Commit to Connect 2050

A target scenario for the renewable energy system in eastern Germany

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Commit to Connect 2050
Zielbild Energieinfrastrukturen für Ostdeutschland
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A joint project of Avacon AG, BALANCE VNG Bioenergie GmbH, DREWAG NETZ GmbH / ENSO NETZ GmbH, E.DIS Netz GmbH, ENERTRAG AG, EWE NETZ GmbH, GASAG AG / NBB Netzgesellschaft Berlin-Brandenburg mbH & Co. KG, HanseGas GmbH, inetz GmbH, Mitteldeutsche Netzgesellschaft Gas mbH, ONTRAS Gastransport GmbH, Stadtwerke Lutherstadt Wittenberg GmbH, TEN Thüringer Energienetze GmbH & Co. KG /TEAG Thüringer Energie AG, VNG Gasspeicher GmbH

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1 Commit to Connect 2050 – FOREWORD FROM THE PARTNERS

Issue: A target scenario for the renewable energy system in eastern Germany in 2050

As a community of fourteen energy companies from eastern Germany, we have observed the change in the energy industry for some time now and determined that there is no master plan. The measures for implementing the Energy Transition have not yet been able to optimally integrate the various sources of energy into one system. However, instead of continuing to develop energy sources individually, what is required is a cross-sectoral perspective combined with networking.

That is why we have launched the "Commit to Connect 2050" (CtC2050) project and committed ourselves to a joint analysis of our energy system across all sources of energy. In particular, we aim to answer the key climate and energy policy question for our region: What is the economically optimised target scenario for a completely decarbonised energy system in eastern Germany in 2050?[1]

Reason: Decarbonisation at minimum economic cost

The reasons why we wanted to find an answer to this question are obvious: We are all aware of the dangers of unchecked climate change and the necessity of achieving climate neutrality for our region by the year 2050. At the same time, we still operate energy technology plants based, among other things, on fossil fuels. It is thus a fundamental challenge for us to determine which technologies for energy supply and use will prevail by 2050 from an economic point of view and which types of networks will transport this energy. With this knowledge we can then determine how we need to transform our assets at the lowest possible societal cost by 2050 in order to be able to guarantee security of supply at all times, even in the face of the climate-neutrality target for 2050. We do not want to wait passively for the energy transformation, but rather see ourselves as proactively shaping the future of energy supply.

CtC2050 Partners: Community of 14 energy companies

We represent different lines of business and various stages of the supply chain: Transmission and distribution grids, energy generation and storage. Together the CtC2050 Partners own and operate an electricity grid of 280,391 km in length, a 94,417 km gas grid, a gas storage volume of almost 2 billion cubic metres, and supply approximately four million MWh of district heating. Already today, we feed about 50 million MWh of renewable electricity from wind and solar power generation into the grids. A total of 82 biomethane production facilities and one hydrogen production facility feed into our gas grids.

1 The term "decarbonised" is understood in this context to mean based on carbon-free energy and climate-neutral, non-fossil carbons. The target scenario of Commit to Connect 2050 is thus based entirely on renewable energy.

Method: Innovative modelling open to results and technology

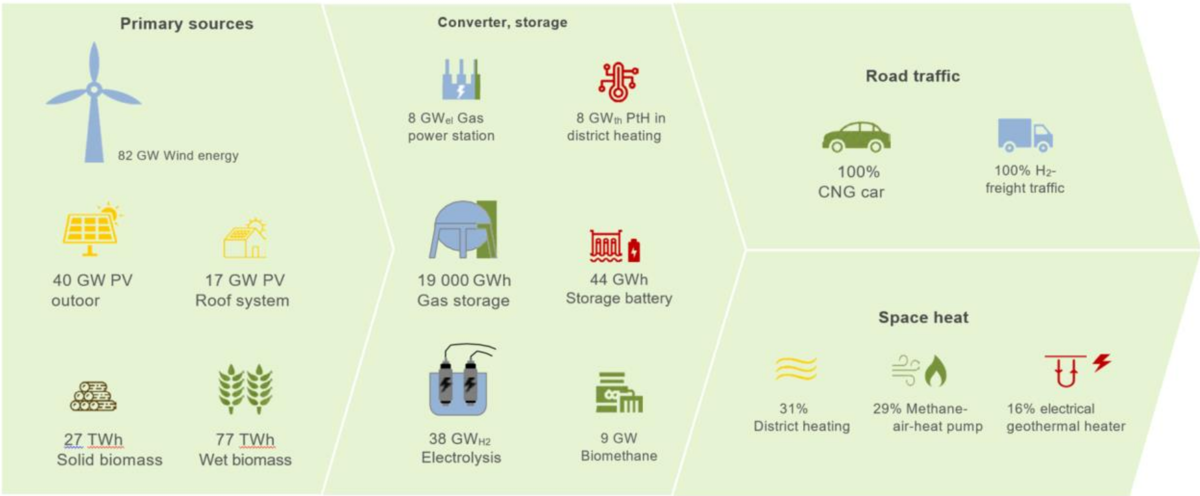
In order to calculate such a target for our region, an innovative method is required that provides us with a clear target scenario, independent of fluctuations in the political framework. The general criteria for the target scenario are climate neutrality, security of supply and economic cost optimisation. Based on these criteria, our calculations are technology neutral and without predefined goals.

For this calculation we also regard eastern Germany as an independent, self-sufficient energy system. This approach allows us to look at what is actually feasible in our region and ignores unreliable forecasts with regard to developments in the energy industry in other parts of Germany and the world. Nevertheless, eastern Germany will of course always be integrated into the flows of national and international energy in the future. If the Energy Transition develops positively elsewhere, the decarbonisation of our region will be all the easier in the long term.

In addition, we have also chosen not to take existing energy technology plants into consideration when calculating the target scenario. Thus we are able to provide the target scenario with immunity against short-term policy decisions. After all, investments in new technologies and the depreciation of existing plants change on an almost daily basis – often driven by politics. Only by basing our calculations on the premise of re-establishing the optimum future energy system is it possible to develop an unbiased target scenario that will be valid even beyond the politically chosen target date of 2050. Existing long-term assets can, of course, continue to be used with this approach – as long as this proves to be economically viable as a means of achieving the target scenario.

The final innovation lies in regionalisation. The project was carried out with the support of fourteen partner companies throughout eastern Germany. The calculation was also carried out for nineteen sub-regions, which together cover the whole of eastern Germany and are connected via energy transmission networks. Thus, energy production and consumption as well as energy transmission in and between the sub-regions of eastern Germany are optimally determined in the target scenario, sub-region by sub-region. As examples, three spotlights in this report provide information on the sub-regional configuration of the target scenario at the locations of today’s lignite production and brown coal conversion in Brandenburg and Saxony.

Overview: The optimum decarbonised energy system for eastern Germany in the year 2050



Source: Wagner & Elbling GmbH, Icons made by Freepik, Smashicons, Pixel perfect, Iconnice, OCHA, Ctrlastudio, Hand Drawn Goods, DinosoftLabs from www.flaticon.com

Key results

On the basis of these specifications and with the aid of a highly developed energy-efficient modelling tool, Wagner, Elbling & Company calculated a correspondingly objective target scenario. The calculation does not represent an ideal desired by the project partners, but instead was carried out free from particular scenarios or political specifications. The only influences on the modelling were the premises of security of supply, decarbonisation and minimum costs as well as the input data.

The key results are:

1. A decarbonised energy system in eastern Germany causes costs comparable to those of the current real energy system, despite new construction and self-sufficiency. In absolute figures such a system costs only slightly more per year at around EUR 53 billion, compared with approximately EUR 50 billion today.
2. The future energy system requires a comparable surface area for energy production – approximately 12-15% of the land area of eastern Germany.
3. Large scale but nonetheless feasible infrastructure investments are required in eastern Germany in order to implement the target scenario – above all, in plants for electricity generation, electrolysis and biomethane injection, as well as in electricity and hydrogen networks.
4. The target scenario represents an energy mix that is completely renewable in which electricity, gases and district heating continue to be required with similar peak capacity to today when it comes to final consumption. Natural gas will be completely replaced by biomethane and renewable hydrogen.
5. The technology-neutral approach of the target scenario is much more favourable than variants that simply give preference to certain technologies. For example, a system without final gas distribution calculated for the purpose of comparison carries additional costs of approximately

EUR 9 billion per year. If gas grids and gas storage facilities are dispensed with entirely, then additional costs amounting to EUR 19 billion per year are incurred.

6. In the model decarbonisation without imports is theoretically feasible, so that approximately EUR 13.6 billion per year in imports of fossil fuels will no longer be needed in future, thus offering great potential for investment in eastern Germany.
7. Decarbonisation of space heating is achieved in the target scenario through a variety of technologies and its individual design depends on the respective population density. There is a fundamental shift towards more district heating, gas-fired heat pumps and electric geothermal heat pumps.
8. In terms of mobility, no drive train is superior to any other. A sensitivity calculation for the results in the target scenario makes it clear that the mobility sector must be considered as flexible in terms of technology if decarbonisation is to be economically efficient. In the target scenario itself, compressed natural gas (CNG) engines are the only drive technology for the passenger car sector. When it comes to commercial transport, vehicles with pressurised hydrogen tanks and fuel cell drive systems are prevalent.
9. As far as process heat is concerned, there is a shift towards hydrogen and electricity at the expense of methane.
10. An optimised, decarbonised energy system requires essential infrastructures for electricity, methane, hydrogen and heat. The target scenario means massive changes with regard to all sources of energy.

Importance for Energy Sources

In detail, these overall results have the following impact on the respective sources of energy:

Electricity

The electricity industry will face an extensive transformation in order to achieve the target scenario. Primary electricity production is completely renewable – 80% from wind energy and 20% from solar energy. For wind energy capacities, this means no less than a fourfold increase of current capacities to 82 GW, and for solar power capacities a fivefold increase to 57 GW.

The electricity system will be regionally regulated, especially with the help of chemical energy sources. Electricity that is not directly consumed will be converted into hydrogen via electrolysers close to the production process and fed to gas storage facilities. Positive residual loads ("electricity shortage") will in large part be compensated by means of gas-fired power plants. Pumped storage and batteries are increasingly used, but to a much lesser extent than gaseous storage.

In electricity applications, the generation of heat become increasingly important. For example, there will be a tenfold increase in the capacity of electric geothermal heat pumps for space heating. Overall, however, the peak load in final electricity consumption will hardly change due to increasing energy efficiency. Nevertheless, the regional power grids will have to be significantly expanded in order to accommodate the massive increase in renewable electric power generation in almost all sub-regions of eastern Germany.

Hydrogen

In the target scenario, hydrogen is the decisive transport medium for energy transmission between the various sub-regions. Often the most economical solution is to transport hydrogen between the different sub-regions and to use it at the point of delivery.

In total, 38 GW of electrolysis plants will be used to convert approximately 60% of primary electricity production into 130 TWh of hydrogen. Approximately 65% of this figure goes into end consumption.

Hydrogen becomes the dominant energy carrier backing up the electricity system, among other things because of its cost-effective, long-term or seasonal storage capacity. For end use applications, hydrogen will become prevalent above all in commercial transport in the form of vehicles with pressurised hydrogen tanks and fuel cell propulsion. It will also play a major role in the generation of process heat. The model clearly shows that a ban on hydrogen in the energy system would result in additional costs of 6.4 billion or 13% per year.

Although the inclusion of hydrogen results in increasing costs for gas networks and gas storage facilities, the massive use of electrolysis plants (power-to-gas) as a link between the sectors and infrastructures makes it possible to achieve climate neutrality in a cost-efficient and safe manner.

Methane

For the gas industry, the target scenario means massive restructuring. All imports of natural gas will be eliminated. These will be more than replaced by large-volume production of biomethane and hydrogen in eastern Germany, amounting to around 200 TWh – more than 50% of the total primary energy input in 2050.

With a share of approximately 20% of primary energy production, biomethane is of elementary importance in the target scenario – principally due to its reliable production capacity. Nevertheless, the surface area available for the cultivation of biomass that is used for energy is hardly increases at all as biodiesel and the generation of electricity from biogas are displaced. Instead of generating electricity from biogas "on site", processing into biomethane and injection into the grid will take precedent on a large scale. Approximately 9 GW of biomethane will be produced and transported in eastern Germany.

The methane end applications also undergo extensive transformation. In space heating, gas-fired condensing boilers are no longer needed, while gas-fired heat pumps play a very important role. When it comes to process heat the role of methane is in significant decline, but its use in CNG passenger cars creates an important new field of application for methane in mobility.

Methane networks will therefore continue to be needed in future. However, an additionally calculated "blended gas" scenario shows that blended networks (methane/hydrogen) are also a relevant option, especially if this results in a simpler transition toward climate neutrality for consumers and for the gas industry.

District Heating

The target scenario sees a significant 30% growth for district heating in relation to its share of the market for space heating. District heating grids thus contribute to decarbonisation of the building sector, especially in high-density areas and particularly in cities.

However, the volume and output of district heating diminishes due to increasing energy efficiency and the declining market share of district heating in the process heating sector.

The generation of district heating is changes completely, away from combined heat and power plants and towards electricity-based generation with large-scale thermal pumps and electrode boilers.

2 SYNOPSIS

2.1 THE PROJECT COMMIT TO CONNECT 2050

A completely decarbonised energy system for eastern Germany in 2050 is

- **feasible without energy imports** (if politically desired or necessary),
- **consumes less energy than today, but more gaseous energy sources and**
- **will cost a smaller share of economic output in eastern Germany than the current energy system.**

The use of fossil fuels is not necessary. All of the gaseous energy carriers can be renewably produced in eastern Germany in the form of green methane or green hydrogen. This is a clear finding of the Commit to Connect 2050 ("CtC 2050") project, which was carried out from summer 2018 to autumn 2019 by 14 energy companies[2] from various sectors[3] in eastern Germany together with Wagner, Elbling & Company, Vienna.

The main objective of the project was to clarify the question as to what the energy system in eastern Germany[4] should look like given the best case scenario if transformation of the energy system is completed with 100% decarbonisation. **This optimal decarbonised energy system was determined for the year 2050 in a manner that was neutral to both results and technology ("Target Scenario$_{2050}$").**

The project aim was achieved on the basis of extensive, optimising energy-efficient modelling. Of the many different scenarios considered, all of which ensured security of supply, feasibility and CO_2-neutrality in 2050, the modelling identified the option with the lowest societal costs. As a secondary aim of the project, this optimal energy system was subsequently compared with other conceivable, but not technology-neutral, designs of the eastern German energy system as well as with the current energy system in eastern Germany.

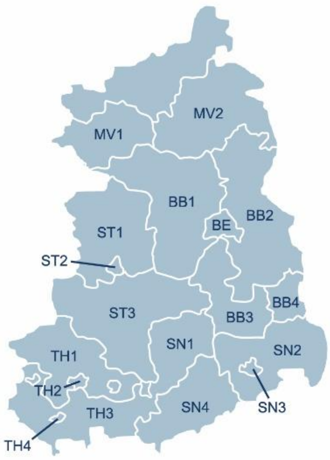
The project work included numerous intercompany working groups and was supported by Wagner, Elbling & Company of Vienna with their highly developed energy-efficient model WALERIE and the provision of extensive input data for the calculations.

The project was carried out with a high degree of methodological stringency and depth of detail in order to create a significant and reliable contribution to existing knowledge and regionally applicable results. Among others things, this was achieved through:

- Mapping of the **entire output chain** of the energy industry from primary production to distribution grids and **including all standardised end user systems capable of being modelled** (motor vehicles, space heat generators …).

2 Or corporate groups
3 Cf. Subclause 4.1
4 Berlin, Brandenburg, Mecklenburg-West Pomerania, Saxony, Saxony-Anhalt and Thuringia

- Representation of **all energy-consuming sectors** (space and process heat, mobility, material use, power/light/...).
- Representation of **all energy carriers** (electricity, methane, hydrogen, biomasses, liquid fuels, district heating ...).
- **Fully integrated (holistic) optimisation of the entire energy system**. Not only was the energy supply system (production, conversion, storage, networks) optimally designed, but at the same time the optimal technological equipment on the end user side was also calculated (for example, the optimal space heating and mobility technologies within the overall context of the energy system).
- **Simultaneous regionalised calculation of 19 sub-regions** ("regional clusters") of eastern Germany (see figure on the right), for which
    - an optimal energy system was calculated *at the same time* as
    - *simultaneous* modelling of the optimal energy exchange (electricity, methane, hydrogen) with neighbouring sub-regions as well.
    - As a result, a well-balanced **picture of the optimal future transmission network capacities for methane, hydrogen and electricity in eastern Germany** was created.



Regional Cluster in the project CtC 2050

- **Consideration of an extensive range of technologies.** About 100 technology decisions (optimal capacity per technology) were made for each regional cluster. In addition, use of all controllable technologies (e.g. energy storage) was optimally determined.
- **Modelling based on the creation of the optimal future energy system.** The target scenario thus shows a permanently optimum scenario for the decarbonised energy system in eastern Germany that remains valid independently of the remaining life span of existing energy technology plants.
- **Extensive data research and coordination** through evaluation of more than 200 data sources to derive the input data for the calculations. The input data were validated in detail in numerous workshops with experts from CtC partner companies.

The findings of Commit to Connect 2050 are extremely varied and are summarised in the following subsections.

2.2 TARGET SCENARIO $_{2050}$ – OPTIMAL ENERGY SYSTEM $_{2050}$ FOR EASTERN GERMANY (INCLUDING MAJOR DIFFERENCES TO THE CURRENT ENERGY SYSTEM)

I. Costs of the Decarbonised Energy System

The energy system in eastern Germany currently generates economic costs of approximately EUR 50 billion per year. The minimum cost, completely decarbonised, secure energy system in eastern Germany in 2050 (Target Scenario$_{2050}$) will generate comparable costs of approximately EUR 53 billion[5] per year. The low additional costs of approximately 5% are contrasted with eastern Germany's economic output in 2050, which is expected to grow by more than 5% compared with that of today. This means that the optimum decarbonised energy system of eastern Germany in 2050 will cost a smaller share of eastern Germany's economic output than the present energy system in eastern Germany.

The most significant difference (today versus 2050) in the composition of the annual costs of the energy system in eastern Germany lies in substantial reduction in the use of raw materials. In particular, approximately EUR 14 billion per year in imports of fossil energy to eastern Germany are then no longer required. In contrast, there is a substantial increase in the costs of energy installations in eastern Germany; these are in the main capital expenditures. If the production of these plants can be established or at least partially retained in eastern Germany, imports can be substituted by domestic value chains.

II. Overview Graphics of Target Scenario$_{2050}$

The following graphics provide an initial overview of the essential structural data of the optimal energy system in the Target Scenario$_{2050}$ (which will be explained in the following sections).

Source: Wagner & Elbling GmbH, Icons made by Freepik, Smashicons, Pixel perfect, Iconnice, OCHA, Ctrlastudio, Hand Drawn Goods, DinosoftLabs from www.flaticon.com

Figure 2.2-1: Structural data (extract) on capacities and raw materials in eastern Germany in the Optimal Energy System$_{2050}$

5 In real money "today" (i.e. without taking the nominal depreciation of money into consideration, but taking expected cost degressions into account)

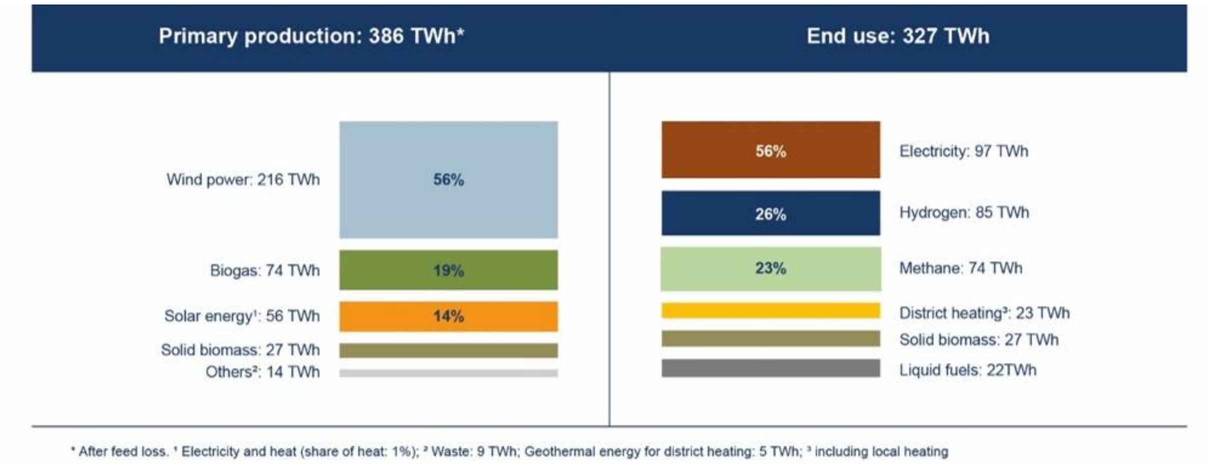


Figure 2.2-2: Primary production and final consumption of energy in the optimal Energy System$_{2050}$ in eastern Germany [TWh]

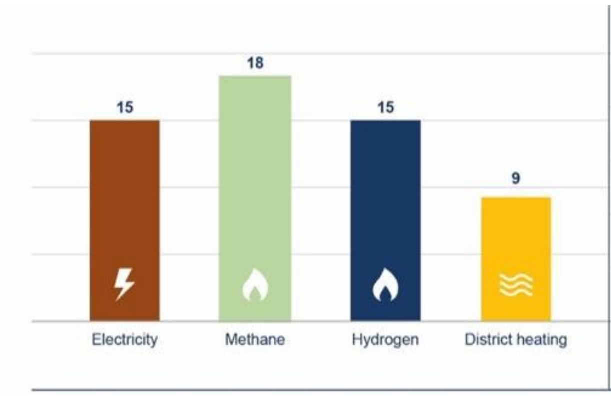


Figure 2.2-3: Peak load final consumption of grid-bound energy sources (excluding conversion input) in eastern Germany in the Optimal Energy System$_{2050}$ [GW]

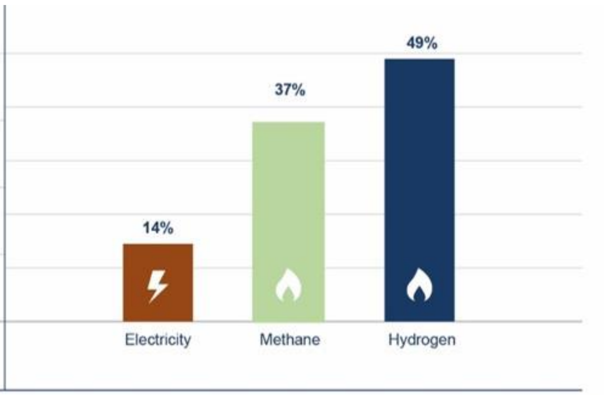


Figure 2.2-4: Share of the national transported energy quantity in the total energy quantity[6] consumed in eastern Germany per energy source in the Optimal Energy System$_{2050}$

III. Primary Energy and Land Consumption

The currently dominant primary energy carriers: oil, coal and natural gas (88% share of primary energy) will completely disappear[7] and will be replaced on the one hand by substantial energy savings (-31% final energy consumption compared to today) and on the other hand by CO_2-neutral energy sources.

In order to generate the CO_2-neutral energy sources the optimal decarbonised energy system has 82 GW of wind power capacity, 57 GW of photovoltaic capacity and 9 GW of biogas capacity (with gas grid feed-in). This corresponds to a fourfold increase in wind power capacity, a fivefold increase in photovoltaic capacity and a fifteen-fold increase in biogas capacity (with gas grid feed-in) compared to today.

6 Final consumption plus conversion input

7 Technologies for decarbonizing fossil fuels were not part of the study.

These plants supply the majority of the primary energy production of approximately 390 TWh, with wind power contributing 56%, ahead of biomass (27%) and solar energy (14%).

With these facilities, all future energy consumption in eastern Germany can be covered by primary energy produced in eastern Germany. This means that eastern Germany will be able to become energy autark in future, provided that this is politically desired or necessary. If economically attractive import options for CO_2-neutral energy carriers become available over time, then these facilities (and the associated land consumption) can be accordingly reduced.

The proportion of land in eastern Germany required for energy production in the area of agriculture/forestry (biomass) will slightly decline by approximately 2.5 percentage points to roughly 11%[8]. On the other hand, the land requirements for technical primary energy production derived from wind and solar – especially for wind power plants – will increase by about three percentage points to around 4%. As a result, the area required for an independent and decarbonised energy supply in eastern Germany amounts to 12 to 15% of the country's total area, which is less than (or at most equal to) the area currently used for the production of renewable energies in eastern Germany.

IV. Final Energy Consumption including Mobility, Production of District Heating

When it comes to space heating (with a sharp drop in useful energy consumption (-42%) due to insulation), the currently dominant gas boilers (> 50%[9]) will be replaced by a "duo" of district heating and methane-air heat pumps (each with an output share of almost one third). Approximately 16% of the remainder will be covered by electric geothermal heat pumps and a further 15% by hybrid devices (hydrogen or methane boilers combined with air-source heat pumps or solar systems). If space heating technologies are grouped according to their main energy source, then gas also takes the leading role ahead of district heating in the Target Scenario$_{2050}$.

With regard to process heat, gas will be replaced as the major energy carrier (currently about 50%[10]). Instead, there will be a new "duo" of electricity and hydrogen in the Target Scenario$_{2050}$, both of which cover around one-third of total output. In road transport the liquid fuel engines that currently dominate the passenger car sector will be completely replaced by CNG engines, with the CNG used consisting almost entirely of upgraded biogas.

> In the case of this perhaps surprising result, it should be noted that the dominance of CNG engines is not a scenario assumption, but rather a calculation result. Like all of the statements made here regarding optimum end-use technologies in 2050, this results from the simultaneous optimisation of the entire energy system (including end-use plants) in WALERIE. The calculation shows that the use of CNG vehicles – in the overall context of the associated costs for the vehicles themselves, but especially for provision of the required drive energy (including storage and networks) and taking the costs saved or indirectly produced in other consumption segments into consideration – is more favourable than the use of battery electric vehicles.

8 Current exports of biofuels, which were not modelled, also contribute to this result.
9 This is the share of gas today with regard to space heating useful output.
10 This is the share of gas today with regard to process heat useful output.

> However, as a sensitivity analysis shows, this is not a particularly large cost advantage: if the cost forecast for 2050 for battery electric vehicles and their fuelling infrastructure is reduced by only 5%, then battery electric cars become prevalent. However, purely from the perspective of economic costs[11], the competition for the future of automobile drive technology does not favour battery electric cars. On the contrary, based on a holistic appraisal of the technologies, CNG passenger cars have a slight advantage over battery electric cars on the basis of current data.

In the area of commercial transport, vehicles with pressurised hydrogen tanks and fuel cells completely replace the liquid fuel drives that dominate today.

These changes in the technologies employed for end use will result in corresponding changes in final energy consumption. Final gas consumption will increase by approximately a third compared with today's figures, i.e. about 160 TWh, with methane and hydrogen each accounting for around half of this final consumption. This is a consequence of the sharp increase in the use of gas in mobility, which more than compensates for reductions in the area of heat production. On the other hand the demand for electricity only slightly increases (+14% to 97 TWh), as gains in the area of heat production from electricity are largely offset by increased energy efficiency in "conventional electricity consumption" (power/light/...). The end consumption of district heating even drops by around 40%. This occurs, despite the increased market share of district heating in space heating, due to the overall decrease in heating demand (→ energy efficiency) and the declining market share of district heating with regard to process heat.

V. Energy Conversion and Storage

On the one hand increased final gas consumption is covered (see above – primary production) by rapidly growing biogas capacities with gas grid feed-in, which inject a total of 74 TWh of biomethane into the gas grid.[12] A second, significantly more extensive, volume of gas is produced by converting renewable electricity into approximately 130 TWh of hydrogen by means of electrolysis. For this purpose 38 GW_{H2} of electrolysis capacity will be installed in the Optimal Energy $System_{2050}$ in eastern Germany.

Most of the hydrogen not used in final consumption (34 TWh) is used for conversion into liquid fuels (approximately 3 GW_{Output} H2-to-liquid capacities).

A much smaller proportion of the gas (8 TWh; of which 7 TWh is hydrogen) go into the "electricity back-up system", which is essential for the security of supply of the energy system. This system ensures that the electricity loads are covered if sufficient wind and solar power is not available.

11 Determined on the basis of current forecasts for the year 2050 with regard to the costs and efficiencies of drive technologies and the technologies required for the provision of drive energy.

12 Synthetic methane from methanisation plants plays a negligible role in the optimal energy system of the Target Scenario.

The optimum electricity backup system has a capacity of approximately 12 GW – two thirds of which consists of gas-fired power plant capacities (8 GW) – with about 80% of these capacities using hydrogen as fuel. These power plants have a short service life of less than 1000 hours (in some cases considerably less). The remaining third is almost entirely made up of electricity storage facilities (3.7 GW) used in the short-term. Pumped storage and batteries each make up about half of this capacity (backup capacity).

Controllable power plant capacities (excluding electricity storage) in eastern Germany will decrease by almost 50% compared to today, although gas-fired power plant capacities will almost double. This is mainly due to the loss of lignite capacities, which are currently also used in part to export back-up capacity to western Germany.

In contrast, the storage capacity of electricity storage facilities increases more than 100% to a total of 44 GWh. Pumped storage and batteries each account for about half of this growth. As a result, pumped storage in the Optimal Energy System$_{2050}$ accounts for 33 GWh and batteries for an additional 11 GWh.

In future district heating will largely be electrically generated with geothermal heat pumps (2.2 GW) and electrode boilers (5.9 GW). Gas technologies will only play a role as a redundancy source in the form of hydrogen boilers. The current dominance of gas-based district heat production in CHP plants will thus end. Very high increases will be seen in terms of thermal storage systems, from today's very low values to around 650 GWh in the Optimal Energy System$_{2050}$.

The extensive use of biomethane and hydrogen in the Optimal Energy System$_{2050}$ will result in significant use of gas storage. The demand for working gas volumes will slightly increase – to about 4.3 billion m³ – compared to today's level. There will be a considerably greater increase in demand for storage rates[13] (i.e. for the actual injection or withdrawal of gas into/from the storage facilities), almost doubling. This is mainly due to the fact that in the Optimal Energy System$_{2050}$ the storage of energy gases is mainly in the form of hydrogen, which has higher volume requirements per energy unit than the methane stored today.

VI. Electricity, Gas and District Heating Networks

Major changes can be seen with regard to electricity, gas and district heating networks compared to today. These can be traced back in particular to changes in the geographical location of energy generation.

> In order to understand these changes, it is necessary to comprehend how WALERIE models and optimises electricity, gas and district heating networks. These networks are differentiated in the gas sector according to the respective energy carrier (methane and hydrogen)[14]. In addition, the networks for electricity and gas are differentiated according to several types of function (transport lines between regional clusters ("supra-regional transport"), regional development, final distribution and service lines for production and storage facilities). The district heating network is modelled with an integrated function type.

13 On a volumetric basis.

14 Alternatively, blended gas networks can also be modelled.

> WALERIE simultaneously optimises the capacities of all these function types for all energy carriers and for all sub-regions with optimisation of the capacities of the energy technology plants (production, conversion, storage, end use) in all sub-regions with the aim of minimising the economic costs.[15] WALERIE therefore optimises, for example, between consuming and/or curtailing renewable electricity in a regional cluster and/or storing it in batteries and/or pumped storage power plants and/or transporting it to other regional clusters (for consumption/storage/...) and/or converting it into gas by electrolysis (and possibly methanisation) and consuming/storing/transporting this gas. In this manner, an overall optimum is achieved across the entire energy system including grids. WALERIE thus also optimises locations of energy technology plants (e.g. wind power plants) with regard to transport costs, which result in different location options (far from/near consumption).

From a locational perspective, the electricity system is clearly recognizable as cellular in the Optimal Energy System$_{2050}$.

In future very significant capacities for renewable electricity production will find their optimum energy-efficient location in almost every sub-region of eastern Germany. The same applies, although to a somewhat lesser extent, to the back-up system for electricity production in the form of controllable gas-fired power plant capacities, battery capacities and (in geographically suitable sub-regions) pumped storage capacities, which each contribute to the regional balance of electricity generation and consumption. In addition, significant electrolysis capacities are used in almost every sub-region modelled in the Optimal Energy System$_{2050}$. These convert renewable electricity produced but currently not consumed or otherwise stored into hydrogen, which is then stored in the same or another regional cluster, with the geological possibility of hydrogen storage. As a result, only 14% of all electricity produced and consumed in eastern Germany flows through supra-regional lines between the regional clusters, with a certain orientation from north to south.

Based on the available data, a comparison with the current electricity grid can only be indicative, but it does show interesting trends. The modelled economic costs of the electricity grid in eastern Germany increase by about 50% to approximately EUR 4.4 billion per year. This is mainly due to the massive increase in demand for service lines, which are used in particular to connect the wind and solar power capacities (+400%) distributed over this area to the networks serving regional development. In contrast, peak electricity consumption rose only slightly (+15% to 15 GW), as the growth in electricity in the heating market was largely offset by improved energy efficiency in the case of conventional electricity loads (power/light/...) and battery electric vehicles are not selected by the modelling. The peak output, with which electricity is provided for regional clusters from supra-regional networks, remains almost the same at 8 GW.

In the optimal energy system the gas system also shows significant differences from a spatial perspective when compared to today.

15 Since an independent energy system was calculated for eastern Germany in the CtC 2050 project, networks for the import or export of electricity or gas to/from eastern Germany do not appear in the result.

The current gas system is essentially based on imported natural gas. The gas system in the Target Scenario$_{2050}$, on the other hand, does not require imports as all future gas demand for eastern Germany will also be produced in eastern Germany. This means that the gas flows in eastern Germany will no longer follow the conventional "downstream pattern" from import points to end consumers, but will also originate in the sub-regions of eastern Germany.

In the Target Scenario$_{2050}$ energy gases are produced on a large scale in almost all of the regional clusters: this includes biomethane from various forms of biomass, and also hydrogen through electrolysis of renewable electricity. Subsequently, the biomethane will also be sub-regionally consumed to a large extent (e.g. for CNG vehicles). In order to compensate for sub-regional surpluses and deficits, methane is transported between sub-regions in eastern Germany. This transport equates to 37% of the total methane produced.[16] Transport will focus to large extent on routes to and from the major storage sites in Saxony-Anhalt, Thuringia and Brandenburg.

Hydrogen transport requirements result from a significant surplus of hydrogen production in the north (which results in a modified form of economically optimal transport of renewable electricity towards the geographical centre or the south of eastern Germany). and also from transport to and from storage sites over the course of the year. These storage sites (caverns) are geologically available in 6 of 19 regional clusters and are all used in the Optimal Energy system$_{2050}$. As a result, almost 50% of the hydrogen produced in eastern Germany flows through supra-regional transport pipelines between the modelled regional clusters within eastern Germany. In relative terms (but also when viewed as absolute quantities[17]) hydrogen is thus the most important energy transmission medium in eastern Germany in 2050.

For the gas networks, as with the electricity networks, a comparison with the current system can only be indicative, but it also shows interesting trends. The modelled economic costs of the gas network in eastern Germany will increase by approximately 75% to a total of about EUR 1.4 billion per year. For gas networks this is also mainly due to the massive increase in the demand for service lines, especially in order to connect sub-regionally distributed biogas plants (+1500%) to networks serving sub-regional development. In contrast, peak final gas consumption remains unchanged at around 33 GW. In this case, the additional demand for CNG passenger cars compensates for the reduction in demand for heat. However, the structure of the peak load for final gas consumption changes significantly. The share of methane used in covering peak loads in final gas consumption declines from 100% to 55%. Hydrogen takes on an essential new role in this respect, contributing the remaining 45% of peak load final gas demand. The peak capacity with which gas is supplied to regional clusters from supra-regional networks drops by approximately 40% to around 23 GW (two-thirds of which in the form of hydrogen). The volumetric grid requirement ("pipe diameter") will naturally decrease to a lesser extent as hydrogen requires a higher transport volume per unit of energy transmitted than methane as a result of its lower energy density.

16 Biomethane plus a very small amount of synthetically produced methane
17 See Figure 5.3-12 in final report

The changes are also noticeable for district heating networks, but less so than in the case of gas and electricity networks. The required peak district heating capacity declines by approximately 20% as losses in the market share of process heat and the overall decline in the heat requirement (→ energy efficiency) clearly outweigh the gains in the market share of district heating in the space heating sector.

The modelled economic costs of the district heating network in eastern Germany thus decline by about 20% to approximately EUR 0.7 billion per year.

2.3 COMPARISO OF TARGET SCENARIO$_{2050}$ WITH OTHER CONCEPTS FOR THE FUTURE DECARBONISED ENERGY SYSTEM IN EASTERN GERMANY

Restrictions in Technology-Neutrality

The Optimal Energy System2050 was determined technology neutral manner. That is, the modelling tool WALERIE had a variety of CO_2-neutral technologies for all of the energy sources at its disposal in order to determine – through corresponding selection and dimensioning of these technologies – the least-cost energy system through calculation with both security of supply and in compliance with all resource limitations (e.g. for wind power or biomass).

As means of comparison, this neutrality towards all types of technology was limited in the case of three scenarios and an alternative – but due to the limitations only conditionally optimal – decarbonised energy system was calculated for eastern Germany with WALERIE:

1. Comparison scenario without any gas infrastructure (i.e. no gas networks, no gas storage facilities, no gas-fired power plants and no gas-fired district heating)
2. Comparison scenario without final gas distribution (i.e. without final gas distribution networks and also without gas-fired district heating, but with gas-fired power plants in the electricity back-up system).
3. Comparative scenario without hydrogen infrastructure (like Comparative Scenario 1; however, the infrastructure elements specified exclude hydrogen, but remain accessible for methane)

Each of these restrictions technology-neutrality results in significant additional costs for the economy in eastern Germany compared with the optimal (and technologically neutral) Target Scenario$_{2050}$. In the case of the comparative scenario without any gas infrastructure these additional costs amount to approximately EUR 19 billion per year (+38%); in the comparative scenario without final gas distribution about EUR 9 billion per year (+18%), and in the case of no hydrogen infrastructure the additional costs are around EUR 6 billion per year (+13%). There are many reasons for these cost increases; for details see Section 7.1.

It is particularly noteworthy that there is a structural change in the case of those comparative scenarios (Nos. 1. and 2. above) that limit the economically optimal use of CO_2-neutral methane and hydrogen technologies. In both cases, there is a significant increase in the final electricity consumption load and, as a consequence, the economically optimal capacities of renewable electricity producers increase by almost one third in the case without any gas infrastructure and by one fifth in the case without final gas distribution.

Correspondingly, in these scenarios, the demand for land in eastern Germany for the primary production of renewable energy sources also increases significantly (by about 50% for solar energy, 10-20% for onshore wind energy and 150-200% for timber as a renewable resource).

The reason for this – at first glance surprising – result is that energy efficiency and economic viability are not always compatible, even in the future decarbonised energy world. Thus, for example, in the case of Comparative Scenario 1 (no gas infrastructure) it is more advantageous in economic terms to – at least in part – replace the relatively cheap option of chemical electricity storage (electrolysis/gas storage/gas power plants – all omitted in this scenario) with more primary electricity generation than to replace it completely with more (highly expensive) batteries.

Blended Gas Scenario

The optimum energy system in the Target Scenario$_{2050}$ was calculated with separate networks for hydrogen and methane at all levels. As a comparison, a scenario was calculated in which a blended gas network is employed at all levels. The blended gas network was designed in such a way that methane and hydrogen flow flexibly through this network to consumers[18] at the economically optimal level calculated by WALERIE. Consumers of pure gases are primarily served through filtering from this blended gas stream. Consequently, the blended gas scenario results in annual costs that are slightly higher than the annual costs of the target scenario (+2.7%). However, this is in any case within the range of the forecast uncertainty for the year 2050.

From the point of view of the political choice regarding the energy system of the future, blended gas networks are thus a relevant option, especially if this results in a simpler Energy Transition for consumers and the gas industry.

2.4 SUB-REGIONALISATION – RESULTS FOR BRANDENBURG 3 AND 4 AND SAXONY 1

The calculations with WALERIE within the scope of the CtC 2050 project were carried out on a sub-regionalised basis. In doing so, the different requirements when it comes to useful energy for each sub-region have been taken into account. These requirements are distributed differently to end consumer segments, and there are different resource potentials/limits for biomass, wind and solar energy, etc. The sub-regionalised modelling was carried out simultaneously for all modelled sub-regions in eastern Germany, while taking into consideration (also simultaneously modelled) optimum energy exchange (electricity, hydrogen, methane) via corresponding energy transmission networks with the respective neighbouring sub-regions.

As a consequence of the sub-regionalised modelling, all of the results of the Target Scenario$_{2050}$ are available for each of the nineteen regional clusters. These results differ significantly in various ways. Differences include, for example, the weighting of wind and solar energy capacities, the balance of energy imports and exports (from the cluster point of view to/from other clusters in eastern Germany), the importance of hydrogen-fuelled gas-fired power plants, the importance of gas in space heating, etc.

18 As well as to/from the storage facilities.

For example, also in light of the current political debate on the end of coal-based power generation, this final report presents examples of the results for those regional clusters in eastern Germany that currently have significant lignite-based power generation capacities. These are the clusters Brandenburg 3 and 4 and Saxony 1[19] Brandenburg (“BB”) 3 and 4 are each exporters of energy in the Target Scenario$_{2050}$, in which more electricity, hydrogen, methane and liquid fuel is produced in the course of the year than is locally consumed. Especially in the case of BB3, the export ratio of sub-regionally produced gas is quite high at more than 50%.

This export is made possible by very substantial capacities for the primary production of renewable energy, for example 4.6/1.6 GW (in BB3 and BB4) wind power and 4/1.4 GW photovoltaic capacities (outdoor and roof systems). There are also significant conversion capacities, for example 2.6 GW_{H2} electrolysis capacities in BB3 and 0.8 GW_{H2} in BB4. Controllable power plant capacities, on the other hand, comprise only around 180/140 MW_{el}.

The situation in Saxony 1 is somewhat different. Due to its high energy consumption, this regional cluster is an energy importer in the Target Scenario$_{2050}$ despite the use of all sub-regional potentials for the production of renewable energy. The sub-regional primary production of electricity in Saxony 1 comprises 4.3 GW of wind power and 2 GW of photovoltaic capacity (outdoor and roof systems) in the Target Scenario$_{2050}$. The optimum electrolysis capacities are also quite high at 1.5 GW_{H2}. Controllable power plant capacities on the other hand are only around 180 MW_{el}. Nevertheless, the security of supply in the energy system of Saxony 1 is always ensured (through integration into the surrounding clusters by means of energy transmission lines).

2.5 IMPLEMENTATION OF THE TARGET SCENARIO$_{2050}$

The Target Scenario$_{2050}$ represents a fundamental structural change in the energy system in eastern Germany. At the same time, it is the most cost-effective option for achieving decarbonisation targets in the long term. The required implementation is a project for decades and can only succeed if it is promptly addressed.

As so often, a key role in achieving the Target Scenario$_{2050}$ will be played by policymakers, who must ensure that what has been identified as optimal from an economic point of view also becomes profitable for businesses and households alike.

It should be taken into consideration that several technical elements of the Target Scenario$_{2050}$ still require significant progress – particularly in the realisation of cost degressions, but also in terms of improvements in efficiency. Such progress will only be achieved if support for these technologies (such as electrolysis, but also other hydrogen technologies, batteries, etc.) is promptly ramped up so that these advances can be successively realised. At the same time, the manufacturing capacities for these new technologies can also be developed to the levels ultimately required. This growth also takes time and the development of manufacturing capacities offers interesting scope for industrial and business location policy.

19 See Figure 4.3-3 in final report for the geographical location of these clusters.

A central tool for understanding these transformation requirements is the development of a **transformation path**. This path describes the milestones to transform today's energy system in eastern Germany to the optimum decarbonised energy system of eastern Germany in the year 2050, and what is required in order to reach each milestone. Economic, technical and political factors are taken into account in development of the transformation path. The main challenge is to ensure that the energy system in eastern Germany is (and remains) secure at all times during this transformation. The required political support when it comes to both the content and timeframe for this transformation can be determined on the basis of the transformation path.

2.6 STRUCTURE OF THE STUDY REPORT

This study report is further structured as follows:

- Section 4 describes the CtC 2050 project, the project order awarded to Wagner, Elbling & Company and the methodology employed in the project.
- Section 5 presents the calculated Target Scenario$_{2050}$ for the decarbonised, secure and least-cost energy system of eastern Germany in 2050.
- Section 6 presents the detailed results of the Target Scenario$_{2050}$ for regional clusters with (current) locations of large lignite-fired power plants. These are the regional clusters Brandenburg 3 and 4 and Saxony 1.
- Section 7 compares the Target Scenario$_{2050}$ with three comparative scenarios without non-preferential technologies in which the use of gas technologies is restricted in various ways. In addition, a comparison is made between the Target Scenario$_{2050}$ (in which methane and hydrogen networks are separately shown) and a “blended gas scenario” in which methane and hydrogen are blended in an integrated network. Finally, the results of a sensitivity analysis of the target scenario with regard to the costs of battery-powered passenger cars are reported in this section.
- Section 8 compares the Target Scenario$_{2050}$ with the current energy system in eastern Germany.
- Section 9 contains lists of figures and tables and the abbreviations used in the report.
- Section 10 contains summary tables with numerical values for the topics reported in this document.
- Section 11 lists data assumptions used in the calculations and data sources relevant to the study.

Due to the abundance of figures calculated in the project, the presentation in this report is largely in the form of graphics. For reasons of textual frugality, the figures contained in the graphics are only repeated in explanatory texts in individual cases.

The graphs only show capacities for those technologies that are part of the cost optimum in the Target Scenario$_{2050}$ (or the comparison scenarios) (and not all other potentially available technologies that are not part of the calculated optimum set of technologies).

Figures are rounded. Rounding is performed for each individual figure. As a result, the sum of the (rounded) individual figures shown in a chart may differ from the (rounded) total figure also shown in the chart.