiency measures - Quantity of energy consumed - Quantity of GHG emissions
Prognos Cost-Benefit Analysis	- Estimated effect/linkage between pollution and social welfare indicators - Emissions shadow prices	- Policy measures - Policy costs (related direct government expenditures and savings) - Emissions factors - Estimated effect/linkage between pollution and social welfare indicators (e.g. employment, health) - Emissions shadow prices	- Public (social and governmental) costs and benefits of environmental policies: - Employment - Production growth - Health expenditures

4.2. Reports about climate and energy investment needs in Germany

This section presents and discusses studies that have estimated Germany's investment needs for the overall economy to reach the 2030/2050 climate targets. We tried as far as possible to present the outcome in a comparable fashion, while different time horizons, key questions, modelling scopes, and approaches make comparability less than straightforward. While some studies have a narrower scope and focus for instance on future costs of photovoltaics (Agora Energiewende and Fraunhofer ISE, 2015) or GHG abatement costs regarding the 2030 targets (McKinsey, 2007), only studies projecting total investment costs as one outcome variable are presented in this section. Chapter 5 will go into more detail for energy efficiency investments in the buildings sector (Section 5.1) and renewable energy investments in the power sector (Section 5.2).

The goal is to present the range of results and to discuss them in the light of the different underlying assumptions and scenarios.

Table 4, therefore, presents an overview of four different reports which provide estimates of investment costs. For better comparability, we divided the total accumulated investment costs by the number of considered years, to derive a virtual annual investment cost figure[19]. It is important to note

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[19] In reality, investment costs may not be distributed equally across the time horizon, but the distribution of investments over time is not our focus of interest here. Moreover, we disregard questions of the discounting of future costs.

that we talk about *additional* investment costs *on top* of those investments already included in the reference scenario. Depending on the assumptions made, the reference cases already contain some level of investment. Referring to *additional* costs, the definition of the reference scenario and its costs is, therefore, a crucial driver. To address this issue, we include the GHG reductions that are already assumed or projected to “happen“ in the reference case in square brackets. The range of investment needs (i.e., *min* and *max)* stems from different considered pathways (reflecting in particular choices and assumptions about the role of energy efficiency vs. scaling of renewables).

Table 4 - Studies investigating total (additional) investment costs in relation to 2030 & 2050 GHG emission reduction targets.

ID	**Study**	**Time**	**Investment needs p.a.**		**GHG reduction target**
	Authors	*Period*	*Min. Bn €*	*Max. Bn €*	*Reference in square brackets*
2050 – 80 % targets					
1	DENA (2018)	2018-50	**+33.3**	**+54.6**	-80% CO2 [-62%]
2	BCG (2018)	2015-50	**+28.6**		-80% CO2 [-61%]
3	Fraunhofer-ISE (2015)	2015-50	**+24.9**	**+38.4**	-80% CO2 [not stated]
2050 – 90/95% targets					
1	DENA (2018)	2018-50	**+34.3**	**+58.3**	-95% CO2 [-62%]
2	BCG (2018)	2015-50	**+50.6**		-95% CO2 [-61%]
3	Fraunhofer-ISE (2015)	2015-50	**+49.6**		-90% CO2 [not stated]
2030 – 55% targets					
4	Prognos et. al. (2018)	2018-30	**+20.0.**	**+22.5**	-55% CO2 [-35%]

Notes:

Scenario defines the amount of GHG reductions which should be achieved until 2050 compared to 1990 levels.

Time Period presents the period for which the accumulated costs were calculated.

Total Min* and *Total Max are the accumulated additional investments costs on top of the reference (i.e. BAU) scenario. *Min* and *Max* are the ranges for possible considered pathways (e.g. focus on scaling of renewables vs. focus on energy efficiency).

P.a. min* and *P.a. max is simply the annual (i.e., “per annum”) investment need to make different time periods comparable.

The additional annual investments for the “80%-targets” vary from EUR 25 billion to EUR 55 billion and for the “95%-targets” from EUR 34 billion to EUR 58 billion. Large discrepancies across scenarios can usually be explained by different GHG reduction targets or different reference cases. However, DENA and BCG follow the same targets and provide similar reference cases, the latter at least in terms of GHG reduction at the end of the period. Against this background, the discrepancies between DENA and BCG are quite significant. Different methodical approaches and assumptions must therefore explain the variation. In DENA, the energy demand for every consumption sector stem from a bottom-up module. These figures are then transferred to the Dimension+ model. The BCG study also relies on an extensive bottom-up cost derivation. Differences in assumptions can therefore be found along the modelling process. **Error! Reference source not found.** presents further details on methodology and s ensitivities. In the following, each study is briefly described.

Fraunhofer-ISE's (2015) study raises the question of how an optimal and cost-efficient transition can be achieved, taking all fuels and consumption sectors into consideration. The in-depth study builds upon the simulation and optimization model *REMod-D* (see description in chapter 3). Regarding the complexity of the German energy system (when including demand and supply side and hence all energy consuming sectors as well), a sheer infinity of possible scenarios exists. Nevertheless, the authors define the following dimensions as the most decisive: pathway and the target value regarding CO2 reductions (1), the development in the building (2) and mobility sector (3) and the usage duration of coal (4). After combining different assumptions for dimensions 1-4, the investment needs for nine different scenarios are calculated (see Table Annex Ch.4 for further details). On top, to address the heated debate on energy transition costs, the authors consider different assumptions on the development of fuel and CO2 prices. The different sensitives do not affect the estimated investment needs but can raise incentives: with higher fuel and CO2 prices, the additional investment costs are compensated through a lower energy demand.

Another study comes from Prognos et al. (2018) and focuses on the sectoral targets for 2030. The approach builds on a cost-benefit analysis and uses a tool developed by the German Federal Environment Agency (Porsch et al., 2014). Core assumptions are made regarding discount rate, economy-wide parameters, energy prices and more. The reference scenario builds upon the scenario including new (policy) measures (*"Mit-Maßnahmen-Szenario"*) from the *forecast report 2017* (BMU, 2017; according to EU regulation). The authors define two target paths, the first focuses on energy efficiency and the second on scaling of renewables.

The study by DENA (2018) investigates two pathways. The first examines a transformation path focusing on electrification, which relies on an increase in energy efficiency and electrification of all sectors. The second case considers a technology mix scenario, which implies an increase in energy efficiency as well but also allows for a broader variation in applied technologies and energy sources. The investigation is not based on simple mathematical optimization exercise but rather on a careful scenario analysis, trying to reflect, among others, expert opinions.

Another flagship publication comes from BCG and Prognos (2018)[20] in which the costs are derived from an extensive bottom-up approach including the opinions from a significant number of industry experts. The reference scenario is derived from a forward projection of historical trends and assumes current political and technological developments. The reference scenario is compared to a transformation path of global climate protection (i.e. international coordination of climate policy instruments, prosperity and free markets, constant low prices of fossil fuels, willingness to pay for climate protection) and to a path of national efforts (i.e., barely any international cooperation, ambitious climate targets only by some countries, decline in speed of innovation, focus on welfare.

Error! Reference source not found. summarizes the most important features of the discussed studies.

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[20] Which was carried out on behalf of the BDI (the German Industry Association).

Table 5 Overview of studies assessing investment needs of Germany.

	Fraunhofer-ISE (2015)	**DENA (2018)**	**BCG and Prognos (2018)**	**Prognos et. al. (2018)**
Subject Matter	Investigation of an optimal and cost-efficient transition under consideration of all fuels and consumption sectors.	Develops and compares transformation paths.	Investigating the "gap" between current conditions and the national climate protection targets. Results derived from an intensive bottom-up process.	Analyses of approaches with which sectoral target can be achieved by 2030. *Klimaschutzplan 2050* is especially considered.
Model & Methodology	Simulation and optimization model with REMod-D hour-by-hour; cumulative total cost as a target function with CO2 target as a constraint	Energy Market Model DIMENSION + and Scenario Analyses	Bottom-Up Cost Derivation; use of several Prognos models	Cost-Benefit Analysis with tool from UBA.
Scenarios	**Reference:** BAU scenario. **Target:** 9 different scenarios stemming from a mix of the following parameters: - GHG reduction target (80/85/90) - Renovation rate in building sector (low / ambitious) - Mobility sector (different drive concepts) - Coal exit (accelerated / not accelerated)	**Reference:** BAU scenario. Progressive forecasting of current and historical trends (politically and technically). **Target:** 80 and 90% GHG reduction target. Electrification pathway or technology mix.	**Reference:** Continuation of historical trends and current developments. **Target:** 80 vs. 95. Global climate protection vs. national efforts.	**Reference:** Mit-Maßnahmen-Szenario based on Projektionsbericht 2017 (BMU, 2017), which leads to a GHG reduction of 35% by 2030. **Target:** 55% reduction. Energy efficiency vs. Scaling of renewables.
Sensitivities	no increase in fossil fuel prices and no CO2 emission costs - annual increase in fossil fuel prices - constant or increasing CO2 prices a higher fuel and/or CO2 prices lead to A compensation of additional Investment costs	No cost decreases in PtX (e.g. PowerToGas), which is crucial for >90% targets [-> leads to substitution of EU vs. non-EU production] - Improved flexibility in the grid, for onshore wind energy to better fulfil its purpose [-> reduces need for grid expansion] - Expansion of hybrid trolley trucks [-> only small effect on additional costs: decrease by 1% in 95% scenarios]	- increase in fuel prices	- +/- fossil fuel prices
Results	- System Composition Development (e.g. regarding renewable energies or heating)	- GHG emissions per sector	- Other outcomes (e.g. excurse of CSS)	Sector-by-Sector Analysis

5. Exemplifying the Climate and Energy Investment Needs Assessment Framework – Two “Sector Prototypes” for “How to Do It in Practice”

Investment needs assessments are relevant to make long term decisions, both for the public and private sector. From a policy point of view, this is particularly relevant when market failures and public goods require policy intervention to achieve a socially optimal level and orientation of investment, and corresponding asset and business model reconfigurations are necessary to achieve societal targets at national sectoral level. Investment needs assessment models produce insights that can be instrumental in motivating, evaluating, and legitimizing, respective decisions.

At the same time, investment needs assessment models often lack transparency for decision makers. Similarly, economic models lack transparency in absence of detailed (and accessible, understandable) descriptions of model structure and inputs. This limits in particular the ability of users of model outputs to have a deep understanding of the factors (and choices) that drive model results; or to interpret (differences between) model outputs.

Therefore, this chapter aims to endow decision makers and others interested with a better understanding of model classes and structures and a thorough appreciation of the underlying drivers, assumptions and choices and their effects on the results of investment needs studies.

Section 5.1 focuses on energy efficiency and sector-integrated renewable energy in the building sector, whereas the decarbonization of energy supplied to the sector will be covered in section 5.2 (which examines the energy sector).

5.1. How to Analyse Investment Needs for Energy Efficiency (and Renewable Energy) in Buildings

5.1.1. The Importance of the Buildings Sector for the Energiewende and the Corresponding Investment Challenge

Relevance and Targets of the Buildings Sector

The building sector plays an important role in the energy transition and represents a significant share of Germany’s final energy consumption: approx. 35% of final energy consumption (DENA, 2018a[21]; BMWi, 2018a), 54% of electricity available for final consumption (AGEB, 2018), and 129.0 million tCO2-eq. or 14.2% of total[22] German GHG emissions (UBA, 2018a).

Private households are responsible for 22.1% (or two thirds of the building sector) of Germany’s final energy consumption, where 18.2% stem from space heating plus another 3.8% from warm water. Buildings in the tertiary sector make up 10.8% and buildings in the industry 2.5% (BMWi, 2018).

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[21] https://www.dena.de/themen-projekte/energieeffizienz/gebaeude/

[22] Excluding GHG emissions from land use, land use change and forestry.

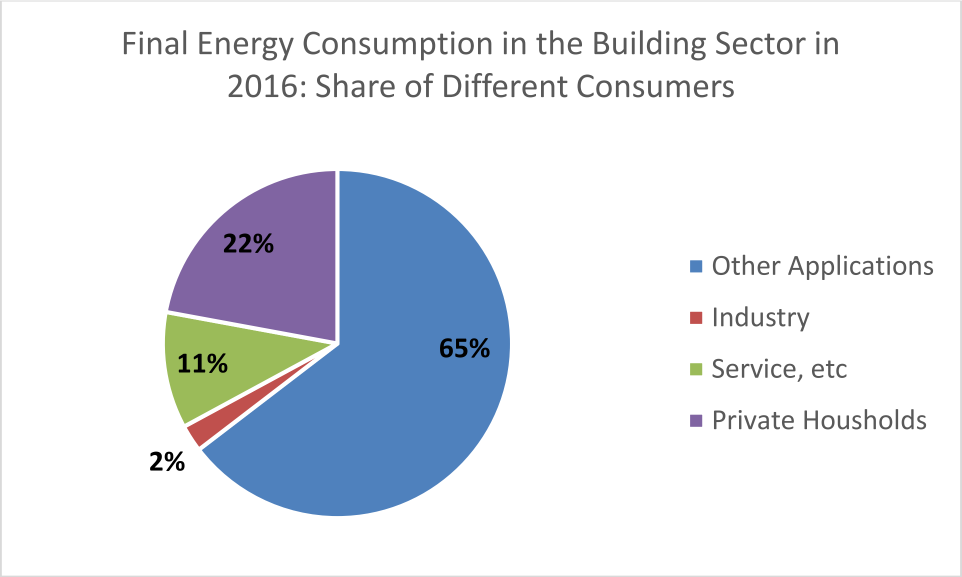
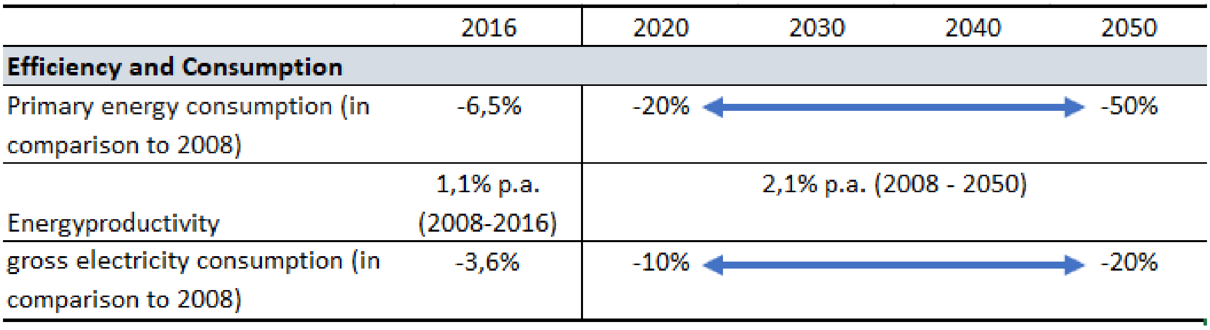


Figure 6 - Final Energy Consumption in the Buildings Sector – Source: BMWi 2018a

Yet, progress towards achieving Germany's targets for energy efficiency is not satisfactory. What are these targets and where does Germany stand on its way to reaching them?

The principal objectives of the German *Energiewende* have been laid out in the German *Energy Concept* (BMWi and BMU, 2010) which includes, among others, targets for buildings' primary energy consumption, which needs to be reduced by 80% by 2050.

More recently, Germany's Climate Action Plan (BMU, 2016) defined GHG emission targets for different sectors and the target of the buildings sector is equivalent to a 66-67% reduction of emissions in 2030 (compared to 1990). To reach these targets, newly constructed and existing buildings shall be climate-neutral from 2020 and 2050 onwards respectively. The primary energy consumption of the building sector shall fall by 80% between 2008 and 2050. Other targets of this action plan, which are also relevant for buildings, are shares of renewable energy in total final energy consumption (60% in 2050), in electricity consumption (80% in 2050), and heat consumption (14% in 2020), while national electricity consumption will need to decline by 20% in 2050 (compared to 2008; see BMWi, 2018a).



	2016	2020	2030	2040	2050
Efficiency and Consumption					
Primary energy consumption (in comparison to 2008)	-6,5%	-20%	↔	↔	-50%
Energyproductivity	1,1% p.a. (2008-2016)	2,1% p.a. (2008 - 2050)			
gross electricity consumption (in comparison to 2008)	-3,6%	-10%	↔	↔	-20%

Figure 7 – Expected development of energy efficiency and consumptions figures over time - Source: BMWi 2018a.

Is Germany „on track"? No!

In terms of the targets for primary and final energy consumption for 2020 set for all EU member states under the EED[23], in 2015, only five member states including Germany had not achieved sufficient savings in primary energy consumption to stay below the linear trajectory level between 2005 levels and the 2020 target year (EEA, 2017).

In 2016, primary energy consumption had declined by only 6.5% (compared to 2008) and with projections of an 11.4% reduction by 2020, the 20% target will be missed by a wide margin. In 2016 and 2017, primary energy consumption even showed a year-on-year increase.

Figure 8 illustrates a number of key drivers of the change in energy consumption in Germany between 2008 and 2016 - namely the demographic component (population growth), the economic component (GDP growth) and energy-intensity component (efficiency).

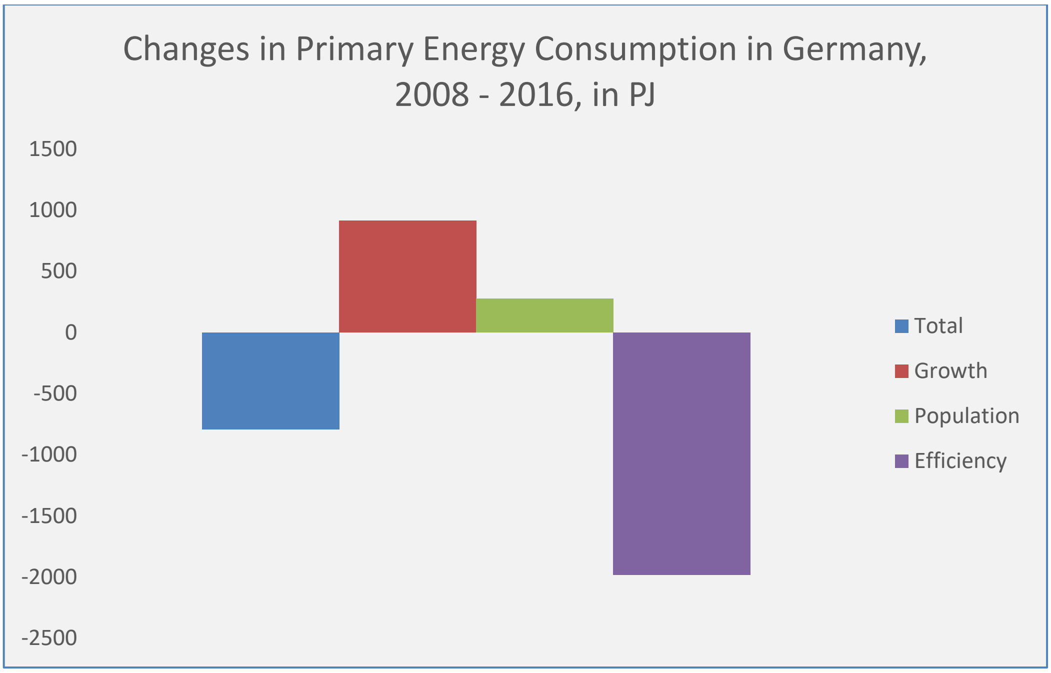


Figure 8 – Key Drivers of Changes in Primary Energy Consumption in Germany (2008 to 2016) - Source: BMWi 2018a

Gross electricity consumption shows a similar picture and the 10% reduction target for 2020 will likely be missed, with a central estimate of 5.5% (and a range of 3.1 to 7.9%).

Nine (out of 28) member states, again including Germany, were not on their target paths for final energy consumption in 2015 (EEA, 2018). Even worse, between 2015 and 2016, the final energy consumption for heating per floor space of private households, i.e. the key metric for private buildings' energy efficiency, increased in Germany by 4.3%[24]. Germany is hence far from reaching its 20% reduction target (compared to 2008) in 2020. With a meagre -6.3% in 2016, the average annual

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[23] Energy Efficiency Directive 2012/27/EU.

[24] When correcting for weather/temperature differences between the two years, the remaining increase amounts to 2.8%

reduction rate would need to increase five-fold in the remaining years, a highly unlikely scenario: 12.5% is the central projection (BMWi, 2018b), within a range of 11.5-15.8%.

The share of renewable energy in buildings‘ heat consumption however increased to 13.2 % in 2016, which is close to the 14% target set for 2020.

What does the situation look like when we turn to the investment figures?

Energy Efficiency and Renewable Energy Investments in Buildings in Germany

Past levels of investment have been estimated as part of this project in the climate and energy investment map CEIM and the results are replicated here. For a more detailed discussion, see Novikova et al (2019, p. 41). This analysis estimates that in 2016 the total investment into renewable energy, incremental investment into energy efficiency, and total investment into cross-cutting measures was at least EUR 5.9 billion, EUR 6.9 billion, and EUR 1.9 billion, respectively.

Estimates by DIW and GWS (see BMWi, 2018a) for energy efficiency investments only for 2016 show EUR 42.5 billion (up from EUR 39 billion in 2015).

The stark difference between the estimates is, among others, related to the difference between full investment costs (for the entire construction or renovation effort), as done by DIW and GWS, or incremental costs, which is more difficult to derive and is the basis for the estimates undertaken by Novikova et al (2019).

Summary

The above discussion shows particularly two things:

1. Significant additional action, including investments, will be needed to achieve Germany’s targets for the building sector, in particular regarding energy efficiency.
2. Investments, in particular in energy efficiency, are difficult to measure and results are driven to a large extent by assumptions and choices about the scope of the estimates, and what to include as “energy efficiency investment”.

The following discussion will show how to estimate investment needs for the energy transition in the buildings sector (5.1.2.), point out the sensitivities of the results to specific model features and assumptions (5.1.3), summarize existing estimates of investment needs and their underlying choices of scenarios (and in particular reference or baseline scenarios) and how those influence the results (5.1.4.). Section 5.1.5 zooms into one specific modelling framework in order to exemplify the more conceptual discussion of sections 5.1.2 and 5.1.3. The final section (5.1.6.) links this discussion of investment needs and their assessment to the next work package of this project, which will shed light on barriers and drivers of investment and on how to raise capital for reaching the 2030 targets. This analysis will focus on CZ and LV and is expected to be finalised by the end of 2020.

5.1.2. How to Do Assessments for the Building Sector in Practice

Key Elements We Need to Understand

The significant potential for GHG emissions reduction in the buildings sector can be unlocked through a wide range of technological and non-technological interventions. Energy services delivered in buildings such as thermal comfort, illumination, hygiene, nutrition, entertainment, communication and others are responsible for a large share of primary/final energy consumption of the European economy and, thus, direct and indirect emissions. Hence, technological and non-technological interventions satisfying these services are the main decarbonization levers of the sector.

As depicted in Figure 9, assessing investment needs for energy conservation and GHG abatement in the building sector requires an understanding of how the demand for energy services may change in the future, what are the technologies and practices that can be used to provide these services in the most energy efficient and low carbon way, what are their technical and economic characteristics, and how quickly and to which extent can they penetrate the market.

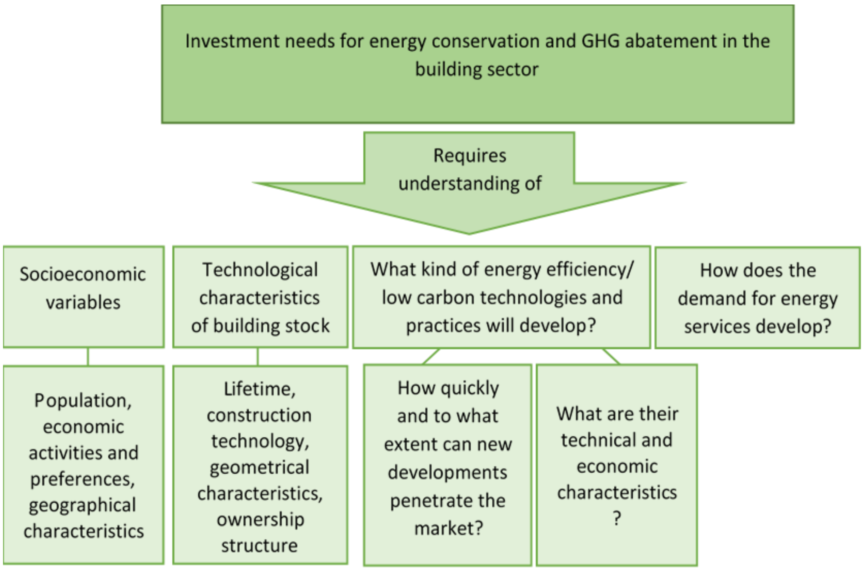

Figure 9 - Underlying questions to assess investment needs in the building sector.

In order to estimate the extent to which energy consumption can be decreased, one shall keep the broader set of factors that affect the demand for energy services in buildings in mind. The amount of energy that is currently consumed in the sector depends, in the first place, on socioeconomic-variables – population, economic activities and preferences, geographical characteristics – climate, and on the existing technological stock – e.g. for building envelopes – their lifetime, construction technology, geometrical characteristics, and ownership structure. Energy demand of different energy services is driven by some common and some different factors. Therefore, building energy demand is split into energy services or specific end-uses during the modelling process.

One of the common approaches for modelling GHG emissions of an energy service is the estimation of GHG emissions as a product of activity (e.g. technology stock), unit energy consumption (final energy of a technology), and carbon intensity (grams CO2 per unit of energy). For buildings, the factors impacting the activity could be buildings age, size, inhabitancy, construction rate, and others. Unit energy consumption will depend on the demand for services (e.g. level of comfort – to which degree to heat, climate – outside temperature, lifestyle etc.) and the technology (mix and its efficiency in) providing the services. Once GHG emissions have been calculated for the base year, often the latest year for which statistics are available, the result is calibrated to the energy balance or other suitable energy statistics (s.t. to their availability).

To model the potential for emission reduction in a target year, scenario approaches are used most commonly. The reference scenario is often either a so-called “frozen efficiency scenario” (no changes), or a business-as-usual scenario (extrapolating the historical trend into the future), or a low efficiency scenario. The scenario we want to evaluate against this baseline could be a GHG mitigation or high-efficiency scenario which is defined assuming a replacement of reference technologies with high-efficiency/low-carbon technologies, for reaching a defined efficiency and emission reduction target.

The “energy savings” or “emission reduction” potential of the proposed scenario (against the baseline) is hence derived from comparing the two scenarios.[25]

Selected mitigation options are evaluated economically to estimate the investment costs of for capturing this potential. The key factors influencing the investment costs estimates are typically technology cost, prices of energy carriers, and discount rates.

Construction of new buildings and retrofit of existing buildings imply the use of many non-energy related technologies and practices, e. g. painting, plastering, as well as a high share of business-as-usual construction or retrofit costs. For example, a house-owner might need to invest into new windows. The costs of double-glazed windows occur in any case, while the more efficient triple-glazed windows come at a cost premium. The total investment costs of building construction and building retrofits are therefore prone to “overestimating” the actual decarbonization cost, as becomes apparent from the discussion in chapter 5.2.a (comparing the incremental investments estimated by Novikova et al, 2019 and the full investment cost estimates by DIW and GWS). Therefore, the more realistic figure to express energy efficiency investments in buildings is the incremental investment beyond the investment in the reference case.

Finally, a more complete picture of the investment case for energy efficiency in buildings is given by adding behavioural aspects and feedback loops, in particular those deriving from the price of energy or gas (running costs) and cost of technologies (investments). The energy price is determined by the interaction between demand and supply on energy markets. In turn, the price of energy affects the demand of energy and the use of technologies, as well as the choice of technologies when renovations have to be made. Secondly, the price of energy also determines the cost savings from energy efficiency investments. High energy prices make energy-efficient technologies more cost-effective.

Figure 10 below represents these dynamics and linkages - and coincidentally underlines the importance of assessing the investment needs of the buildings sector using a bottom-up approach i.e. aggregating individual technologies and elements to a sector picture. Each of the blocks identified is crucial to have a complete picture of the sector and to make a robust assessment of investment needs. This is a simplified representation, focusing on the key buildings blocks and interactions. Other relevant factors (not depicted here) include the incorporation of multiple-benefits of energy efficiency, behavioural aspects, and various other effects (such as spill-over effects, free-riders and others).

Different models can be used to identify these building blocks or key elements, with different levels of granularity. In particular, macroeconomic and integrated assessments can be used to identify the integrated economic outlook. Furthermore, buildings sector models are crucial to depict the activity of the sector, i.e. buildings ownership structure and buildings types and characteristics. Then various energy demand models allow to calculate the demand for energy carriers as deriving from sectorial services and technology choices.

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[25] A standard method used for estimating this ”potential“ are supply curves for energy conservation/GHG mitigation which, among other, has the advantage of avoiding double counting of the ”potential“ between inter-depending technologies (e.g. building insulation technologies and space heating systems). Examples for such supply curves are the Remap Model used by IRENA (see chapter 3; or IRENA, 2015).

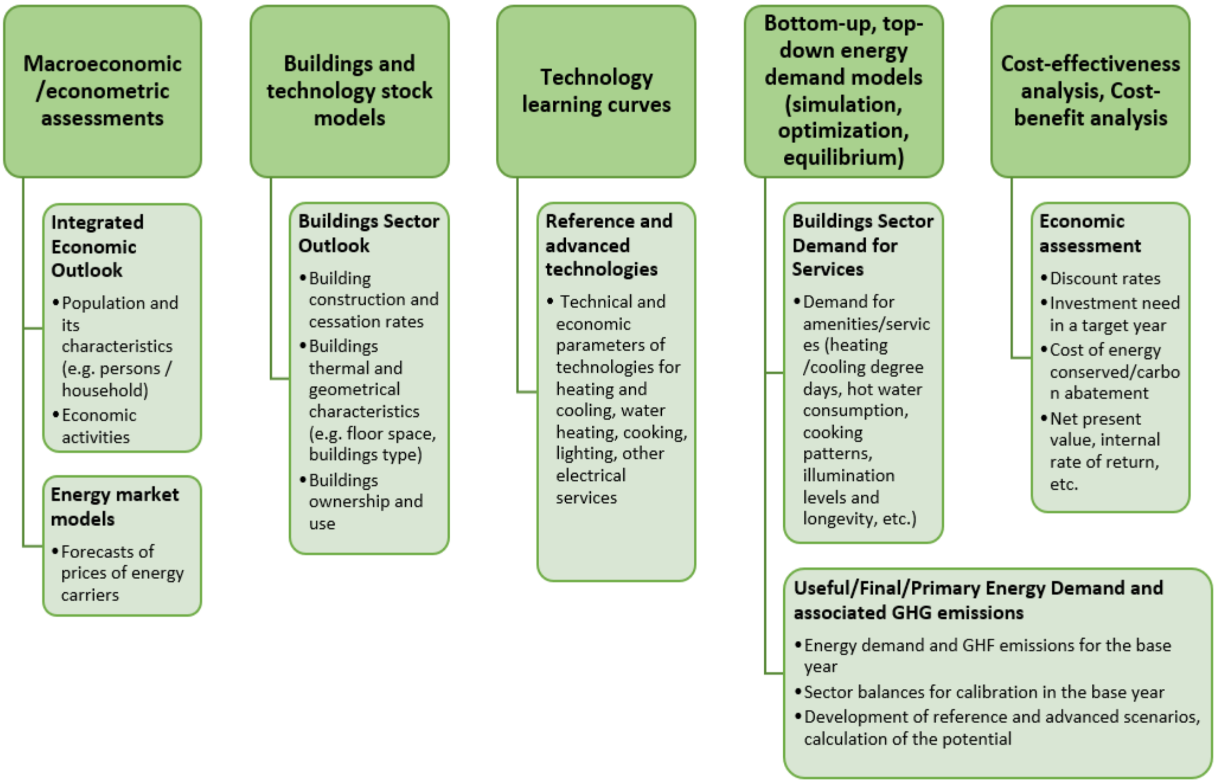
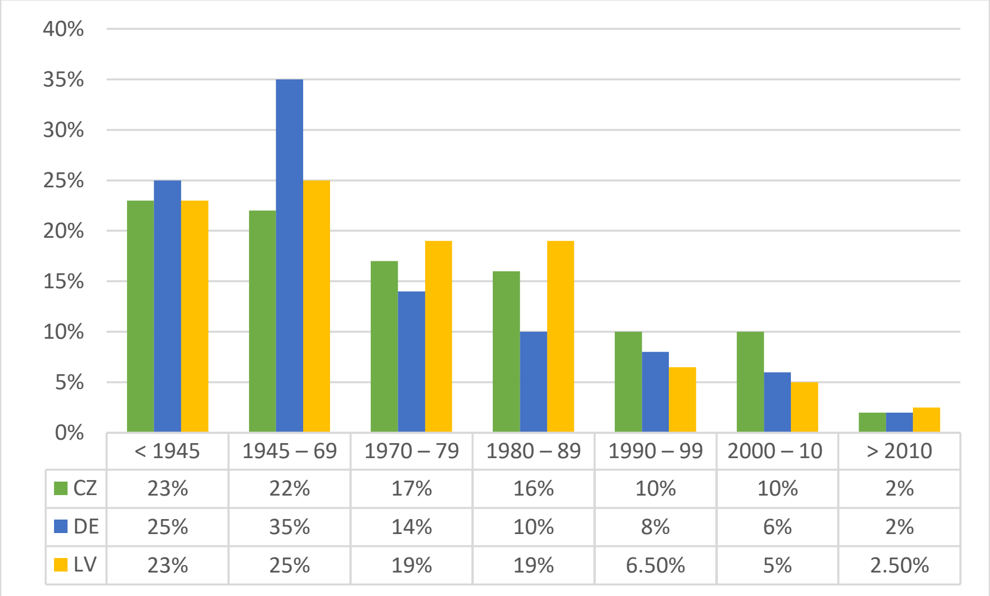


Figure 10 – Input Parameters of Bottom-Up Models for the Building Sector

The Efficiency Potential of the Buildings Sector

It has been estimated that almost 97% of buildings built before 2010 in Europe needs partial or deep renovation to comply with the long-term strategy ambition (ECOFYS, 2012). Figure 11 shows the breakdown of residential building by age category, as reported by the building stocks observatory (EC, 2018).



	< 1945	1945 – 69	1970 – 79	1980 – 89	1990 – 99	2000 – 10	> 2010
🟩 CZ	23%	22%	17%	16%	10%	10%	2%
🟦 DE	25%	35%	14%	10%	8%	6%	2%
🟨 LV	23%	25%	19%	19%	6.50%	5%	2.50%

Figure 11 – Breakdown of residential building sector by age category – Source European Commission, 2018

The emissions abatement potential can be identified looking at the sectoral share of final energy consumption and the technologies employed to serve the focal activity.

Typically, most of the energy consumed in buildings is used for space heating, hot water production and cooling. According to the European Buildings Observatory, space heating alone uses almost 71% of all energy consumed in Europe's residential building stock. The figures for Germany are very close to European level estimates, as reported by the German Federal Ministry for Economic Affairs and Energy (BMWi, 2015).

A further step of disaggregation is necessary to understand the efficiency potential of the sector - the building typology is fundamental to draw an accurate portrait. For instance, in Germany there are currently 355 building classes and 40 possible combinations of energy sources and heating technologies, making together 4459 building segments (BPIE, 2016).

BOX 1: Exemplification: the case of space heating

As mentioned, the final energy consumption (FE) of a building derives from summing up final energy consumption for space heating and cooling, water heating, appliances, lights and cooking technologies.

$$FE = FE_{SpaceHeating\&Cooling} + FE_{WaterHeating} + FE_{Appliances\&Lights} + FE_{Cooking}$$

Zooming into one specific service, such as space heating, it is easier to detect the elements that are affecting final energy consumption the most. Generally, the type of building and the efficiency of the technologies installed are the main factors determining the buildings’ energy need.

A building is constantly gaining and/or losing heat and for thermal comfort we need to keep temperature at least to the levels recommended by national standards. The accurate estimate of the space heating requirement of a household is based on the estimate of energy required to compensate heat loss due to its transmission and infiltration and the estimate of solar heat gains, internal heat gains from human bodies, appliances equipment and thermal mass gains. We often consider the largest two components, the energy required to compensate heat loss due to its transmission through building components and air infiltration.

Energy required to compensate heat loss due to its transmission depends on several factors that include the insulating properties of buildings' walls, doors and windows, buildings' size and shape, the difference between the inside and outside temperatures (which varies according to seasons and geographical coordinates). The transfer of heat from the building to the outside is measured in U-values (W/m^{2}K), that is the relationship between conductivity and thickness of materials that separate the two spaces. The reduction of the U-values of a building is possible by adding different thicknesses and types of insulation in a solid brick wall and a cavity wall. Energy required to compensate heat loss through a building component due to its transmission is estimated as a product of its U-value, area of the building component and demand for heating energy reflected in Heating Degree Hours.

The energy required to compensate heat loss of a building due to air infiltration is estimated as heat in air exchanged, multiplied with demand for heating energy reflected in Heating Degree Hours. The heat in air exchanged is a product of the air change per hour rate in a building type, the volume of a building, the air density and the specific heat of air.

Building final energy consumption depends also on the efficiency of the heating solution installed.

$$FE_{SpaceHeating} = \frac{HeatDemand_{Transmission} + HeatDemand_{Infiltration}}{Efficienty_{SpaceHeatingSystem}}$$

Since different building typologies and uses imply different heating requirements, the final energy consumption of buildings using the same heating technology can vary largely. For this reason, diagnoses of the building sector are propaedeutic to make robust assessments of the investment needs necessary to achieve energy targets. This is crucial also when estimating the GHG emissions of the focal building (building typology) and the entire sector, as shown in the equation below.

$$GHG_{SpaceHeating} = FE_{SpaceHeating}\ x\ EF_{SpaceHeating}$$

The carbon emissions of a service, such as space heating, can be calculated as a product of the final energy consumption and emission factor (EF) of the energy source that provides each service.

In turn, to assess the cost of reducing one GHG emission unit, the cost of substituting carbon-intensive technologies with energy efficient ones must be assessed. In particular, the substitution cost is measured through different steps:

- Identification of alternative technologies that can offer the focal service;
- Estimation of the savings that can derive from the use of those technologies, in terms of energy and GHG emissions – such estimation will depend on the energy efficiency of the technology and the service requirements of the building type;
- Estimation of the monetary returns and savings related to the savings brought by the new technologies – these, will depend on the expected price of energy over the lifetime of the technologies;
- Assessment of the net present value of the costs, the monetary returns and savings that derive from the installation of the technologies taking into account the time preference of money reflected in the discount rate;

Several studies have been carried out to compare different substitution options, assessing the integration potential and cost of such technologies. In the next section we report interesting case studies for Germany.

The Landscape of Models for Assessing Investment Needs in the Building Sector

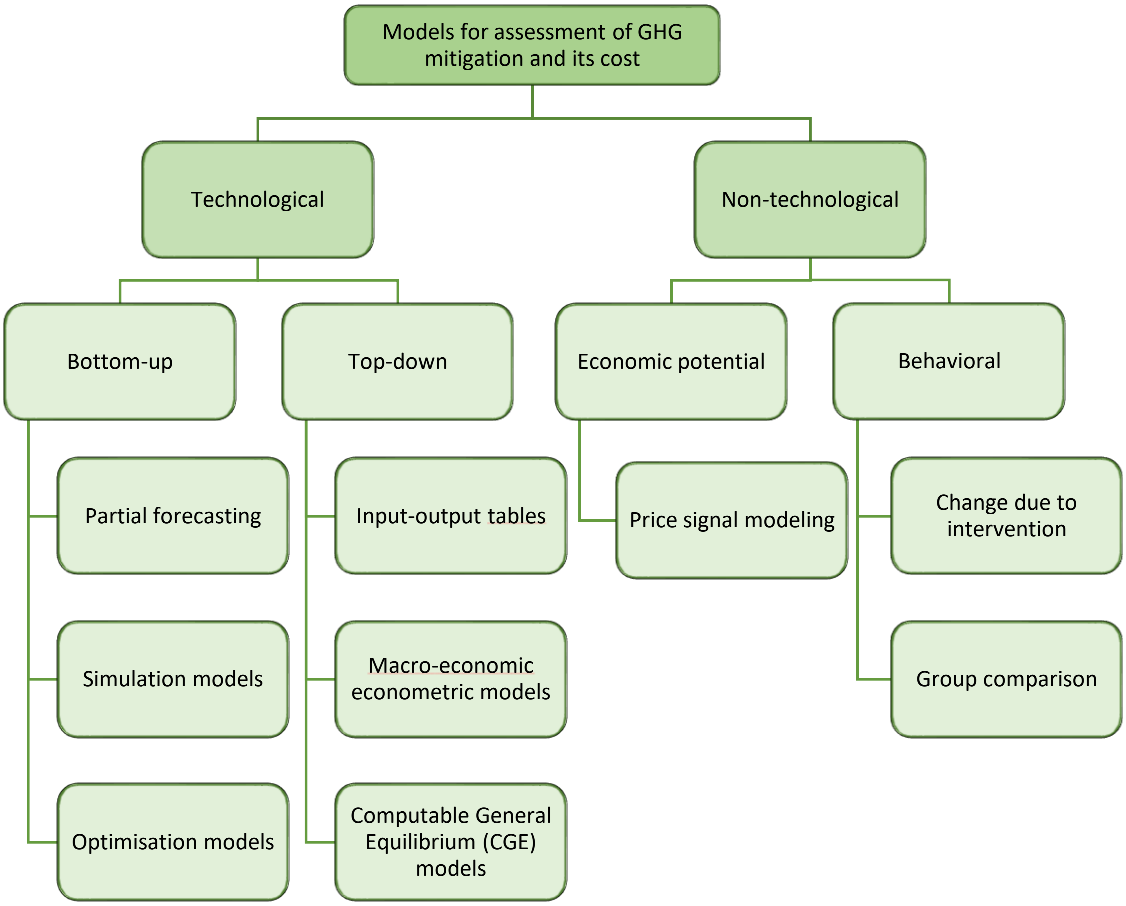


Figure 12 - Models for the Assessment of GHG Mitigation and Its Costs

Figure 12 compares technological and non-technological modelling frameworks assessing GHG mitigation and its corresponding costs in the building sector. There are two approaches on the technology-side - bottom-up (synthesis) and top-down (decomposition). The top-down models examine interactions between energy-related variables and macro-economic indicators, whereas bottom-up modelling relies on the analysis of individual technologies which are then merged into a sectoral picture.

There is a limited number of top-down models examining the energy efficiency potential and associated costs with a focus on the buildings sector. Therefore, bottom-up models are usually used for detailed sector assessments[26]. They are commonly utilized for time horizons of up to 25 years due to uncertainty in assessing the development of technologies. Finally, the application of a particular type of model should be justified by and fit for its specific purpose (i.e., the question we want to solve).

Concerning the non-technological side, modelling the effect of behavioural changes and its associated costs is not very well researched. Non-technological drivers of an economic nature are usually studied through models learning price signals. The rest of the decision models are used to research and understand behaviour or design and evaluate the impact of interventions. These are comparison of energy consumption by groups of users characterised by different behavioural characteristics and to examine change in energy use due to an intervention. Such interventions (policy, pricing, technology,

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[26] Most bottom-up models use simulations; some of them include an optimisation function; and some include top-down elements to a different degree.

information, etc.) could lead to a change in knowledge, motivation, and attitude that impacts energy consumption in treatment groups compared to a control group.

5.1.3. What to Pay Attention To?

As discussed above, the variety of models that can be adopted to assess investment needs in the buildings sector is large. Each model focuses on specific factors and its outputs are sensitive to certain sets of input data and assumptions. In the following, we discuss the most critical assumptions and factors affecting the model outputs. Assumptions regarding discount and interest rates to finance renovation and reconstruction projects play a crucial role in determining final (future) investment costs, whereas energy prices influence the cost-effectiveness of replacing carbon-intensive technologies. The choice of technologies is similarly important to the choice of technology and labour costs. Finally, we shed light on the definition of the reference scenario since most studies present their investment needs as additional costs on top of a baseline.

1. Discount Rate

The discount rate, namely the rate used to discount all future cash inflows and outflows is required to calculate the net present value. Models are highly sensitive to even small discount rates variation. Higher discount rates have a negative effect on the net present value of future cash flows when expenses and revenues do not occur at the same time. The internal rate of return of, for example, investment projects decreases with higher discount rates when investments have a high share of upfront capital costs and long payback periods. Discount rates differ across countries as they reflect the riskiness of investing capital in a certain country and across projects – projects that are perceived to be less risky will have lower cost of capital. In the context of long-term investment needs assessments, it is important to note that projects with long payback periods implicitly carry also higher risks, which increases the uncertainty connected to the investment and its sensitivity. Hence, energy efficiency investment needs assessments are particularly sensitive to interest rates as well, due to the long time-horizon and its capital-intensiveness.

2. Price of Energy

The price of energy is a crucial determinant of the cost effectiveness of substituting carbon intensive with low-carbon technologies. The energy price limits or enhances the savings that can be achieved through energy efficiency renovation measures. Accordingly, the higher the forecasted energy prices, the more economic sense the installation of energy efficient technologies will make. When the price of energy is low, energy bills savings are not high enough to incentivize the uptake of energy efficiency measures. Therefore, models are extremely sensitive to changes in energy prices. This is especially the case for models where feedback loops are present, as mentioned in the previous chapter.

3. Choice of Technologies and Their Penetration Rates

The potential and costs are estimated replacing reference technologies with more energy efficient technologies. As there are several technologies which may satisfy the same service, the model results will be influenced by the selected technologies. Also, neither the type of energy services nor technologies are fixed over time (for example, compare communication technologies some 20 years ago and today) and while learning rates[27] are not just made up but parametrised based on empirical

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[27] i.e. cost reduction as a function of market penetration, i.e. the more of a technology has been actually used in a market, the lower the cost due to learning effects both in production and in installation of a technology.

literature, in particular the transferability of the shape and slope of such learning curves across technologies or different policy and socio-economic settings is controversial and therefore assumptions about technology cost evolution may vary while significantly influencing modelling results.

4. Cost of Technologies and Labour

Technology and labour cost assumptions are major assumptions of investment needs assessments for the buildings sector. The cost of technologies is a crucial factor seizing the opportunities for the energy transition in the buildings sector. In the case of new technologies, learning curves and resulting future cost are uncertain and, therefore, depend on assumptions (see discussion under point 3 – choice of technology). Furthermore, when it comes to analysing the potential of countries with high cost of labour, such as Germany, wages become a further determining factor as they can considerably increase the installation cost of technologies. In the case of Germany, the largest share of installation costs of, for example, PV panels is today represented by the cost of labour while the cost of the technology itself, the PV modules, has come down significantly. Therefore, labour costs frequently drive investment costs and therefore affect investment needs assessments.

5. Definition of the Reference Scenario

As shown in Chapter 2.2, studies usually present a baseline (or reference) scenario and one or more low carbon/energy efficient scenarios which are characterised by diverse combinations of technologies and policies. Comparing scenarios allows to understand differences across pathways and related potential outcomes. It is important to differentiate between differences across results stemming from different model inputs, on the one hand, and different scenarios (e.g., energy-efficiency strategy vs. renewable energy expansion strategy) on the other hand. Nonetheless, since model outcomes are usually stated as *additional* costs *on top* of the reference case, the baseline scenario and its assumptions are the most decisive driver.

All of the above-mentioned elements and corresponding choices and assumptions made in models and scenarios can be explored and made more transparent by the use of sensitivity analysis, where one executes numerous model runs while changing only one of the factors and then observe the changes (i.e. sensitivity) of the output variable of interest. This also holds for our question of investment needs and the extent to which different levels of investments can be envisaged for the coming years up to 2030 in order to achieve climate and energy targets.

5.1.4. What Do We Know Today? Review of Sector Specific Studies and Results Available to Date for the Buildings Sector

Table 6 presents an overview of selected studies which estimate necessary investment costs in the building sector to reach the GHG reduction targets or to reduce the final energy demand of the building sector by 80% compared to 2008-levels. In most cases, the numbers represent the *additional* investment costs for building envelopes and technologies *on top* of a reference scenario, which is generally a business-as-usual (BAU) scenario (assuming no changes in terms of policy intervention).

Table 6 - Selected Studies and Their Results on Investment Needs in the Building Sector

ID	**Study**	**Time**	**Investment needs p.a.**		**Reduction target**
	Authors	*Period*	Min. bn €	Max. bn €	*Ref Scenario in square brackets*
1	IFEU et al (2018)	2017-50	**+3.4**	**+7.7**	-87.5% CO2 [same]
2	DENA (2017)	2015-50	**+12.6**	**+25.4**	-80.0% CO2 [-60%]
2	DENA (2017)	2015-50	**+12.9**	**+29.3**	-95.0% CO2 [-60%]
3	IFEU and Beuth (2017)	2011-50	**+12.8**	**+21.9**	No target scenario
4	IFEU et al (2015)	2014-50	**+10**[b]	**+20**[b]	-80% energy demand [-72%][C]
5	BMWi (2017)	2014-50		**<12**[a]	-80% energy demand [-59%][C]
6	BMWi (2015)	2008-50	**+2.1**	**+6.4**	-80% energy demand [-61%][C]
7	BCG and Prognos (2018)	2015-50		**+ 12.3**	-80% CO2 [-61%]
7	BCG and Prognos (2018)	2015-50		**+18.2**	-95% CO2 [-61%]

Notes:

Explanation of Columns: **"Investment needs p.a.**" state the additional investment needs on top of the reference scenario. **"Reduction target"** links to the target achievement scenario. The reduction in GHG emissions achieved by the BAU case is presented in square brackets.

a) Costs in this study are not stated in accumulated terms but only for every 10th year. Annual additional investment costs range from +1.1 bn € in 2020 to +12 bn € in 2050.

b) As in footnote a), costs are not mentioned in accumulated terms. In the majority of years they are 10-20 bn € higher than the reference case. c) compared to 2008.

Footnotes on IDs: 1 – see IFEU et al, 2018, chapter 3.3.1); 2 –see DENA, 2017, figure 7; 3 – see IFEU and Beuth Hochschule, 2017, table 6.6 & 6.7; 4 – see IFEU et al, 2015, section 5.2.4 ; 5- see BMWI, 2017, module 3, table 41; 6 – see BMWi, 2015, table 24; 7 – see BCG and Prognos, 2018, figure 66

Overall, the estimated investment figures range between 2.1 and 29.3 bn € per year, which seems to limit the usefulness of the results and suggests a somewhat limited explanatory power of the models. However, the high estimates from the DENA (2017) study derive from the cost-intensive scenario specification *Electrification*, which can be ignored if a cheaper alternative is feasible. Similarly, the study by IFEU and Beuth Hochschule (2017; *Anlagenpotenzial*) does not take economic viabilities into account and rather focuses on the potential scaling of renewables. Therefore, the estimated costs would be lower in a cost-efficient scenario analysis. The figures in IFEU et al (2015) and BMWI (2017) do not present annual averages over the entire time period but annual investment costs for every 10th year instead. Hence, these numbers can be interpreted as ranges but not as averages. The report by BMWi (2015), which is Germany's official *Efficiency Strategy for Buildings* to reach the sector's targets*,* presents significantly smaller investment needs than DENA (2017). The differences may be explained by different modelling approaches and their respective sensitivities[28].

Each study is briefly described below.

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[28] We are planning an additional review and discussion with the modelers to explore these differences in more detail for the purpose of up-dating this section and for using a more thorough explanation for the model differences in the working packages of the project focusing on how to use the German experience for estimating investment needs in CZ and LV.

IFEU et al (2018) investigate the role of efficiency in the transformation process in their report *The value of energy efficiency in the building sector in times of sector coupling* (hereinafter: "Value of efficiency"). The entire costs are calculated as additional costs compared to the reference scenario, which is defined as the scenario *efficiency*, emphasizing a reduction in energy demand through efficiency scenarios. It contains higher efficiency standards than today. Three other scenarios contain less ambitious standards. The corresponding gap is closed by a focus on different technologies (renewable energies, heat pumps, and power-to-gas). To draw a contrast, the authors also define a BAU scenario (i.e. today's efficiency standards) with a decarbonization through power-to-gas, which leads to (by far) the highest costs across all scenarios. The figures are the result of pairing four models (see section 5.1.5 below for more details).

DENA's (2017) reference scenario does not aim to fulfil the 2050 targets. It simply forecasts current trends of the German building sector (e.g. no acceleration of replacement rates for old and inefficient heaters; renovation rate and depth remain at a low level). The second scenario, *electrification*, achieves a reduction in emissions through a very high electrification rate in the building sector – electricity demand is predominantly driven by electric heat pumps, which requires a significantly higher share of renewable in the power sector to meet the GHG reduction targets. The third scenario, *technology mix*, allows for a diverse mix of different technologies. The costs are stated as annual differential costs compared to the reference scenario, once each for the 80 and 95% GHG reduction target. *Technology mix* is cheaper in every year than *electrification*. Significantly higher accumulated capital costs for building envelopes and plant technology in the latter scenario are driving this result. The building modelling is done exogenously via an extensive bottom-up cost derivation. The derived energy demand is translated into time profiles in DIMENSION+ w.r.t. to their type of use (room heating, hot water). DIMENSION+ then optimizes the short and long-term supply costs for electricity, heat and synthetic fuels across sectors.

IFEU et al (2015, *Sanierungsfahrplan*) build upon Ecofys' Built-Environment-Analysis Model (BEAM), which maps the existing building stock and is able to deal with future scenarios according to boundary conditions. The reference scenario, *trend*, is not an update of the current development. Rather it presents current measures with a moderate progress (e.g. renovation rate and depth). In a next step, four different pathways to reach the GHG reduction scenarios are depicted. They result from a combination of "very ambitious" vs. "only moderate" isolation of the building envelope on the one hand and an emphasis on heat supply through electricity-based systems (i.e. heat pumps) vs. other renewable energies on the other. This setup is therefore similar to the structure of DENA (2017) (electrification vs. technology mix). The total investment costs are divided into maintenance and energy refurbishment of building envelopes and plant engineering. Over time, the annual investment cost varies between EUR 40 and EUR 70 billion/year (including reference scenario). In terms of differential costs, the four possible target scenarios are up to EUR 20 billion/year higher, but obviously result in lower energy costs. Therefore, in terms of total annual costs (i.e., investment costs plus energy costs), all scenarios are very similar and there is no clear "winner" since higher efficiency comes along with higher investment needs but lower energy costs and vice versa.

The study from **IFEU and Beuth Hochschule (2017, *Anlagenpotenzial*)** differs from previous studies significantly since it does not imply target achievement scenarios and simply shows saving potentials. After quantifying the *potentials* of renewable heat technologies in the building sector, the report emphasizes a maximum exhaustion of the (previously derived) potential of renewable energy sources. From there, two scenarios are derived: a) "maximum renewables expansion at conventional efficiency" and b) "maximum renewables expansion with maximum efficiency". The modelling is based on GEMOD to mirror the current building stock and Heat Map which derives the heat demand on a local level. In terms of final heat demand, which should not be confused with the final energy demand, scenario a) leads to a reduction of 37%, whereas in b) it shrinks by 65% compared to 2011 values. Most importantly, the modelling process does not take economic viability into account since the aim is to show the limits of what is technically feasible. Is the climate reduction target in b) achieved?

With the ***Energy Efficiency Strategy for Buildings*** **(BMWi, 2015)**, the federal government outlined steps on how to reduce the non-renewable primary energy requirement of the building stock by around 80% by 2050 compared with the reference year 2008. This target is not achieved by scenario a) but by scenario b). The important take-home message is therefore that lower efficiency cannot be offset by more renewables.

The **BMWi (2017) studies *Langfrist- und Klimaszenarien*** are focusing on the costs of the energy transition. Therefore, a fictitious reference scenario is derived, which implies a termination of the German *Energiewende*. Hence, the outcomes of this scenario present a world without energy policy interventions. The basis scenario is the central target of the study and examines an achievement of GHG reduction targets and energy policies (e.g. 80% reduction in energy demand for building heat) at the lowest possible costs. The difference between the reference and basis scenario can therefore be interpreted as the energy transition costs. Other target achievement scenarios (e.g. less expansion of transmission grids) are only variations of the basis scenario and could thus also be interpreted as sensitivities. As part of the entire modelling process, energy demand for space heating and warm water supply were derived. The most important costs for the building sector consist of investments in building envelopes, in heating and hot water systems as well as the costs for the use of various energy sources. The derived costs are then presented in terms of additional (reference vs. baseline) annualized investment costs in 2050. In 2050, the reference scenario requires EUR 12 billion/ year annualized investment costs, offset by EUR 3 billion savings in energy costs. It is important to understand that final energy demand also shrinks in the reference scenario due to given assumptions (e.g. increasing CO2 and energy prices). Otherwise the net additional costs would be significantly larger than in other studies

The study ***Klimapfade für Deutschland*** **by BCG** and **Prognos (2018)** has already been described in chapter 4.

5.1.5. Selected Studies - an In-Depth Review

A very interesting and comprehensive setup has been applied by the study *Value of Energy Efficiency* (IFEU et al, 2018). To investigate the building sector in feedback with the overall system across sectors, the authors couple four different models (as depicted in Figure 13).

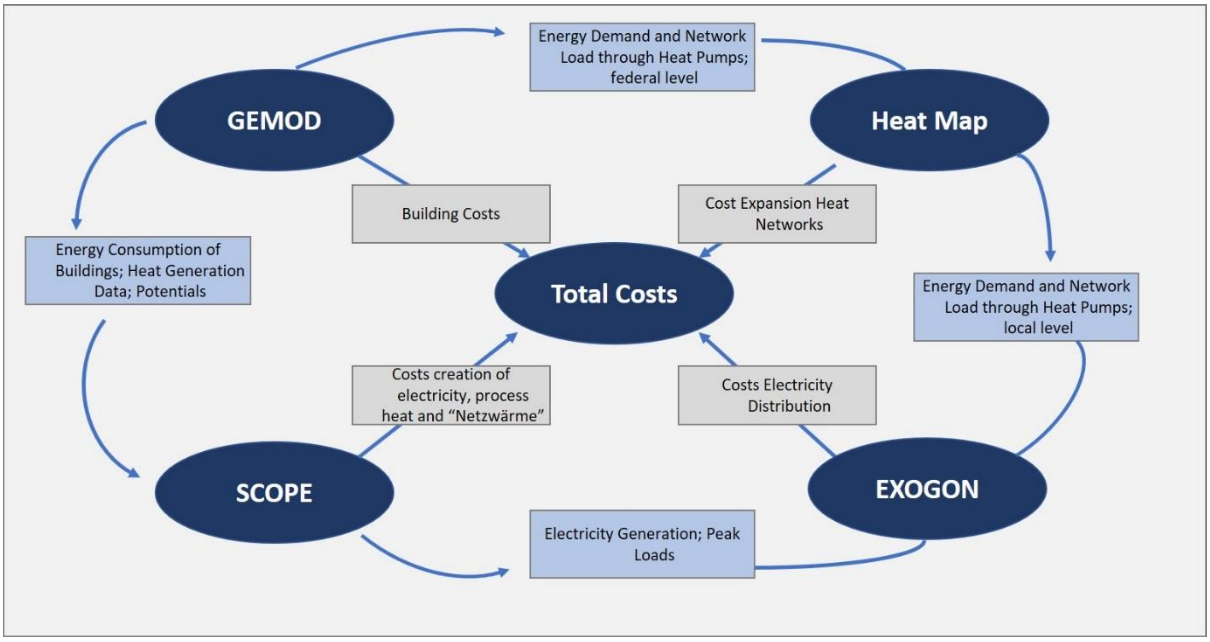

Figure 13 - Model setup in "Value of Energy Efficiency", simplified and adjusted from IFEU et al (2018)

In the report's model setup, the GEMOD model delivers three results. First, as one part of the total costs, GEMOD determines the amount for investments in building envelopes and heat generators. Second, it models the demand for space heating and hot water and delivers relevant data for heat pumps (e.g. grid load) to the Heat Map model. The third deliverable is transferred to the system-optimization model SCOPE, which consists of the final energy demand by fossil fuel and building type.

SCOPE minimizes the overall system costs of energy supply (electricity, process heat, heat grids) given the demand from the GEMOD model. SCOPE draws upon historical weather data and optimizes on an hourly level, therefore taking fluctuating renewables into account. The results on electrical peak loads are then transferred to the electricity grid model EXOGON to map the grid load due to electricity generation. EXOGON follows the methodical approach of a model network analysis on a high level of abstraction.

The Heat Map model receives grid load data through heat pumps on a federal level from GEMOD and determines regional peak loads in a GIS system since it draws upon a database of 49 million German buildings, enriched by the building typology of 17 million residential buildings[29].

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[29] Database by IWU (2010), Institute for Housing and Environment.

BOX 2: Some Key "Sensitivities" in Selected Studies:

The report *Value of Energy Efficiency* (IFEU et al, 2018), which is more thoroughly presented in section *5.1.5.,* assumes a discount rate of 1.5%. In a sensitivity analysis, the authors compared the pattern of scenario costs over time in terms of non-discounted vs. discounted figures. Their graph (see Figure 13, *Value of Energy Efficiency*) reveals that discounting pushes costs in a narrower range, whereas cost differences across scenarios increase in non-discounted terms. The overall costs of the BAU scenario, for instance, increase by around 8 billion € per year.

In a second sensitivity analysis, the authors shed light on the role of the Power-to-Gas (PTG) price. In their report, the BAU scenario still achieved the GHG reduction target through large imports of PTG. The assumed price is based on an in-depth investigation by Agora Energiewende, Agora Verkehrswende and Frontier Economics (2018), which also states optimistic and pessimistic price developments. Considering the bandwidths, the uncertainty on the overall costs are obviously highest in the BAU scenario (+/- 2.8 billion € p.a.).

However, *Value of Energy Efficiency* does not discuss the assumed interest rate. This has been done by BMWI (2017). A reduction of their interest rate from 7% to 3% would halve the annualized investment costs per year by 2050.

5.1.6. First Ideas on Policy Drivers of Investment and How the Discussion of Investment Needs Informs the Assessment of Strategies for Capital Raising for the 2030 Targets

We discussed in this chapter how to get a handle on estimating investment needs to decarbonize the building sector. While it is important to grasp the current state of investment, as conducted within the first stage of this project (Climate and Energy Investment Maps, CEIM[30]), and to build know-how on assessing the investment challenge for 2030/2050 (INGAs, as presented in this report), the ultimate goal is to understand how the required capital can be raised in order to fill the investment gaps. Therefore, step one (CEIM) and step two (INGA) of this project are only intermediate steps to pave the way for capital raising plans (CRPs).

In the context of this project, this third stage (i.e., CRP) will be deployed for CZ and LV as primary target countries, while the German case served as a learning example for stages 1 and 2 (the results of which are presented in this report). Still, even though it is beyond the scope of this report to discuss (not to mention fully capture) the underlying investment barriers and drivers, we would like to attempt at least a general overview, with the purpose of identifying elements that may be important also in the context of the CZ and LV analysis.

What Drives (And Has Been Driving) Investments in Buildings in Germany?

The 2018 monitoring report for the energy transition (BMWI, 2018a) summarizes the "most important fields of action for energy efficiency policy" as follows:

1. Promoting energy efficiency in the buildings sector
2. Establishing economically viable business models for energy efficiency
3. Increase a pro-active sense of responsibility for energy efficiency [among all relevant groups]

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[30] The current investments (i.e. investments in the most recent years for which data is available) are discussed in more detail in Novikova et al (2019), which is part of the same project as this report.

To increase energy efficiency and, amongst others, reduce energy consumption and carbon emissions in the building sector, the German government developed the “National Energy Efficiency Action Plan” (NAPE) in 2014, which comprises a number of measures and processes and have the objective of reducing primary energy consumption until 2020 by 390-460 PJ. Additional decisions by the government coalition on 1 July 2015 aim for further reductions in GHG emission through energy efficiency measures in buildings (and other sectors).

The Energy Efficiency Strategy for Buildings (ESG; BMWi, 2015), which is linked to the NAPE, the Energy Saving Act with the Energy Saving Ordinance (EnEV), and the Renewable Energy Heat Act (EEWärmeG), continues to play an important role for the energy transition in the buildings sector as well.

A non-comprehensive overview of relevant government-programs which directly or indirectly promote green investments in the building sector is presented in the following, covering incentives through funding, such as a range of KfW programmes for energy efficiency and renewable energy in buildings – and Market Incentive Programme (MAP)

- In 2016, a range of KfW programmes under the KfW Infrastrukture, KfW Umwelt, and KfW Wohnen umbrella programmes provided EUR 22.3 billion as concessional loans with a grant element (repayment grants) for energy efficiency, renewable energy, and cross-cutting low carbon measures in buildings (Novikova et al 2019).
- MAP promoted the construction of ca. 67.800 renewable heating installations in 2016 (80% up from 2015) with an investment grant of EUR 182.3 million (and a total investment volume of EUR 937 million (BMWi, 2018a). In addition to MAP, the “incentive program energy efficiency” was set up (and implemented via BAFA) to substitute the planned tax incentive for energy renovations of buildings, for which national government and the States could not find agreement.
- Energy Efficiency Incentive programme funds modernization of heating and ventilation systems, expecting 13 PJ savings by 2030.

A detailed assessment of all measures included under the NAPE and a review of results so far is included in the monitoring report for the energy transition 2018 (BMWi, 2018a). The energy saving effects of energy efficiency policies and measures is however difficult to capture, in particular when it comes to information and advisory programs and their combined effect with other policy measures.

From a more institutional perspective, the German climate and energy finance landscape is characterized by a strong role of public banks, which serve as important intermediaries for supporting green investments in the buildings sector. In particular, KfW and BAFA played a prominent role in providing finance and facilitating information and advice. KfW was the main provider of finance for retrofits of buildings, construction of buildings above the building code, and various types of integrated renewable energy installations within the sector. Funding from BAFA was especially important for supporting investment into renewable heat and other advanced heating and cooling technologies of the sector. Regional state banks and commercial banks play an important role as intermediaries as well. However, their role could not be quantified. Accessible information on specific state level public banks are included in the annex of Novikova et al (2019).

Outlook and link to CRP

The discussion above provides first insights on the importance of the (evolving) policy regime for investments in energy efficiency. This holds in particular for understanding investment needs over a longer time horizon, as discussed in this project (namely for the period up to 2030).

To unleash the whole potential, policy and public finance measures need to tackle existing barriers (mostly related to market and policy failures) and understand and reinforce investment drivers. This type of analysis needs to capture the investment challenge from all relevant perspectives, as barriers and incentives/drivers differ between:

- Demand versus supply side of finance: project developers (i.e., the demand side of finance) vs. to investors and financiers (i.e., the supply side of finance)
- Sectors (private households, commercial buildings, public buildings)
- Scale of the investment
- Policy framework, institutional setting (country context): regulatory uncertainty and administrative barrier

Another important dimension is the existing energy policy framework and how it incentivizes investment in energy efficiency of buildings.

The discussion of capital raising plans for CZ and LV will focus on this discussion in more detail but draws to a significant degree on the insights provided in this report for the German case.

5.2. Investment Needs for Renewable Energy in the Power Sector

5.2.1. The Importance of Renewable Energy for the Energy Transition and the Corresponding Investment Challenge

Relevance and Targets of Renewable Energy

In 2016, the energy sector was responsible for 332.2 mil tCO2-eq. or 36.6% of total[31] GHG emissions of Germany (UBA, 2018). Germany has set itself the goal of reducing its greenhouse gas emissions by year 2020 compared to 1990 by at least 40% (BMUB, 2016). This corresponds to an overall reduction of about 500 million tons of tCO2-eq. to 750 mil tCO_2-eq. In 2016, Germany's GHG emissions had decreased by around 27% compared to the year 1990 (BMU,2018).

Fossil-fuel-based energy and electricity still represents the largest share of energy/electricity generation in Germany and the deployment of renewable energy is the main instrument to reduce the emissions intensity of the sector. In 2018, 33.3% of all electricity was generated from renewable energy sources (BMWi, 2018a), with targets set at 35% by 2020, 50% by 2030, and 80% by 2050.The current German government even increased the 2030 target up to 65% in their coalition agreement (Bundesregierung, 2018).

Critiques may argue that renewable energies “only” decarbonize the electricity sector. However, a decarbonized electricity sector has vast potential spill-over effects mainly driven by the electrification of other sectors. A great example is the transport sector: while biofuels can have low associated emissions, they leave other doubts about their sustainability such as competition with food and loss of biodiversity when sourced unsustainably. Therefore, electrification via electric vehicles is certainly one significant decarbonization pathway. Further, also certain strategies for the industry sector hinge on electrifying carbon-intensive processes, thus requiring even more renewable power.

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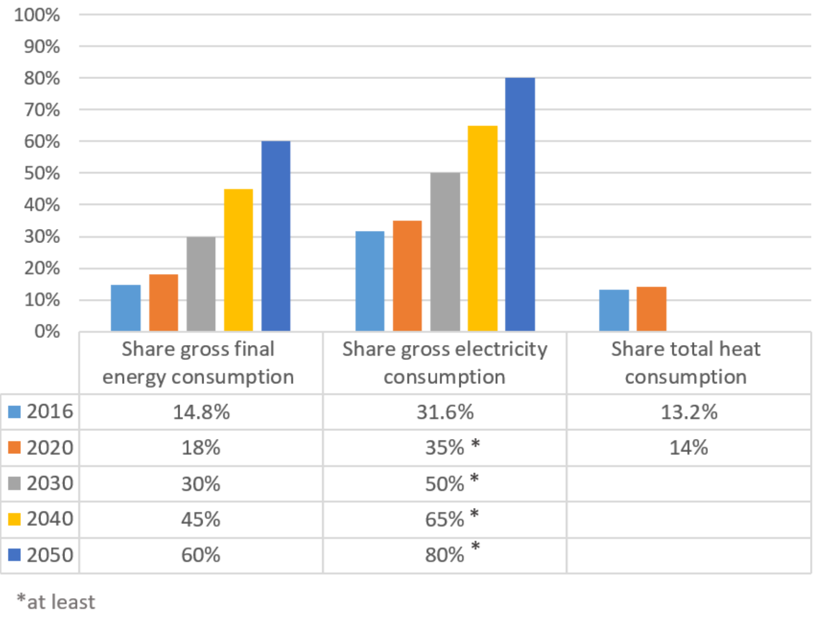
[31] Excluding land use, land use change and forestry.



	Share gross final energy consumption	Share gross electricity consumption	Share total heat consumption
🟦 2016	14.8%	31.6%	13.2%
🟧 2020	18%	35% *	14%
⬜ 2030	30%	50% *	
🟨 2040	45%	65% *	
🟦 2050	60%	80% *	

*at least

Figure 14 – Share of RE on gross final energy, electricity and heat consumption. Source: BMWi (2018)

Is the Sector on Track to Reach Its Targets?

Germany appears to be on target to reach 35% of its electricity supply from renewable sources by 2020, considering that in 2016 renewable energy sources had a share of 31.6% and of 33.3% in 2018 (BMWi, 2018a).

Germany is obliged to reach a share of 18% renewables in gross final energy consumption under the European Renewable Energy Directive 2009. Despite the strong expansion of renewables in the electricity sector, Germany has not yet reached this goal due to a slower expansion in the heat and transport sectors. A remaining 3.2% gap will need to be filled compared to the 14.8% reached in 2016, requiring a substantial expansion of renewable energy in electricity and heat supply as well as more effort in the transport sector (BMWi, 2018a). BMWi expects to overachieve the target value of 18% (projection of 18.4%, BMWI, 2018b). However, the most recent statistics from Eurostat (2019) present a share of 15.5% in 2017. Predicting expansion trends from recent years and taking into account relatively low wind power tender results, Germany is likely to miss its target. This could result either in a fine for the German government, which could be avoided for example through a statistical transfer of renewable energy, as was done for instance between Lithuania and Luxembourg (European Commission, 2017a)

Renewable Energy Investments in Germany

The pattern of renewable energy investments in Germany over the last decade is presented in Figure 15. Investment in renewable energy installations increased from EUR 15.1 billion in 2016 to EUR 16.2 billion in 2017.

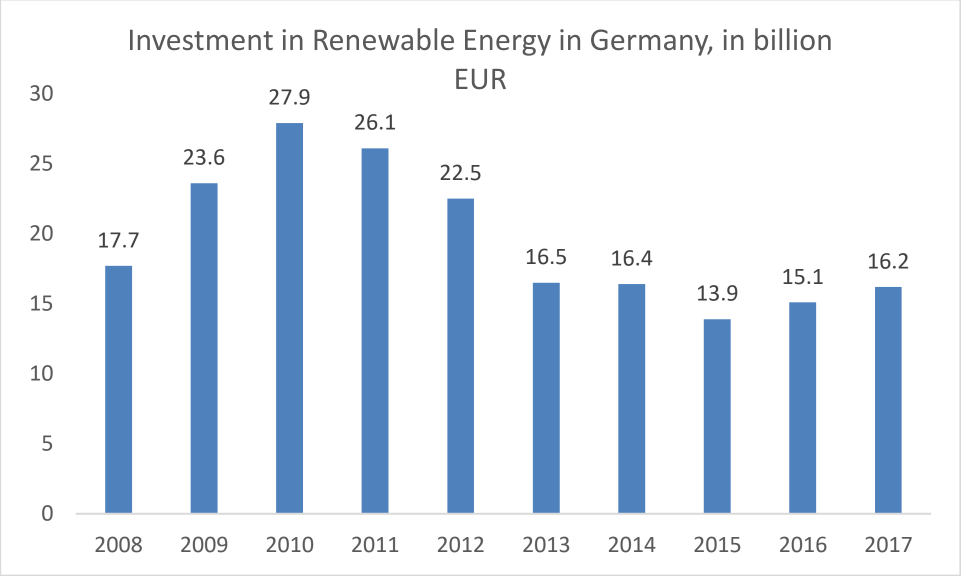


Figure 15 – Investments in RE in Germany 2008-2016 – Source: AGEE-Stat (2018)

Both recent figures are relatively low, especially when compared to the "peak years" 2009-2012, which were characterised by large solar investments. Since then, costs have fallen significantly for solar power and to a lesser extent for wind power, meaning that lower investments are required to install the same capacities. Besides, solar remuneration faced massive cuts, which is one reason for reduced investments in PV installations. Feed-in-tariffs (FiT) for solar power have also been reduced significantly in the last decade. In 2010, FiTs for small rooftop PVs were around 35 ct/kWh, and decreased down to 10 ct/kwH in 2019 (Fraunhofer ISE, 2019).

The above discussion particularly highlights two things:

1. Significant additional efforts are required in the coming years leading up to 2020.
2. Although some parts of the decrease in renewable energy investment are explained by fallen costs, a remaining share can be linked to changes in the policy regime -, a discussion we are going to return to in the final section (5.2.6)

The following discussion will show how to estimate investment needs for the expansion of renewable energy in the power sector (section 5.2.2), point out the sensitivities of the results to specific model features and assumptions (section 5.2.3), summarize existing estimates of investment needs and their underlying choices of scenarios (and in particular reference or baseline scenarios) and how those influence the results (section 5.2.4). Section 5.2.5 zooms into specific analytical (modelling) frameworks used for the analysis of investment needs in Germany, to exemplify the more conceptual discussion of sections b and c. The final section 5.2.6 links this discussion of investment needs (and how to assess them) to the next work package on barriers and drivers of investment and how to raise capital for achieving the 2030 targets (which will focus on CZ and LV and be finalised by end of 2020).

5.2.2. How to Analyse Investment Needs for Renewable Energy in the Power Sector in Practice

This section focuses on the decarbonization of electricity production, i.e. the activities that transform primary energy into the electricity necessary to satisfy the demand of the different sectors of an economy.

The electricity industry serves every sector of the economy, meeting the electricity demand at any point in time. For this reason, as well as due to the property of limited storability, the electricity market is very complex and accordingly, modelling the capacity and investment needs of the sector is not an easy task. Assessing investment needs for primary energy decarbonisation implies a thorough understanding of green technologies and how they are (to be) embedded in the energy system.

For estimating the extent to which energy generation can be decarbonised, it is important to consider the factors that influence the cost-effectiveness of a renewable energy or fuel-based power plant - namely electricity grids constraints (i.e. physical energy flow constraints), balance needs (i.e. physical necessity to balance electricity supply and demand), and the related energy management costs. Further important factors are those related to the focal electricity exchanges such as short- and long-term trading of electricity, and electricity system factors such as the interaction of demand and supply. The above-mentioned elements are presented in a simplified manner through numerical models.

BOX 3 – Definition of Numerical Models:

A numerical model is a set of equations that represent real-world relationships (causal, correlation) in simplified form. A model allows to zoom in the crucial aspects that substantially affect the phenomenon under study while discarding all the others. Only the relationships that are relevant to the processes under study are modelled, according to the focus and objective of the study.

In the following, we briefly address power sector models and their possible differentiations according to three key dimensions: focus, scope, and resolution.[32]

One way of differentiating between power sector models is according to their **focus**. In general, one can distinguish four main categories (or types of questions):

1. Load flow and optimal power flow models – identifying the electricity flows of networks' lines, nodal prices, system's security and redispatch requirements
2. Network stability models – studying the stability of the electricity network
3. Energy system models – assessing electricity demand, fuel prices and carbon emissions
4. Power market models – focusing on power plants dispatch and defining electricity wholesale prices

A second way of differentiating between them is their **scope.** Models differ in their coverage, focussing for example on the electricity sector, electricity plus other sectors such as buildings, transport, industry (and possibly sector coupling) or the entire economy. Moreover, models can differ along the spatial dimension (geographical coverage, i.e. share of world regions/countries included) and time dimension, including time horizon, temporal resolution (i.e. minutes, hours, days, years) and "structure" (i.e. dynamic vs. static models).

Models can also be distinguished by **resolution**, i.e. granularity of data, which can vary according to geography and time resolution, or sectoral disaggregation, for example. Even if a model has a national scope and aims at generating national-level decision variables (outputs), the data and information that is used to derive these outputs can be more or less granular and be modelled in a bottom-up or top-down approach[33], respectively. The resolution of a model can vary according to the reference unit of analysis that may be single power plants, individual power production companies, individual market

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[32] A further important element of distinction is the method of solution of the model, but this would require a more technical discussion. In short, the three main methods are optimization (where one objective function is either maximized or minimized), simulation (mechanical) and multiple optimization problems (involving an explicit representation of individual decision-making agents).

[33] The distinction between bottom-up and top-down models was already discussed in section 5.1.

participants, aggregated (groups of) market participants, aggregated technologies adopted and/or innovative technologies that market participants can use to serve the market.

There is often a trade-off between scope and resolution. Large scope and large resolution analysis are very expensive. They require large amounts of input (data), hence, costly data collection, numerical solving time, and model maintenance[34]. The balance between scope and resolution depends on the ultimate objective of decision makers that can involve the need to inform operational decisions (short run and different possible degrees of spatial resolution), planning decisions (long run and different possible degrees of spatial resolution) or insights about, say, global welfare issues (wider spatial and temporal resolution). Hence, the choice of the type of model depends on the ultimate objective of analysis.

The stronger the focus on electricity production, system operation and related technical details, the higher the temporal resolution and granularity necessary for modelling them. Vice versa, the stronger the focus on the electricity sector and the long-run development of the energy system, the more operational and macroeconomic factors have to be considered. Nevertheless, operational details remain important and shall be examined when it comes to system planning and investment decisions.

In order to assess investment needs for the electricity sector to achieve its energy and climate targets, it is important to consider the above-mentioned dynamics. They are also represented in Figure 16 below. Each of the blocks identified is crucial to have a complete picture of the sector and make a robust assessment of investment needs.

Macroeconomic Models	Energy System Models	Investments in Power Plants	Electricity Production	Grid Models
•Economic activities •Population •(..)	•Electricity demand •Electricity supply •Sectors coupling •Fuel markets	•Investments and de-commissioning potential •Optimal capacity mix	•Unit commitment and dispatch •Zonal power prices •Electricity flows	•Local marginal prices •Load flows •System security and stability

Figure 16 - Parameters of Models for the Power Sector

As shown in Figure 16, operational decisions are taken using dynamic and static **grid models** (high granularity), which allow to assess system's stability, security, load flows, and economic dispatch. Grid models are complemented by **power production models** (or electricity production models), which allow to consider power plants unit commitments and dispatch, electricity prices and cross-border energy exchanges. The broader term, **power market models** also allow to model investment decisions (*Investment in Power Plants*, see Figure 16) which can determine the optimal capacity mix. **Energy system models** account for electricity demand, demand side changes, assess cross-sectorial linkages and sector coupling. Finally, **macroeconomic or integrated assessment models** cover the entire economy, can include GHG emissions assessments and fuel markets. Nevertheless, once knowing the emission factor of a specific production activity, one can estimate the related GHG emissions, following the principle of the formula introduced in Chapter 5.1.

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[34] You may remember our World map versus national map analogy from chapter 2!

Another categorisation comes from Ventosa et al. (2005), who divide power market models into three categories: optimization models, equilibrium models and simulation models. The first category, optimization models, focuses on the profit maximization problem for single firms competing in the market. In these models, the profit function is maximized subject to technical and economic constraints. Instead, equilibrium and simulation models represent the market behaviour of all the market participants. They allow to identify the simultaneous profit maximization equilibrium for companies participating to the market. In particular, equilibrium models are more suitable to long-term planning and market power analysis. On the contrary, optimization models are more suitable for building daily bid curves and operational decisions of single firms.

Production decisions include power plants unit commitment and dispatch, zonal electricity prices, and flows across the borders. They are defined using endogenously determined information on load flow, security-constrained dispatch and locational marginal electricity prices. Indeed, their scope is broader than grid models and can serve (directly) operational decisions, as well as (indirectly) investment decisions. In other words, after operational decisions, energy production modelling is also the basis for assessing investment and decommissioning of power plants decisions – and the capacity mix of a power system.

Power market models are crucial to provide the information necessary to assess the profitability of an investment. To this objective, they usually complement investment models.

Power plants profitability highly depends on electricity prices. In order to make investment decisions, project developers look at the prices that are expected to prevail on the market from the start of power plant construction until the end of the power plant’s lifetime. The length of the lifetime is variable across technologies. In Germany, a low fraction of investments is currently based on long-term power purchase agreements, and power markets are liquid up to a maximum of five years into the future. Hence, the estimates are highly based on expected electricity prices which are derived from power market models.

Once electricity prices forecasts are factored into investment models, combined with the operation and maintenance costs (O&M costs) and variable costs of running the power generating asset, future expected cash flows can be modelled. This is usually done through net present value (NPV) calculations.

Long-term energy market models are often inadequate to calculate revenue streams for renewable energy projects. Particular attention must be paid when it comes to investments in renewable energy power plants. Wind and solar power run when the wind blows and the sun shines. When the weather changes, power output changes, making power output harder to predict. To analyse power supply and required flexibility, models must reflect this and model short-term changes, e.g. hourly power supply and demand.

The integration of renewables into energy markets cannot be depicted by commonly applied optimization models (De Jonghe, 2011; Deane, 2012) – such tools fail to represent the need for increased power system flexibility brought by RE deployment and fail to correctly estimate the future value of electricity generated by renewable resources since they lack high temporal resolution. Short-term demand and supply dynamics are important to have optimal renewable power dispatch and investment decisions (Welsch, 2014). Higher granularity for large temporal resolution and coverage of operational constrains is necessary to model renewable energies deployment.

Energy System Models

As mentioned in Chapter 3, energy system models estimate electricity production quantity, quality and price at a certain point in time. Demand and supply dynamics – determining the quantity and price of energy exchanged – are endogenous to such models; consumption and production technologies – which define the efficiency and carbon content of the electricity in the market – are exogenous though crucial to determine the quality of electricity exchanged, i.e. the carbon content of the energy produced. Energy system models are central to assess investment needs of a country. Nevertheless, they have to be integrated with energy market models and demand-side sector specific models in order to identify the technologies that are going to be used to supply electricity to the market.

The set of factors that need to be accounted for when assessing investment needs in the energy sector is broad, hence sensitivities analyses play a crucial role. This is especially the case of the German electricity sectors where the deployment of renewables is increasing and needs to increase further to achieve its climate and energy targets. Indeed, even granular details such as rid balance, security and flexibility modelling are of outmost relevance to assess the profitability of RE resources.

5.2.3. What to Pay Attention To

As in section 5.1.3, where we explained key drivers of building sector models in more detail, we provide the same analysis for renewable energy expansion in the power sector. The discount rate, the (relative) costs of technologies, and the importance of the reference scenario, which were already described in section 5.1.3., also apply for RE models and should therefore only briefly be mentioned here. A higher discount rate decreases the internal rate of return, especially for projects that require high shares of upfront capital costs like renewable energy expansion. In terms of technology costs, especially the cost development for wind power and solar PV systems are crucial for RE models, since most models heavily rely on the expansion of both. Regarding the importance of the reference scenario, assumptions on social norms and policy trends, such as Germany's phase-out from coal or international efforts on combating climate change, play an important role in this context.

On top of the three above-mentioned elements, studies conducted on the power sector show results in particular highly sensitive to the energy price and electricity demand, which are outlined in the following.

1. Price of Energy

The price of energy is a crucial determinant of substituting fossil fuel with RE technologies. The higher the fossil fuel prices forecasted, the more profitable are investments into renewable energies. Countries that import fossil fuel have even more pressure to invest in RE technologies in order to relieve their trade balances. When the price of coal and gas is low, incentives to invest into renewable energies might not be sufficient to support the transition. Therefore, models are sensitive to changes in energy prices.

Carbon prices, another important pillar of this section, like the price of emission allowances under the EU Emission Trading Scheme, matter as they increase the costs of fossil fuel-based power generation. They also increase the price of electricity when gas or coal power plants provide the marginal unit of electricity. Furthermore, they also indirectly affect the price of electricity as determined in forward power purchase contacts, i.e. over the counter trade, which is where most transactions are carried out, as they affect market participants' general price expectations.

2. Electricity Demand

Electricity demand is crucial to forecast the demand for renewable energy supply. Demand-side changes driven by sector coupling, energy efficiency measures and demand response technologies are expected to shape demand curves in the future. Close attention needs to be paid to demand-side developments, which need to be modelled and iterated with supply curves. Developments in other sectors like the transport, heat and industry sector matter as well. For example, if electric vehicles are expanded on a large scale or if the building sector pursues a higher electrification, electricity demand rises rapidly.

The above-mentioned factors of course do not affect every model equally. Power market models, for instance, are particularly sensitive to demand estimates and cost of technologies. When complemented by investment models, the role of the discount rates suddenly becomes important as well. More details follow in the next section where insights spark from the analysis of relevant studies.

5.2.4. What Do We Know Today? Review of Sector Specific Results Available to Date for Renewable Energy Investments in the Power and Energy Sector

Table 7 presents an overview of selected studies which estimate necessary investment costs in the electricity and energy sector to reach the German GHG reduction targets. In the following, we will discuss their main findings, their varying estimates of investment needs and how their differences can be explained. [35]

Table 7 - Overview of Selected Studies - RE Investment Needs Assessments.

ID	**Study**	**Time**	**Investment needs p.a.**		**GHG reduction target**
	Authors	*Period*	*Min. Bn €*	*Max. Bn €*	*GHG reduction of the reference in square brackets*
2050 GHG reduction targets					
1	BCG and Prognos (2018)	2015-50	**+4.2**		-80.0% CO2 [-61%]
1	BCG and Prognos (2018)	2015-50	**+9.5**		-95.0% CO2 [-61%]
2	GWS (2018)	2000-50	**+12.8**		-80%-85% CO2 [none]
2030 GHG reduction targets					
3	IRENA (2015)	2010-30	**+6.9**		-55% CO2 [-44%]
4	Prognos et al (2018)	2018-30	**+6.7**	**+9.2**	-55% CO2 [-35%]

Notes:
Explanation Columns: “Investment needs p.a.” state the additional investment needs on top of the reference scenario. “GHG reduction target” links to the target achievement scenario. The reduction in GHG emissions achieved by the BAU case is presented in square brackets.

Footnotes on IDs: 1 – see BCG and Prognos, 2018, figure 75; 2 – see GWS, 2018, chapter 3.2.5, comparison to a counterfactual scenario!; 3- see IRENA, 2015, table 10, number stated in US dollars; 4- see Prognos et al, 2018, Summary file chapter 5.1

To avoid confusion, we should also highlight that the terms “power sector” and “energy sector” are some commonly confused terms and are sometimes used interchangeably. The term power sector focuses on the electricity production, whereas the energy sector can also cover heat and transport. In

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[35] Other studies addressing the topic but without providing numbers on investment needs are BMWi (2014). The authors provide numbers on investment needs but not especially for the energy sector. Due to its advanced methodology the study is nonetheless included in ANNEX 3)*;* another report comes from Fraunhofer-IWES (2015). The authors suggest with EUR 21 billion per year a significantly different investment need for the energy sector. However, the report combines data from relevant studies but does not apply an own modelling procedure. Also, no information regarding the reference scenario are state. We therefore exclude this report from the overview.

our terms, the figures by studies 1-3 only deal with electricity production but study 4 also includes the heating sector. Once the electricity sector is mentioned, it is commonly annotated solely with “renewable energy investment”. While this certainly makes up a large share, most studies also address expenses on infrastructure such as grid- or storage-expansion.

Diving into Table 7, IRENA (2015) and Prognos et al. (2018) only consider the development until 2030, whereas the remaining two studies run their calculations until 2050. To compare the usually accumulated investment needs, the results are stated per annum (see column “Investment needs p.a.”). The estimated investment figures range between EUR 4.4 and EUR 12.8 billion per year. The scale of the differences may seem striking but can easily be explained. One should keep in mind that the figures present the additional investment need on top of the reference scenario. Therefore, the definition of the reference scenario is the most important key driver of this number. The differences across the BCG-estimates result from the deviating target values (80% vs. 95%). The GWS (2018) report exceeds the BCG and Prognos (2018) study since its reference scenario does not assume a BAU pattern. Instead the target achievement scenario is compared to a counterfactual scenario in which no policy intervention happened since 2000. Whereas BCG and Prognos’ (2018) reference scenario achieves 60% GHG reduction, the GWS (2018) scenario barely diminishes GHG emissions. Non-surprisingly, estimated *additional* investment needs are significantly different. The discrepancies between IRENA (2015) and Prognos et al. (2018) are less severe and can be explained by varying levels of ambition in the reference case (see the last column), different time frames, and the fact that IRENA (2015) does not consider necessary grid expansions. While the studies and their sensitivities are more thoroughly presented in Appendix 3, we provide a brief description of each in the following.

The report by BCG and Prognos (2018) has already been explained in chapter 4. The differences in costs derive, non-surprisingly, from the more ambitious GHG reduction target (i.e., 95%). The reference scenario provides a classic BAU case and assumes that historical trends, and current technology and policy developments will continue. Nonetheless, it assumes sustained global trade and economic growth. As an indicative scenario, the modelling ends up with a GHG reduction of 61% by 2050 compared to 1990 levels.

The IRENA (2015) report is part of the REmap 2030 program which assesses 38 countries, Germany being one of them. REmap’s analytical approach draws on BMWi (2014), a report by Prognos, EWI and GWS investigating energy market developments. The reference case assumes a BAU development, which already achieves an increase in the share of renewable energies in TFEC from 10.5% in 2010 to 27% by 2030 due to Germany’s implemented policies. Moreover, it foresees a GHG reduction of around 44% by 2030. The REmap case predicts a 37% share of renewable in TFEC and a reduction of 55% in GHG reduction compared to 1990 levels.

GWS (2018) investigate two scenarios. The first, the energy transition scenario, allows for a CO2 reduction between 80 and 85% by 2050 and assumes that all future targets of the German *Energiewende* are met. For 2000-2014, the actual costs are taken and then forecasted until 2050. The second, the counterfactual scenario, assumes that no energy policy intervention has happened since 2000. Thereby, the authors want to show the entire costs of the energy transition. Since all other reference scenarios assume policy interventions with no increases or modest increases, the additional investment costs are higher than those of other studies (see Table 7).

The report by Prognos et al compares a scenario focusing on energy efficiency with a scenario focusing on the scaling of renewable energies. Non-surprisingly, the latter scenario leads to higher annual investment costs in the power sector (see column P.A. max). The reference scenario is a *Mit-*

Maßnahmen-Szenario (i.e., a scenario with further measurements) from Germany's government (BMU, 2017), which leads to a reduction of -35% by 2030 for the entire economy.

5.2.5. Klimapfade for Germany – an in-depth review

There is a broad literature of studies in Germany calculating investment needs for Germany's energy transition. However, many of these studies are not very transparent concerning sensitivities of different price and cost developments on future investment needs. To illustrate some important sensitivities in more detail, we select the study *Klimapfade for Germany* by the Boston Consulting Group and Prognos AG (2018), which has recently been published and gained a lot of attention.

BCG presents a model with three scenarios: (1) reference case, (2) national climate strategy (no UN globally harmonized approach, only few European countries engaged in climate mitigation) and (3) global approach to limit warming to 2 degrees). According to the study, 76% of energy production in Germany will be based on RE-technology in 2050 under the reference case, 88% in scenario two and 100% in scenario three. Total investment needs to comply with 2050 targets in an 80% scenario is estimated to 470 billion EUR (Governmental[36] perspective, cumulative 2015-2050, not discounted) and 960 billion EUR in a 95% scenario. Both scenarios are based on the assumption that fossil fuel prices would rise to 115 USD/barrel in 2050.

Sensitivity of Investment Needs with Regard to Fuel Prices

As mentioned above (see section 5.2.3, *What to Pay Attention To*), investment needs calculations are extremely sensitive to energy prices, which has been exemplified in the BCG study: If the price per barrel would stay in the range of 50 USD/barrel in 2050, overall investment needs would be 820 billion EUR (cumulative 2015-2050) in an 80% emission reduction scenario and 1,420 billion EUR in the 95% case (see Figure 17 below).

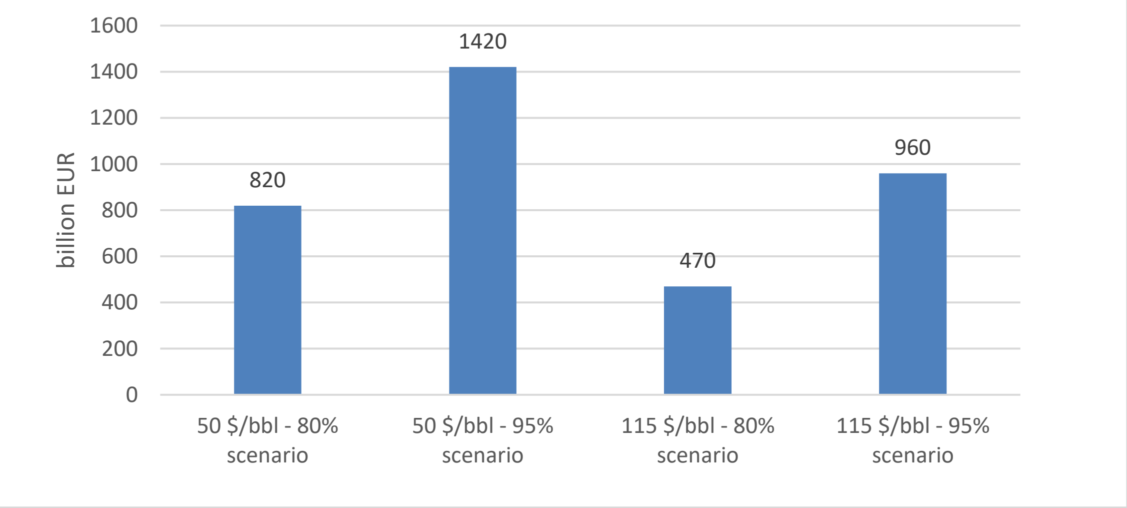

Figure 17 – Sensitivities to investment needs under different price scenarios for fuel costs[37]

Notes: Scenarios differ in energy prices [USD/barrel] and in terms of the emission reduction target.

However, if fuel prices were higher (115 USD/barrel), economic costs are lower since the economy as such would benefit by importing less oil, thereby making investments in renewable energy much more

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[36] Governmental perspective versus Business perspective. The Governmental perspective uses a lower discount rate (2% versus 8% p.a.) and does not consider taxes, subsidies, prices for EU allowances.

[37] See BCG and Prognos (2018, p.92).

attractive. In consequence, total additional investment needs in an 80% high-fuel price scenario is estimated to 470 billion EUR (Governmental perspective) and 960 billion EUR in a 95% scenario.

Sensitivities of Investment Needs with Regard to Cost of Technologies

BCG estimates that transforming the energy sector in compliancy to an 80% emission reduction scenario would require the installation of 343 GW (mostly green) net power plant capacity, thereof 105 GW PV, 144 GW wind power, and 61 GW from gas. For reference: in 2015 Germany had implemented only 40 GW PV and 45 GW wind power on and offshore (BCG and Prognos, 2018). BCG estimates the additional investment need on top of the reference case (290 billion EUR) for the electricity system to be 146 billion EUR in the 80% scenario and 333 billion EUR in the 95% scenario (Governmental perspective, cumulative 2015-50).

In the 95% scenario, BCG assumes the installation of 413 GW net power plant capacity in total, thereof 130 GW PV, 102 GW wind onshore and 60 GW wind offshore.

Table 8 - Different RE Investment needs under different price Scenarios.

	Installed Capacity in 2050 (GW)	Reference price in 2015 (1000 EUR/MW)	Price expectation 2020/30/40/50 (1000 EUR/MW)	Total investment needs (billion EUR)***
Wind onshore (Price scenario I)	102	1.3	1.2/1.1/1.05/1	65.8
Wind onshore (Price scenario II*)	102		1.25/1.15/1.075/1.025	68.1
Wind offshore (Price scenario I)	60	3.3	2.9/2.2/2.1/2.0	53.0
Wind offshore (Price scenario II*)	60		3.1/2.55/2.15/2.05	56.8
PV (Price scenario I)	130	1.3**	1.2/0.95/0.7/0.65	74.8
PV (Price scenario II*)	130		1.25/1.075/0.825/0.675	82.8
Scenario I, billion EUR				**193.6**
Scenario II, billion EUR				**207.6**
	*Reduction in investment costs by only 50%, compared to assumed pattern in the BCG study. ** PV Rooftop *** In addition to installed capacity 2020. See BCG and Prognos (2018, p. 264).			

To illustrate the sensitivity of investment costs to differences in assumptions about cost development, we carried out a little sensitivity analysis. We adjusted the assumed cost development of each technology and cut the decrease by 50% (see Table 8). For wind power onshore, for example, the price in 2015 is EUR 1300 /kW. The BDI study assumes decreasing costs, down to EUR 1000 /kW by 2050. For each technology, we halve the development in cost reduction and calculate the resulting differences in investment costs. For the sake of simplicity, we assume only rooftop PV modules to abstract from the different cost patterns for ground-mounted PV. The results show the following: if technology costs were more expensive (i.e., a lower cost reduction), total investment costs would increase from EUR 193.6 billion to EUR 207.6 billion.

A further illustration of the sensitivity of results to modelling assumptions can be made if we look at predicted cost patterns for offshore wind power. According to the BCG estimates (of investment cost), offshore wind power is even in 2050 still twice as expensive as onshore wind power. However, a current study conducted by Fraunhofer ISE (2018) already predicts overlaps in the levelized cost of electricity (LCOE). LCOEs are predicted to be between 3.49 to 7.09 ct/kWh for onshore wind locations and between 5.67 and 10.07 ct/kWh for offshore wind locations in 2035.

5.2.6. First Ideas on Policy Drivers of Investment and How the Discussion of Investment Needs Informs the Assessment of Strategies for Capital Raising for the 2030 Targets

As highlighted in section 5.1.6, step one (CEIMs) and step two (the current report, INGAs) are only intermediate steps and pave the way for developing CRPs. In the following subsection, we therefore briefly focus the discussion on possible investment barriers and drivers, to identify important elements for the upcoming CRP analysis (step three) for CZ and LV, building upon experiences and lessons learned in Germany.

In the context of this project, this third “stage” of the investment challenge will be tackled for CZ and LV as primary target countries, while the German case served as a learning example for stages 1 and 2 (the results of which are presented in this report). As in section 5.1.6., we briefly touch the discussion on underlying investment barriers and drivers in the following, with the purpose to identify important elements in the context of the CZ and LV analysis.

What Drives (And Has Been Driving) Renewable Energy Investment in Germany?

The EEG (Renewable Energy Act) has been the central policy framework for the expansion of renewable energy in Germany since its introduction in 2000 (and its various revisions in 2004, 2009, 2012, 2014 and 2017). Its original Feed-in Tariff (FiT) has been one key driver of renewable energy investment, with payments to operators of installations (99.7 GW installed capacity) equivalent to EUR 24.3 bn both for selling (through transmission system operators) and direct marketing of electricity. Evolvement of the EEG over time strongly correlates with the FIT development (BNetzA, 2017). This and other key policy measures are depicted in Table 9 to provide an overview.

Table 9 - Overview on key policy measures in relation to renewable energy in electricity, heat and transport – Source: BMWi 2018a.

	Policy Measure (English)	**German title**	**Year**
1	Renewable Energy Act 2017	Erneuerbare-Energien-Gesetz (EEG) 2017	2017
2	Tenant electricity law	Mieterstromgesetz (part of EEG)	2017, part of EEG
3	Revision of the market incentives programme of 2015	Novelle des Marktanreizprogramms (MAP) von 2015	2015
4	Coordinated regulation framework for the heat market	Abgestimmtes Regelungswerk für den Wärmemarkt (GebäudeEnergieGesetz, GEG – regulation still in progress)	Still in progress
5	Measures for electro-mobility, biofuels and railways	Maßnahmen Elektromobilität/Biokraftstoffe/Schienenverkehr (“Mobilitäts- und Kraftstoffstrategie der Bundesregierung”, MKS)	2013, frequently updated
6	Heat pump support	Wärmepumpen-förderung (part of MAP)	Part of MAP

Renewable energies are capital intensive investments with close to zero marginal costs. Thus, the costs of electricity hinge on the capital costs. Low capital costs have been facilitated by these support policies by ensuring that renewable energy operators receive secure revenue streams for their output – they still carry the volume risks, but not the power price risks. For wind power, the volume risk has also been largely mitigated through the *Referenzertragsmodell*, which increases payments for locations with unfavourable wind resources, enabling investments there, and which decreases windfall profits at locations with favourable wind resources. As a result, Germany has the lowest financing costs in Europe (Noothout et al, 2016).

With the introduction of the optional feed-in premium (FIP) schemes back in 2012, fixed tariff payments for new installations were phased out. With the revision of the Renewable Energy Law in 2014, all new RES plants became part of the FIP scheme and FIT was only granted to very small RES plants (BMWi, 2014).

The revision of the EEG in August 2014 mainly aimed at incentivising innovative technologies to enter the market with support by variable premium payments that top up the revenues from selling the electricity. In sum, renewable energy operators kept very high levels of certainty about their revenues since the premium payment is higher, the lower the revenues from selling the electricity. The major difference for operators is the obligation to sell the electricity themselves or through a service company and the resulting balancing responsibility. EEG 2014 and EEG 2017 introduced a shift to auctions for all technologies, and away from feed-in tariffs, thereby incentivizing cost-efficiency (BMWi, 2018a). In the case of new installations, the results of the first tenders indicate a cost reduction potential through technical progress and decreasing EEG remuneration rates.

Support for installed renewable energy plants rose from EUR 9.5 billion in 2010, over EUR 16.1 billion in 2012, to EUR 23.4 billion in 2017. In this case, ”support” is defined as the difference between EEG compensation payments to the operators of renewable energy plants and the income from the sale of the electricity from renewable energies on the electricity exchange (BMWi, 2018c). This development is mainly caused by a significant decrease in wholesale electricity prices. The annual average spot price fell from a peak of 76 €/MWh in 2008 to 32 €/MWh in 2015. According to Hirth

(2018), the expansion of renewable energy, the decline of the EU ETS price, the fall in fuel prices and the decreasing electricity demand have contributed largely to the price drop, whereas the post-Fukushima nuclear phase-out in 2011 and the increase in net exports were price-increasing elements.[38]

In general, the policy regime for renewable energy is changing drastically in Germany. Due to plummeting renewable energy technology costs which are approaching the costs of conventional technologies, the role of renewable energy policies has changed. In most liberalized power markets, prices are therefore hedged against volatile patterns via forward contracts, which lasts usually for 1-3 years. However, this time horizon does not necessarily apply to investments in PV and wind power, which are characterized by uncertain cost developments, by availability and cost of storage and by political choices in terms of grid expansion. In combination with uncertain CO2 prices and fuel costs, three-year contracts are not sufficient for PV and wind power. Renewable energy policies, therefore, need to shift their focus from driving down technology costs to keeping financing cost low and certain. One-sided sliding premium systems have been historically a suitable hedging instrument. However, they are less and less functioning as a financing instrument[39]. On the contrary, contracts for difference, are shown to do a better job and ensure that falling costs are passed to the end consumers (Neuhoff, May and Richstein, 2018).

Outlook and Link to Capital Raising Plans

The section above provides a first discussion of the role of the (evolving) policy regime and its impact on investments in renewable energy. Understanding and forecasting the dynamics of the policy framework also plays a crucial role in understanding investment needs and gaps, as discussed at length in this report. As already mentioned in section 5.1.6, policy measures need to address market failures and reinforce investment drivers to unfold the best possible effect.

The third stage of this project[40], therefore, needs to incorporate several perspectives, as investment barriers and drivers differ in terms of:

- Demand versus supply side of finance: project developers ("demand") vs. investors and financiers ("supply)
- Sectors (power, manufacturing, services, households, government)
- Scale of the investment
- Country context: a country's institutional setting and its implied regulatory uncertainty

Understanding this need for differentiation is crucial to develop effective CRPs. For the power and energy sector in particular, the energy policy framework needs to be understood including its effect on investment risk and financing costs (e.g., Neuhoff, May and Richstein, 2017).

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[38] See figure 8 in Hirth (2018) for a great graphical presentation on the contributing ten individual factors and their impact on declining electricity prices.

[39] Since wholesale prices are more likely to exceed the strike prices of the sliding premia. For more detailed information see Neuhoff, May and Richstein (2018).

[40] A reminder to the reader: 1) Climate and Energy Investment Maps (CEIM) & 2) Investment Need and Gap Analyses (INGA) -> 3) Capital Raising Plans (CRP).

The discussion of CRPs in CZ and LV will focus on this discussion in more detail, while building on the experience of the German situation presented in this report.

6. Discussion and Conclusions

6.1. Take-home Messages for the Assessment of Climate and Energy Investment Needs

The report has explored the case of Germany in order to illustrate what it takes to analyse and identify the investment needs in relation to national climate and energy targets. Building on existing studies, we explained how different models and modelling frameworks are structured, employed, and combined to finally derive estimates of investment needs. In particular, we have elaborated on the important underlying and often “invisible” assumptions and inputs that determine and alter outputs; in our case investment needs estimates.

Investment needs assessments are based on the building blocks identified and discussed in this report. A thorough understanding of the future overall activity of an economy, the related energy demand and supply, together with the cost of technologies that can enable the transition of the focal sectors of the economy is key to estimate the investment needs. As the review of relevant studies has shown, different scenarios and assumptions lead to different results.

In order to make the best use of the outputs of the models, it is important to understand what lies behind their numbers – what they do and do not represent. Instead of reiterating the above-stated discussion on sensitivities and assumptions, we provide the reader three important take-home messages:

Take-home message 1: Pay attention to assumptions! Estimates of investment needs depend on assumptions that are taken at different places in the analytical/modelling framework. Some are more important than others, some are more controversial than others and some may not be obvious in the face of the (necessarily) complex modelling framework required for sophisticated estimates.

Key assumptions are those related to factors that have a big impact on the final estimates (i.e., modelling outputs). These are for example price assumptions for fuel, carbon credits, technologies, model boundaries, macroeconomic expectations on economic growth, and size of population.

But even if we are aware of these assumptions and understand how they influence the modelling outputs, at least in terms of the direction (i.e. higher energy demand results, ceteris paribus, in higher investment needs) and order of magnitude, we have to make sure that we capture the second layer of variation that drives modelling outputs - namely the choice of scenarios![38]

Take-home message 2: Understand the scenarios used and especially what is and what is not included in the baseline! Make conscious choices about conducted scenarios – and when looking at investment needs, make sure you understand the policy scenario and in particular what is included in the baseline!

Using models for saying something about twenty-something years down the road requires not only the underlying “hidden” assumptions within the modelling framework, but also a comparison of alternative future pathways expressed in terms of scenarios, which are (or should be) coherent sets of assumptions about which question exactly we want to answer! Scenario analysis is hence suited to answer “what if” questions.

Even if the underlying assumptions about economic growth, population growth, and energy demand turn out to be realistic or are comparable with other studies, we need to make sure, when comparing investment needs assessments, to be aware of the following aspects:

- Different time frames are different things! (e.g., average annual investment up to 2030, either starting in 2010 or 2020)
- Different metrics: incremental cost, full cost, investments related to reducing total final energy demand or to greening energy supply
- Different sectoral scopes: renewable energy investments in the power sector or across all sectors, including heating or only electricity?
- And others…

Our analysis shows that the single biggest factor causing variation comes from the definition of the baseline scenario, as studies are always comparing scenarios against a counterfactual case which assumes certain political ambitions. What is more, investment cost estimates are (generally) stated as *additional* costs *on top* of the reference case.

Take-home-message 3: Climate and energy investments are no ends in themselves but are important means for reaching specific energy and climate policy objectives.

Policy targets for energy efficiency, energy consumption or GHG emission allow us to derive investment needs and gaps. Translating targets (and their corresponding gaps) into investment needs (and gaps) enhances our understanding of the required steps to achieve decarbonisation in the long run. This translation exercise can guide decision makers to the specific challenges in specific (sub-) sectors, the role of actors or technologies where the policy framework may need to be adjusted for investment barriers to be overcome, private capital expenditure to be stimulated, or investment drivers to be reinforced.

Currently, one crucial field of action for decision makers lies with the development of National Energy and Climate Plans (NECPs), where European Member States must report their climate and energy objectives and policies for the period 2021 to 2030.

6.2. Linking the Modelling Discussion to the Climate Policy Process And NECP

Why should the reader –policy makers and particularly decision makers in charge of developing and implementing NECPs - deal with models, modelling frameworks and even understand their limitations?

First of all, we have found the models presented in chapter 3-5 in all kind of economic analyses. We believe that readers of such studies should have a general understanding of the models when dealing with their overall results and recommendations.

Secondly, and even more importantly, this background know-how is crucial to manage complex transformation processes. In Europe, for instance, accomplishing the 2030/2050 CO2-targets would have a tremendous impact on the overall society with large structural effects on how we produce and consume energy, on how we produce and deliver goods and services, and finally on the way we organize our daily lives. The presented models in chapter 3-5 provide the reader with a flavour of how a carbon-neutral future may look like. It is therefore important to understand the structures and limitations of the models.

And thirdly, very hands-on, ministries in all EU member states are obliged to develop National Energy and Climate Plans (NECPs) until the end of 2019 to provide insights on their climate and energy policies for 2021-30 – and then implement them. It goes without saying that an understanding on forward-looking models and their limitations is a useful skill in drafting the NECP and in understanding the challenges ahead when member states move on to the implementation phase.

The NECPs are the new framework that consolidates many of the already existing workflows under different EU legislations across climate and energy policy fields. Countries are obliged to develop NECPs on a ten-year rolling basis with mandatory updates during the implementation period. The NECP which is due 2019, covers the period from 2021 to 2030 and addresses the EU's 2030 targets.

As the NECPs are standardized, chapter 5.3 of each national report has to address the investment needs required for the implementation of planned policies and measures[41]. For the purpose of, eventually, estimating these investment needs, primarily for a country's' own sake (and besides that, for reporting them to the European Commission), it will be important for those involved and charged with this task to have a sound understanding of the available (and suitable) analytical frameworks, as well as their key features and "what to pay attention to" when planning such an assessment, when commissioning respective studies or when, as a last step, interpreting modelling outputs provided to them.

So far, not much has been reported, as far as investment needs and chapter 5.3 of the NECPs are concerned. A quick review through the draft NECPs submitted to the European Commission at the end of 2018 shows that UK and Ireland already provided information on investment needs. UK provided a short list of investment pledges in the Clean Growth Strategy; Ireland made a small abstract on planned policy measures (without providing information on costs). Other countries (Germany, Austria, Netherlands, Sweden) promised to provide information in 2019[42].

This report does not solve this issue, it does not fill the reporting gap and it does also not miraculously enable everybody to assess the "2030 investment needs and gaps". But this thorough and structured review of the "German case" provides an excellent basis for starting the discussions and interactions with decision makers, desk officers, analysts, and stakeholders more generally about how to tackle this task and how governments (in particular) can be supported in this endeavour. Our project takes a modest start by working with CZ and LV as two EU member states. The next phase of this project will be focused on providing support to the relevant actors in these two countries to tackle the "2030 investment challenge".

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[41] For all draft NECPs submitted to the European Commission to date see: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union/national-energy-climate-plans

[42] Link to the German draft NECP: https://www.bmwi.de/Redaktion/DE/Downloads/E/entwurf-des-integrierten-nationalen-energie-und-klimaplans.pdf?__blob=publicationFile&v=8

6.3. Outlook - How to Take It from Here and Build on the Review to Strengthen Capacity and Provide Support to the Relevant Decision Makers and Stakeholders in CZ and LV?

The individual investment need figures presented in Table 4 (“*Studies investigating total ‘additional’ investment costs in relation to 2030 & 2050 GHG emission reduction targets*”) give the reader an impression on the transformational effect that climate targets for 2030 and 2050 will have on the society. It will be interesting to see the corresponding number for the Czech Republic and Latvia in the future.

However, comparing and assessing figures is not the main goal of this current EUKI-project. Transferring expertise and know-know on “how to do it” to partner countries, to jointly analyse different approaches and to find suitable models and frameworks for each specific setting is even more relevant. Output I of the EUKI proposal therefore defines:

“Skills for preparing and using the Climate and Energy Investment Maps (CEIM) and the Energy and Climate Investment Gap and Need Analyses (INGA) are developed in Latvia and Czechia based on CEIM and INGA prototypes for at least two sectors per country”.

Against this background, exchange among the partners has from the beginning been a core element of the project. As of end February 2019, three workshops haven been implemented - in Berlin (10/2018), Prague and Riga (02/2019). In Prague and Riga, we had participants from national Ministries that are currently developing the National Energy and Climate Plans in which investment needs are one important element. Other relevant participants from, for instance, the Environmental Ministries, Financing Institutions, and NGOs participated actively in the workshops.

In addition, monthly teleconferences on different topics have been organized (and will still be during 2019/2020) in order to transfer specific know-how to the Czech Technical University and to the Riga Technical University as our local implementing partners.

A modelling workshop relevant to understand and use technics to develop baseline-scenarios and deduct investment needs has been organized in Berlin on 15 March 2019 and experts from the Czech Republic and Latvia have participated.

Finally, it is our approach that the underlying study serves as a learning tool, and we intended to write the study as much as possible as the basis for what could be developed into a manual or textbook about “how to do INGAs”.

In the coming months, our task will be to build on this review and to provide support and develop training materials through training sessions, webinars, workshops and/or bilateral discussions and working sessions (prepared and executed together with our partner institutes, Technical University Riga and Prague University) for and with our target groups in CZ and LV.

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Annex 1 – Studies on Building Sector

Study	Subject Matter	Model	Scenarios	Sensitivities	Results
Fraunhofer IWES and Fraunhofer IBP (2017) – Heat Transition 2030 ***(not included in table of results)***	The role of energy efficiency, low-carbon district heating and local renewable energies to reach the 2030 targets; definition of minimum levels for key technologies that have to be reached by 2030 in order to reach the 2050 targets.	SCOPE	**Reference:** no classic BAU scenario **Target:** The target scenarios (80 and 95%) follow the principles for a Consensus on coal (developed by Agora Energiewende). Both are compared to define minimum levels of key technologies. Supplemented by deficit scenarios (see column "Sensitivities")	What happens if deficits in one technology must be offset by another one? - lower building insulation standards - lower share in e-mobility - less flexibility in electricity demand	- energy efficiency is key (therefore renovation of existing building stock) - 6 million heat pumps are needed by 2030 (which can offset deficits in energy efficiency) - minimum levels for key technologies
IFEU, Fraunhofer IEE and Consentec (2018) – Value of Energy Efficiency	The study shows how climate targets can be reached and highlights the role of building efficiency and its consequences on total economic costs. On top the study asks what needs to be done if	Flow of models(SCOPE; GEMOD; EXOGON; Heat Map)	**Reference:** No classic BAU scenario. Scenario "Efficiency" is the reference case. However, scenario BAU+Power-to-Gas is a BAU case in which the	- Efficiency is the report's variable of interest. The reference case is supplemented by scenarios with lower efficiency but higher focus on a) renewables,	- Value of efficiency = THE key driver to keep climate targets after 2030 achievable and to allow for openness towards other technologies

	deficits in building insulation appear.		climate targets are reached by PTG imports. **Target:** All scenarios are target achievement scenarios. They assume a -87.5% GHG reduction by 2050, with -55% by 2030 as an important sub-target.	b) heat pumps, c) power-to-gas - Sensitivity analysis on discount rate & Power-to-Gas price	- annual cost differences compared to reference: -3 billion € (scenario b) to + 7 billion € (scenario d)
DENA (2017)	Study is part of dena Leitstudie (add reference). How can the transformation of the building sector happen as an interaction of building insulation, systems technology (“Anlagentechnik”) and scaling of renewables? Energy demand from industry and transport comes from other studies.	Exogenous bottom-up modeling of the bulding sector; DIMENSION+ model to optimize electricity supply	**Reference:** Classic BAU scenario. Forecasting of current trends. **Target:** 80 and 95% targets are considered. Each is achieved by an *electrification* or *technology mix* pathway.	No specific calculations on sensitivities. But capital costs on building envelopes and plant engineering are key drivers of the costs.	- reduction in final energy demand of the building sector by 2050 compared to 2015: a) –43%, b) - 73%, c) -57% - Additional investment costs per annum compared to reference: 17 – 30 billion €, see table of results.
IFEU and Beuth Hochschule (2017)	Model-based, spatially resolved quantification of the *potentials* of renewable heating technologies in the building sector. After	Combination of HeatMap & GEMOD	**Reference:** Study focuses on potentials of renewable energies. Hence, no typical BAU case is stated.	No specific calculations on sensitivities in terms of investment costs. However, sensitivities can be extracted comparing both	- Final Energy Demand building sector: a) -76 %, b) -83,7 % by 2050; - Additional annual costs (building envelopes &

	conducting single potentials, possible (efficient) interactions are analyzed.		**Target:** No cost-minimizing target-achievement scenario. Aim is the maximum expansion of renewables given the derived potentials with a) conventional efficiency (e.g. slow increases in u value) and b) maximal efficiency ambition (e.g. more demolition and new construction)	scenarios: - High influence of building efficiency when renewable are scaled. - Lower efficiency cannot be offset by increased use of renewables	plant engineering): see table of results.
IFEU et al (2015)	Investigation of possible transformation paths to achieve an almost decarbonized building stock by 2050.	BEAM (Built-Environment Analysis Model)	**Reference:** Assumes an "increase in dynamics" and is therefore more ambitious than other BAU cases. **Target:** The target is a 80% reduction in the building sector's non-renewable energy demand by 2050. Four pathways are considered, combining two different levels on building envelopes and a focus on either heat or electricity ("Efficiency	Specific calculations: -> high influence of interest rates on economic viability of renovation measures -> even higher influence of assumed remediation costs on investment volume -> Changes in discount rate can influence annual costs with up to 14 bn €. -> higher energy prices until 2030 lead to +/- 6	- Heating Demand - Total Final Energy Demand; - Investment costs are significantly higher in all *Efficiency* scenarios compared to the trend. However, total annual costs are very similar across all scenarios (reference case included). - Total Annual costs between: 128-135 bn €/year - A neat comparison

			plus RE-heat/Power & High-efficiency plus RE-heat/Power”)	bn € energy costs per year	with other studies (section 5.4)
BMWI (2017)	Transformation process of the entire economy. Focus on (cost-efficient) power sector. Nevertheless, other sectors have to be illustrated as well. Central question: What does the energy transition cost?	Variety of models; *Invert EE* for space heating & warm water	**Reference:** No classic BAU approach. Assuming a termination of the German *Energiewende*. Hence, a scenario without policy intervention. **Target:** 80% GHG reduction through a cost-efficient approach.	Reduction in interest rate with significant effects (a decrease from 7 to 3% would halve the net additional costs);	Net additional costs in terms of annual investment needs are stated. In year 2050: 12 bn €/yr (15 bn € fixed costs, 3 bn € energy savings); lower differences in previous years) [stated in report 3, table 41].
BMWi (2015)	Germany’s strategy paper to reach the building sector targets. Development of measurements to fill the gap between current developments and 2050 sectoral targets.	Micro-simulation model by IWU; Prognos model	**Reference:** BAU approach with modest increases in renovation rate and other parameters. **Target:** Target scenarios “Energy Efficiency” and “Renewable Energies”.	No specific calculations on sensitivities.	- Investment costs stated in table of results.

Annex 2 – Models on Building Sector

ID	Institutes	Model and description	Inputs (data)	Output	Questions that can be answered	Sensitivities
1	IFEU (link)	Heat Map is a bottom-up model that classifies buildings in the residential, non-residential and industry sectors according to fine-scale spatio-temporal analysis of heat demand forecasts against local heat resources	- individual buildings 3D building models - type of energy used - age structure of buildings - site-specific climate data - linked with heat consumption calculations from GEMOD.	- energy classification and spatial distribution of all residential and non-residential buildings in Germany	- Heat source potential of specific territories - potential of low-carbon heat technologies (geothermal energy, solar energy, industrial and commercial waste, thermal storage) - Spatial development strategies	- availability of heat resources in the territory
2	IFEU (link)	GEMOD building model allows to calculate energy consumption for space heating and hot water in buildings. Energy needs are calculated through a bottom-up approach and calibrated top-down to the statistical final energy demand.	- insulation levels or U-values of buildings components, - current renovation conditions - heat and hot water supply technologies stock - building demolition or new construction - climate change	- future energy consumption for space heating and hot water in buildings - related greenhouse gas emissions and fuel costs. - replacement cycles and timeframe for energy renovations - related investment costs	- efficiency potential (climate mitigation potential) of buildings insulation, heating and equipment - consequences of energy efficiency or renewable policies for the sector - material flows necessary for building restructurings (data input for lifecycle assessments) - impact of efficiency measures on climate targets	- renovations rate and constructions rate - cost of materials and technologies installed

			- detailed buildings classifications: 234 building types (age, type of use and geometry)	- related material flows		
3	IFEU (Link)	EMOD domestic electricity model	- appliances, related efficiency and use patterns - building insulation - hot water consumption - storage volume of heat and electricity storage - type of heat pump - tax strategies for heat generation - electric vehicles and use pattern	- electricity consumption in households, - electricity generation potential (photovoltaics and cogeneration units) - related consequences of self-generated electricity for infeed	- simulation of electricity consumption of households, - estimation of sector coupling potential - estimation of DER integration potential - analysis the potential of energy sufficiency and/or energy efficiency measures - impact of sufficiency and efficiency measures, and DER integration on climate targets	- DER installation rates - learning curves - tax incentives - electricity price (consumption savings and trading revenues)

4	Institut Wohnen und Umwelt (IWU) – the institute for housing and environment (link)	Energy balance model is a top-down model based on statistical data and a seasonal energy balance approach	- insulation levels or U-values of components of six synthetical average buildings: two types of buildings (SFH, MFH) and three construction year classes and related energy savings	- primary energy consumption of non-renewable energy sources in residential building stock - primary energy consumption after application of energy saving measures	- modelling and monitoring refurbishment processes - primary energy consumption after application of energy saving measures - impact of energy savings measures on climate targets	- methodology of synthesis/ grouping of different building categories
5	TU Wien and Fraunhofer ISI (link)	Invert/EE-Lab model is an agent-based optimization model that models residential and non-residential buildings owners renovation decisions. The choice between refurbishment technologies is modeled through a logit approach combined with logistic diffusion curve models	- building stock data, - space heating and hot water technologies information, - shading systems efficiency, - ventilation systems efficiency - U-values of building shell - refurbishment technologies information	- Installation of heating and hot water systems by energy carrier and technology -Refurbishment measures - energy demand by energy carriers and building categories - On-Site generation of renewable energy - Total investments (M€)	- simulate the scenarios of building stock development and its energy demand in the EU-28 up to 2030/2050/2080 - test the effect of policy instruments on renovation investment decisions and related costs	- information on investment costs - service lifetime - technological learning curves - energy prices

6	Fraunhofer ISI (link)	FORECAST is a bottom-up simulation (not optimization) model with four individual modules (namely, industry, services, residential and others (i.e. agriculture, transport)).	- weather - energy balances, employment, value added or energy prices - energy efficiency policies - buildings and heating system technologies available and related stock	- appliance specific annual demand projections - energy efficiency potential - cost of energy efficient measures	- modelling investment decisions and replacement of assets stock considering their age distribution - modelling of energy-efficiency policies - modelling of diffusion of technologies	- energy prices - activity of assets to replace - technology efficiency
7	Fraunhofer ISI (link)	eLoad is a mixed-integer optimisation the model which allows to estimate the evolution of electricity load curves on the basis of appliance specific load profiles (bottom-up) and annual demand projections (FORECAST)	- annual demand projections (FORECAST) - historic load curves - temperature time series - demand response parameters i.e. electric vehicles and storage heaters potential	- hourly load profiles resulting from FORECAST - load flexibility and demand response potential - cost-optimal load shifting activities	- transformation of the load curve after structural changes and the introduction of new appliances on the demand side - least cost scheduling of appliances that allows to smooth the net load	- annual demand in the base year according to which specific appliances load curves can be generated for the base year
8	EWI (link)	COMODO model is a behavioral optimization model of consumers decision-making on heating and electricity	- consumers' preferences - consumers' characteristics	- distributed generation technologies in the	- energy supply optimization according to consumers classes - analysis of DERs potential and deployment roadmaps	- electricity price

		technologies and efficiency measures, allowing to identify optimal solutions for individual consumer classes and insights into the potential of DERs and their temporal/spatial diffusion	- information on DERs options	residential, tertiary and industry sectors. - temporal and spatial diffusion processes of distributed generation	- effect of policy incentives on the diffusion of DERs	- optimization behavior of consumers - technology costs
9	Enerdata (energy intelligence and consulting company)	Spatial agent-based model (homeowners multistage decision-making regarding insulation)	- homeowners characteristics - insulation activity indicators	- homeowners insulation activity - Energy consumption per household		

Annex 3 – Studies on Energy Sector

Study	Subject Matter	Model	Scenarios	Sensitivities	Results
BDI	Investigating the "gap" between development under current conditions and the government's climate protection targets. Results are derived from an intensive bottom-up process.	Bottom-Up Cost Derivation; use of several Prognos models	**Target:** Global climate protection vs. national efforts; each for the 80 and 95% reduction **Reference:** continuation of historical trends and current developments (-> -61 % by 2050)	- Increase in fuel prices	Sector-by-Sector Analysis (Industry, Transport, Agriculture, Households, Power Sector)
IRENA (2015)	Report as part of the REmap 2030 program. It aims to close the gap between national climate plans and the potentials of renewable energies. It also highlights where the German *Energiewende* can be expanded.	Remap 2030 methodology (drawing on data from other studies)	**Reference:** Germany's plans as of mid-2014. **REmap 2030:** aims to determine the feasible potential of renewables.	None	Potential share of renewables in TFEC; Additional annual investment costs compared to the reference case
GWS et al (2018)	A (macro) economic analysis of the energy transition since 2000 to take investments since the implementation of the *EEG* (German	Bottom-Up cost derivation; PANTA RHEI for macroeconomic analysis	**Reference:** A contrafactual scenario, assuming that no policy intervention happened since 2000 and will	Energy transition only driven by a) the electricity sector (e.g. scaling of renewables, nuclear exit etc.)	- Overall economic and sectoral effects - positive economic effects through the energy transition: in

	Renewable Energy Sources Act) into account.		neither happen in the future. **Target:** *Energy transition scenario* – assumes GHG reduction of 80-85%.	b) energy efficiency & renewables by consumption sectors. → sensitivity a) with smaller impacts than b). Plus, calculations with restrictions on capital and labour markets → Germany benefits from very good overall economic situation.	2050 the GDP is 4% higher compared to the contrafactual scenario - see Table 8 for investment needs of the energy sector
BMWi (2014) ***(not included in table of results)***	Forecast of the probable development of the energy industry by 2030, including a forecast till 2050. On top, it entails a target scenario and sensitivity calculations.	Bottom-Up modelling and variety of models for different sectors; PANTA RHEI for overall economy and scenarios	**Reference:** Probable development until 2030, assuming intensification of policy efforts. Extrapolation until 2050. Achieves 65% of GHG reduction. **Target:** 80% reduction target is achieved.	+/- costs for renewable technologies; +/- costs on fuel markets; increased international climate protection efforts (= sensitivity with highest influence on results: reduction of GHG emissions by further 7%);	- No specific results for the energy sector. - Additional investment needs for Industry, Households, Commerce and Services. - Overall economic effects.
Prognos et al (2018)	Analyses of approaches with which sectoral target can be achieved by 2030. The *Klimaschutzplan 2050* is especially considered.	Cost-Benefit Analysis with tool from UBA	**Reference:** Scenario with further measurements (*Mit-Maßnahmen-Szenario)* based on *Projektionsbericht 2017* (BMU, 2017) leads to a	- +/- fossil fuel prices;	

			GHG reduction of 35% by 2030. **Target:** *Energy Efficiency* vs. *Scaling of Renewables*		

Annex 4 – Models on Energy Sector

ID	Institutes	Model and description	Inputs (data)	Output	Questions that can be answered	Sensitivities
1	Fraunhofer ISI (link)	FORECAST bottom-up energy demand model (industry, tertiary, buildings and other sectors) which follows a simulation approach.	- demand-side technologies (logit function of penetration of technologies + vintage stock approach) - socioeconomic trends - weather - energy efficiency policies	- appliance specific hourly load profiles - annual demand projections	- efficiency potential (climate mitigation potential) of buildings insulation, heating and equipment - consequences of energy efficiency or renewable policies for the sector - material flows necessary for building restructurings (data input for lifecycle assessments) - impact of efficiency measures on climate targets	- renovations rate and constructions rate - cost of materials and technologies installed
2	Fraunhofer ISI (link)	eLOAD	- hourly load profiles of appliances and annual demand	- transformation of the load curve (peak load, load	- transformation of the load curve and resulting decisions about power plants	- availability and cost of demand

		optimization model for the estimation of long-term evolution of electricity system load curves.	projections from the FORECAST model	levels, load ramp) over time - active adjustment of load curve (demand response technologies)	investments and decommissioning - potential effect of demand response technologies (electric vehicles or storage heaters) on electricity markets	response technologies - expected demand-side activity
3	TU Dresden (link)	ELTRAMOD Bottom-up electricity market model that studies the effect of supply and demand changes over time on the energy market	- electricity prices - transmission grid capacity - RE technologies learning curves - flexibility capacities	- investments into RE technologies and flexibility options - dispatch of RE technologies	- changes in consumption loads according to electricity price signals. - investments into RE and flexibility technologies according to different scenarios - impact of market integration of technologies deployment on the energy system.	- learning curves - policy assumptions
4	KIT-IIP (link)	PowerACE Agent-based bottom-up simulation model for wholesale electricity markets. It contains also an	- Electricity market designs (energy-only-market,	- Power plant investment decisions	- Impact of different market designs options and policy measures on	

		investment planning module (and different criteria e.g. NPV)	strategic reserve, capacity markets) - low-carbon technologies (including flexibility options) - main generation assets	- Day-ahead electricity market prices - Forward market prices - profitability of different investment options	investments in low-carbon technologies - Potential of market coupling	
5	Digsilent (link)	PowerFactory Power grid model including different types of electrical networks	- energy production values - load profiles	- System reliability and security - Analysis of power generation components - Load flow Analysis - Network Analysis - Optimal power flow	- Study of different scenarios for the generation, transmission, distribution of electricity - Integration of RE into distribution, transmission and industrial networks. - System reliability and security after the introduction of nondispatchable energy resources	
6	Energy Exemplar (link)	PLEXOS	-	- power transmission - demand forecasts	- Capacity expansion planning	

		Integrated set of power market, grid and power system models with high temporal resolution		- grid reliability	- Power market analysis - Future power market design	
7	link	LEAP Tool for energy system (medium- to long-term) modeling that supports bottom-up, end-use accounting techniques to top-down macroeconomic modeling.	- energy and environmental costs - historical energy related data	- tracking of energy consumption, production and resources extraction - energy sector GHG emissions	- evaluation of alternative policies, social costs and benefits under different scenarios	
8	IIASA (link)	MESSAGE Modeling framework for medium to long-term energy system planning. It allows for the integration of energy supply, demand and end-use analysis, and both top-down and bottom-up analytical representations	- energy production technologies and substitution potential - technologies costs -	- utilization of energy resources - energy imports/exports and monetary flows - energy production conversion (substitution) technologies - investment costs	- energy system planning - development of technology strategies and investment portfolios to meet climate and energy targets	
9	EWI (link)	DIMENSION+ European power markets simulation model. It allows to estimate investment needs using a cost-	- granular details on electricity, gas and heat networks	- forecasts for the energy markets	- energy prices forecasts - power plants evaluation and	-

		minizing framework for energy system planning.			investments decisions - energy markets regulation and grids expansion decisions - long term scenarios analyses, including demand-side management and batteries deployment	