Fraunhofer
ISE

FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

WHAT WILL THE ENERGY TRANSFORMATION COST?

PATHWAYS FOR TRANSFORMING THE GERMAN ENERGY SYSTEM BY 2050

Considering all sectors and energy carriers, the model-based study investigates scenarios of system development and related costs to transform Germany's energy system in line with climate protection targets.

Hans-Martin Henning, Andreas Palzer

Fraunhofer Institute for Solar Energy Systems ISE, Freiburg

The model REMod-D (Regenerative Energy Model – Germany) was developed within a self-funded research project. Further additions to the model were carried out in both a self-funded research project as well as in the research project "Grid-interactive buildings," funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). Results presented in this study are based on the self-funded research project.

Freiburg, November 2015

Brief Summary

The main goal of the German energy transformation is to drastically reduce greenhouse gas (GHG) emissions. By 2050, Germany is to decrease its GHG emissions by at least 80 percent, and wherever possible by 95 percent, below 1990 levels. Energy-related carbon dioxide (CO_2) emissions make up the largest share of GHG emissions and account for about 85 percent of the total GHG emissions in Germany today [1]. To achieve its climate protection targets, the German federal government has declared to fundamentally transform its energy system, requiring a thorough restructuring of the energy system as we know it today. This leads to the guiding question of this study: How can a cost-optimized transformation of the German energy system – with consideration of all energy carriers and consumer sectors – be achieved in line with meeting the declared climate targets and ensuring a secure energy supply at all times. We address this question in the present analysis. In this study, we assume that the nuclear phase-out is successfully achieved by 2022 according to plan and that no large-scale use of carbon capture and storage (CCS) will be implemented for decarbonizing the electricity generation from fossil fuel power plants. Besides environmental sustainability and cost-effectiveness, the model also addresses security of supply, the third aspect of the energy policy triangle, through time-resolved simulations which ensure the energy demand is met each hour throughout the entire year.

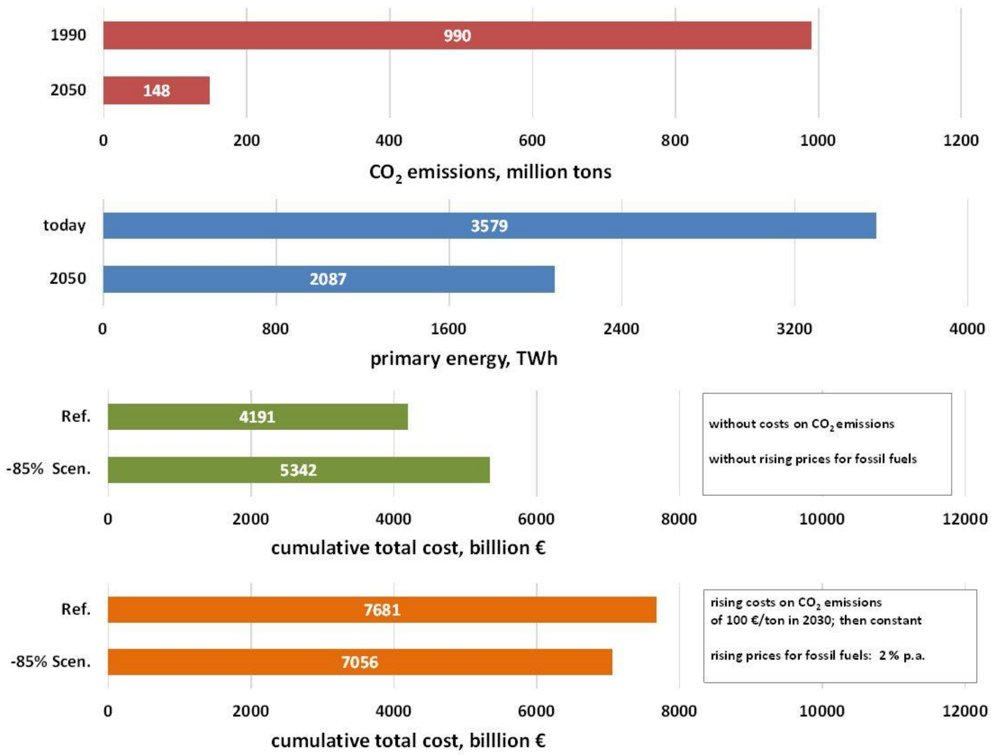

Fig.1 Overview showing the main results from the study. Primary energy consumption, CO_2 emissions and cumulative total costs for one of the scenarios investigated (85 % less energy-related CO_2 emissions in 2050 than 1990 levels) are compared to the reference case (Ref.) which assumes that Germany's energy system continues to operate in 2050 as it does today.

Figure 1 summarizes the main results of the analysis. A future energy scenario emitting 85 % less CO_2 emissions than 1990 levels is compared with a reference scenario, which assumes that the German energy system operates in 2050 the same way as it does today. Results show that ii) the primary energy in the minus 85-percent scenario will drop 42 % below today's values by 2050. iii) Assuming that no penalty is imposed on CO_2 emissions and the price of fossil energy remains constant, calculations show that the cumulative total costs to maintain and operate today's energy system will be 27 % less than transforming the energy system to the targeted minus 85 percent scenario. iv) On the other hand, if the penalty for CO_2 emissions increases to €100/ton by 2030 and thereafter remains constant and given that fossil fuel prices increase annually by 2 percent, then the total cumulative costs of today's energy system (Reference) are 8 % higher than the costs required for the minus 85 percent scenario up to 2050.

In the study presented here, potential pathways for the transformation are compared using various scenarios. The scenarios differ with regard to the mix of drive concepts used in the future mobility sector, the extent of the energy retrofits in the building sector and the exact time at which coal-fired power generation is no longer used. In addition, various climate targets are considered, namely, reducing CO_2 emissions by 80 %, 85 % or 90 % below 1990 levels by 2050. Important results from our analyses are briefly summarized in the following:

The most important results concerning the structure of the future energy system are:

1. Investigations of the various scenarios show that there are a number of different transformation pathways and system configurations that enable the targeted reductions in energy-related CO_2 emissions to be met and at the same time offer technically feasible boundary conditions for renewable energy capacity.

2. For all of the investigated scenarios, the use of fluctuating renewable energy sources (primarily wind and solar PV) to generate electricity plays a key role in the future energy supply. This holds true even if a massive increase in opportunities for electricity import and export occurs. Indeed the installed power required ranges quite widely in the different scenarios: from a total of 290 GW up to nearly 540 GW. The lower value was calculated for the scenario targeting an 80 percent decrease in energy-related CO_2 emissions and the upper value was calculated for the scenario with a 90 percent decrease in energy-related CO_2 emissions, respectively.

3. As the share of fluctuating renewable energy sources continues to grow strongly, an increasing flexibility in electricity generation becomes just as necessary as a flexibly reacting electricity demand. Increased flexibility can become reality only if new applications for electricity use – over and above the conventional uses known today – are implemented. Such new applications are particularly important in the building and mobility sectors. At the same time, increased electricity use in these sectors implies that combustion systems (boilers, combustion engines) shall be gradually replaced by electric powered units (electric heat pumps, electric motors). These units convert the final energy (electricity) more efficiently into useful energy (heat, traction) than the fossil fuel based combustion processes used today.

4. All of the investigated scenarios foresee a rise in electricity generation and electricity consumption due to a growing demand across all sectors. Depending on the scenario, values that are 20 % to 40 % higher than today are to be expected, despite the assumption made that due to efficiency increases, the electricity consumption of classical electric powered applications like lighting, mechanical drives, etc. will be reduced by 25 %.

5. A reduction of energy-related CO_2 emissions of at least 80 % below 1990 levels requires that fossil fuels, like gas or oil, be replaced more and more by renewable fuels. Accordingly the targets for CO_2 emission reductions cannot be achieved without the installation of large plants for producing synthetic energy carriers from renewable energy. Such systems would manufacture hydrogen, methane or liquid fuel using electricity generated from wind or solar PV. Here also, the total installed capacity of such systems varies widely among the different scenarios: from less than 80 GW up to 180 GW. The lower value is for a scenario which assumes a large expansion in electric mobility. The upper value was calculated for the scenario targeting a 90 % reduction in CO_2 emissions compared to 1990 levels.

6. A dominant feature in the future energy system is the electrification of the heat supply. In almost all of the investigated scenarios, electric heat pumps are the main technology used to supply heat for single buildings. The percentage of electric heat pumps installed in the energy system increases with higher target values for CO_2 emission reductions. In all of the scenarios, solar thermal systems are to cover part of the low temperature heat demand in buildings and in industry.

7. In the scenarios that assume the rate of building renovation is much higher than today, a lower overall capacity of renewable energy converters for electricity generation is required. As a result, the overall costs in these scenarios are lower than for the scenarios with more moderate renovation rates. In all of the investigated scenarios (except the scenario with a reduction target of 90 %), the majority of the building stock is retrofitted to meet today's standards for new buildings and not to meet passive house standards.

8. An accelerated withdrawal from coal-fired power generation by 2040 was shown to have a significantly positive influence on reaching the emission reduction targets successfully. In all scenarios with an accelerated withdrawal, the calculated total costs for the energy transformation were lower than for the same scenarios with no accelerated withdrawal. If coal-fired power plants are still in operation in 2050, then it will be very difficult to achieve more than an 80 % reduction in energy-related CO_2 emissions.

9. A tipping point is observed between the transformation pathways having 80 % and 90 % reduction targets. In scenarios that target CO_2 emission reductions of 90 % only a very small amount of fossil fuels is available. Therefore, the energy systems in these scenarios require an appropriately large capacity of wind and solar PV to generate electricity, a large amount of installed storage as well as an appropriately large amount of plants that produce synthetic energy carriers from renewables. At the same time, the 90 % reduction target requires a more extensive energy retrofit within the building stock. For single buildings that are not connected to a district heating grid, electric heat pumps will be almost exclusively installed for heat provision in this scenario.

10. During the occasional periods when the available renewable electricity is not able to meet the electricity demand, i.e. times of residual load, there must be enough complementary power plants available to supply power. These complementary power plants operate on fossil fuel, biogenic and synthetically manufactured energy carriers. Depending on the scenario, these plants consist of combined cycle power plants, CHP units as well as gas turbine power plants, in varying ratios.

The most important results concerning the costs of the energy transformation are:

1. For the case of stable fossil fuel prices up to 2050 and long-term low costs for CO_2 emissions (e.g. low trading prices for CO_2 certificates), simulations show that based on the least expensive scenario, the extra costs for transforming the energy system are approximately 1100 billion euros between 2015 and 2050. In this scenario, the transformation costs about 25 percent more than continuing to operate the present energy system as is up to 2050. Per year this is equivalent to about 0.8 % of Germany’s gross domestic product (GDP) today.

2. The cost situation is dependent, of course, on the price development of fossil fuels and the costs levied on CO_2 emissions. If one assumes that fossil fuel prices increase annually by 3 %, then the cumulative total costs for transforming the energy system and achieving the targeted 85 % reductions in CO_2 emissions by 2050 are practically identical to the costs required to operate today’s system as is up to 2050. A similar effect is achieved when one assumes constant prices for fossil fuels up to 2050 and a constant penalty of 100 € per ton for CO_2 emissions.

3. After successfully completing the energy transformation scenario in which CO_2 emissions have been reduced by 80 to 85 percent, the total annual costs for the new system are no greater than the costs needed to operate today’s energy system, i.e. €250 billion euros distributed over all end customers. This figure is valid based on today’s prices for fossil fuels and today’s trading costs for CO_2 emissions.

All costs stated here are based exclusively on the pure system costs. This means costs incurred from investments, their financing, the operation and maintenance of the systems and the purchase of fossil fuels and biogenic energy carriers, i.e. no external costs were included in the cost calculation.

From the macroeconomic perspective, the transformation of Germany’s energy system demands a significant shift in cash flow, moving the cash spent on energy imports today to spend it instead on new investments in systems, their operation and maintenance. In this respect a transformed energy system requires a large expenditure for local added value, a factor which also does not appear in the shown cost analysis.