The Sustainability of the Growth of Renewable Energy Sources in the Electricity Provision of Germany and How to Tackle the Issues with Governmental Policies

By Asim Cagri Kenanoglu

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Student:

Asim Cagri Kenanoglu

Student number: s4644573

Address: Bulent Ecevit Caddesi, 6753/11 Sokak, Korfezkoy Sitesi,

No: 80/5, Karsıyaka/Izmir   Turkey

Telephone: +90505 3974287

E-mail: asimcagrikenanoglu@gmail.com

Supervisor:

Dr. H.P.L.M. Korzilius

Associate Professor

Research Methodology Department

Nijmegen School of Management

Radboud University Nijmegen

Co-supervisor:

Dr. Pål Davidsen

Full Professor

Department of Geography

University of Bergen, Norway

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1. Introduction

According to the February report of the German Federal Ministry for Economic Affairs and Energy in 2014, there has been a big transition in the world from conventional energy sources to renewable energy sources and renewable energy is primarily used for electricity production. Germany is known as one of the pioneering countries in renewable energy and Germany's renewable energy sector is among the most innovative and successful worldwide (Burgermeister, 2009).

The energy transformation in Germany has been triggered by the following reasons. It helps to reduce human health costs, environmental costs and fossil fuel import costs and boosts economic growth and can diminish the energy prices in the long-term (International Renewable Energy Agency, 2015).

Aslani et al. (2013) hold similar ideas for energy security and the role of renewable energy in energy security and they state that economic growth, social welfare and safety of a country is directly impacted by energy security and the policy makers have to attach importance to the role of diversification of energy portfolios and the utilization of renewable energy sources due to growing energy demands, scarcity of fossil fuels, threats of CO_2 emission and global warming.

Governmental policies are acknowledged as main drivers for renewable energy investment in the literature by the variety of scholars having different opinions on renewable energy growth in the world. Germany enacted “The German Renewable Energy Act” (German: Erneuerbare-Energien-Gesetz, EEG) in 2000 to stimulate renewable energy production and it led to the boost of renewable energies in Germany (Commission of the European Communities, 2005). Furthermore, the vicious patterns of the cost dynamics of renewable energies were dealt with the EEG which boosted renewable energy investment in Germany (Green Paper, 2014).

According to the report of the Irena, “Remap 2030”, in 2015, Germany has dramatically increased their renewable power generation capacity and it has been raised from 12.3 GW to 85 GW between 2000 and 2013, which was mainly driven by onshore wind and Solar Photovoltaic (Solar PV) , followed by various forms of bio energy. Moreover, the renewable generation capacity reached to 93 GW in 2014 and half of this capacity has been run by the farmers and the citizens which implied decentralization of the power capacity ownership.

The renewable energy growth has been supported by the local governments and the communities as well. Almost one-third of the total municipal value added comes from the production of the plants and related equipment and so it is very crucial for the German industry development (International Renewable Energy Agency, 2015). Accordingly, 261500 jobs were created by the renewable energy investments in 2013 in Germany but total employment related with the renewable energy sources decreased by 28400 compared with 2012 (UNIDO and GGGI, 2015). Thus, it weakens the argumentation of the renewable energy supporters in Germany.

Climate protection is one of the main drivers of EEG. Greenhouse gas emissions should be cut by 40% in 2020 and at least by 80% in 2050, compared with 1990 levels. Although Germany meets the Kyoto protocol targets, they should develop more efficient strategies to meet EEG's long- term targets (International Renewable Energy Agency, 2015).

Renewable energy investments and growth are not only a popular issue in Germany but in the EU as well. EU leaders in the EU commission declared their targets called as "20-20-20" for 2020, which include increasing the share of renewable energies in the Gross Final Energy Consumption to 20%, decreasing green house emissions by 20% from 1990 levels and reducing the energy consumption of the EU by 20% compared to the projections conducted by the EU. At national level, the German Parliament enacted the Energiewende (energy transition) policy document in 2011 and the policy document defined the ambitious targets for the share of renewable energy in the electricity provision, which are 40% to 45% in 2025, 55% to 60% in 2035, and 80% in 2050 (German Energy Blog,2014).

1.1 Research Objective

International Renewable Energy Agency (2015), Prognos, EWI and GWS (2014) and Frank et al. (2007) and other institutions and scholars did research on the topic with possible scenarios and targeted policy mixes but they did not include dynamic complexities, delays, feedback mechanisms and non-linear relationships. Quantitative System Dynamics (SD) models provide to include these main mechanisms for problem definition and solution. Likewise, System Dynamic Modeling has some advantages over the other methods to grasp the system more deeply and recommend some policy options that will help tackle the problem. Olsina et al. (2004) state that power markets are likely to have business cycles. For example, after a high investment period, a low investment term will follow it and these cycles lead to fluctuations of capacity reserve and electricity prices. Moreover, they reveal that classical business models are not able to represent these cycles because they cannot capture the dynamics of the system. These cycles come from the delay structure of the system to adjust the pricing and the capacity and a SD modeling is powerful to show it in the models.

Moreover, Arango (2007) claims that SD helps figure out if government policies activate instability which could influence the performance of the system via its feedback and delay mechanism in the energy markets.

Additionally, SD models incorporate bounded rationality and the investor's behaviors and this approach is more realistic than the classical economic approach to get the dynamics of the liberalizing energy markets (Larsen and Bunn, 1999).
Important researches based on the SD modeling have been done in the past on the topic but they missed out some important variables for the system. Kubli (2014) did not include potentially important variables for supply security and risk modeling and did not model organizational learning. Osorio and Ackere (2014) did not model risk and perceived return, also did not model organizational learning although they modeled supply security very detailed. Moreover, to my knowledge, there are no models that include residual load, curtailment and minimum generation. These elements are vital for supply security in a system which has a high share of renewable sources in electricity supply. Also, in the SD literature, there are no studies that give insight into reaching the German targets for the renewable energy share in the electricity supply in Germany in a cost effective manner.
My contribution to the existing theory is to build a SD model combining the main variables which have been built in the different studies to see the dynamic impacts of them in a consistent system. Then, the analysis of the growth of the renewable energy sources in the electricity production mix in Germany through a quantitative System Dynamics model under the past and current conditions of governmental policies, electricity market, physical capacity, supply security and investment mechanism is made to give policy recommendations that lead to reaching out the initial ambitious targets set by the German government in 2011 in a cost effective manner through different mix of the policy options.

1.2 Research Questions

1-What are the elements of the electricity market, physical capacity, the risk of the electricity plant investments, the investor behaviors, organizational learning, the supply security and renewable energy characteristics for a SD model in the case of Germany?
2- What are the past governmental policies on the renewable energy in favor of electricity provision from the renewable energy sources in Germany since 2006 until 2015?
3- What are the focal variables and the causal feedback loops in the model leading to achieve or block to achieve the targets?
4- Which SD model scenarios are plausible to be developed based on the literature review and the analysis of the SD model to insert the SD model after 2015 and what are the impacts of them on the SD model results?
5- Which insights and recommendations does the SD model give on the mix of policy options to achieve Germany's set targets on the electricity provision from the

renewable energy sources through different scenario and policy runs in the SD model?

6- What are the results of the mix of the policies implemented in the model and which one seems the best policy mix in terms of cost minimization from the electricity consumer perception?

2. Theoretical Background

This section consists of five parts and each part gives insight and information from the past studies about a particular area of present work. Part 1 is an overview of electricity supply that describes general concerns about renewable energy characteristics and electricity supply in Germany. Part 2 describes electricity market terms and mechanisms about electricity market in Germany and measures to have an efficiently functioning electricity market in Germany in terms of supply security. Part 3 defines the dynamics of investments on renewable and conventional electricity plants. Part 4 describes types and impact of the policies implemented so far in Germany in favor of renewable energy investments and general discussions about these policies. These four parts of this section are interrelated with each other and transitivity among them could be noticed. Last part of this section gives brief overview of SD studies that have been conducted on the topic so far to use in my model.

2.1 Overview of Electricity Supply

The growth of the renewable energy sources in the electricity provision of Germany has different aspects which are social, environmental, technical, economical and legal (International Renewable Energy Agency, 2015).

Germany decided to shut down their nuclear plants in 2000 and the idea was enforced in 2011 due to the nuclear accident in Fukushima, Japan. Germany has eventually made certain plans to phase out all nuclear plants by 2022 (International Renewable Energy Agency, 2015). The decision might threaten the energy security and drive up the energy prices and these arguments are held by the opponents of the renewable energy investments in Germany to undermine the renewable energy governmental policies.

Renewable energy sources have cyclic changes which refer to the natural variability of renewable energy sources. These natural cycles have different types, which are observed in the short-term (intra and inter day) and are observed in the long-term (seasonal changes). These cycles should be managed by grid operators with different strategies which will provide energy security (International Energy Agency, 2005). Energy security is described by the International Energy Agency as “the uninterrupted availability of energy sources at an affordable price”.[1]

Thus, intermittency and unpredictability of renewable energy sources might threaten the supply security in Germany. The joint report of Prognos, EWI and GWS called “Energy Reference Forecast” (2014) revealed that the installed power generation capacity in Germany has been growing steadily not only due to the expansion

[1] Available on https://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/

potential of renewable energy sources, but also their relatively small contribution to the secure power supply.
The report of Irena called as “Remap 2030” on renewable energy in Germany in 2015 also emphasizes the significance of how the grid infrastructure can be expanded to ensure security supply and the integration of the renewable energy power sources with the grids in the sense of expansion and management of the grids. It states that by 2015, only 463 kilometers of power lines had been added, and BNetzA identified the need for 1 883 kilometers of additional lines.
On the other hand, different renewable sources have different natural cycles which help mitigating the impact of the intermittency of renewable energy sources by the diversification of the renewable energy portfolio. Dybvig and Ross (2010) and International Energy Agency (2005) state that the risks of higher prices and supply disruptions from sources can be mitigated by energy portfolio diversification. International Energy Agency (2005) also states that while wind or solar PV technologies change their output within minutes or hours, hydro and biomass have seasonal variations and it indicates practical implications for the favor of portfolio of renewable energy sources.

The shift to renewable energy sources in the electricity mix in Germany is threatening conventional power plants. Frank et al. (2007) state in their report that they cooperated with the Fraunhofer Institute for Systems and the Innovation Research ISI that the main reasons of decommissioned capacities are low efficiency, expensive oil and gas prices, maintenance and repair costs and low utilization rates.

2.2 Electricity Market

Germany’s BMWi (Federal Ministry for Economic Affairs and Energy) has released a “Green Paper”, An Electricity Market for Germany’s Energy Transition, and then a “White Paper” which was built on the feedback on the “Green Paper” to advocate an “electricity market 2.0” which is the regulation of the German electricity markets.
The Green Paper (2014) discusses about future electricity market design and a regulatory framework to ensure that Germany’s power supply is secure, economical and environmentally friendly.
According to the Green Paper, an effective market should have the following functions:

1) It must be able to produce a price signal which electricity production and consumption can match perfectly.
2) The grid operators should balance out unanticipated differences between supply and demand.

3) Electricity markets should incentivize capacity investments and generation via price signals, capacity reserve and balancing capacity.
4) The grid operators should overcome bottlenecks via expanding and upgrading the grids and the dispatch measures which are the intra-day market, curtailment of the production of the power plants, the balancing market and the capacity reserve plants.

The list emphasizes the significance of efficiently functioning electricity markets and grid management for energy security in Germany in the sense of economical and uninterrupted supply of electricity.
The electricity spot market covers day-ahead and intraday markets (Green Paper, 2014). According to the report of the German Ministry for Economic Affairs and Energy in 2014, 40% of the electricity trading takes place at the day-ahead market. Merit order is a crucial term in the electricity market to show the functioning of the market. The Green Paper defines merit order and related concepts as following: “The price quoted on the exchange is the point where supply and demand intersect. In the electricity market, the generation facilities with the lowest variable costs are the first in line to meet demand (“merit order”). This helps to minimize the cost of supplying electricity. As a general rule, the exchange price for electricity corresponds to the variable costs of the most expensive generation plant in use. This plant is known as the “marginal power plant”. The exchange price is therefore also referred to as the marginal cost price” (2014: 10).
Renewable energy plants have the competitive advantage over conventional energy plants in the context of the variable costs in the German electricity market. Variable costs of the wind farms and the PV solar plants are close to zero and they benefit from the Feed-in Tariff which provides higher prices than the market prices most of the time. Thus, their contribution margin is high and they can compensate their high investment costs. The variable costs of the conventional power plants depend on fuel prices, the degree of the plant efficiency and the costs of CO2 emission prices. The conventional power plants whose variable costs are lower than the market price can still compensate their fixed costs (Green Paper, 2014).
Thus, according to the Green Paper (2014), power stations in the future should have the following features to run profitably in the context of high share of the renewable energy sources in the electricity supply: Low CO2 emission rates, high efficiency rate for using fuels, low start up and shut down times and costs; comparatively low number of load hours for running the plants.
Also, price of C02 certificates is a central issue for the growth of electricity generation from renewable energy sources. Prognos, EWI and GWS claim in the “Energy Reference Forecast” report in 2014 that until 2020, the price of C02 certificates will

remain on a modest level because of the surplus of the certificates resulting from economic and financial crisis but then it will start to rise.
Residual load is another vital term to provide supply security in the electricity markets. Residual load refers to electricity demand that cannot be met by renewable energy plants and should be provided by conventional power plants, imports and storages. There are two extreme types of residual load that should be managed efficiently in terms of secure and cost-effective electricity supply:
Maximum residual load: This happens when electricity demand is too high or electricity generation from renewable energy plants is too low.
Minimum residual load: This happens when electricity demand is too low or electricity generation from renewable energy plants is too high (Green Paper, 2014).
Moreover, minimum generation is an important term to guarantee supply security in the electricity markets. The Green Paper describes minimum generation as "Minimum generation refers to the production of electricity by certain thermal conventional power stations which even takes place at low residual load and exchange prices of zero or below ("minimum load problem"), particularly because electricity generation is required for ancillary services (balancing capacity, reactive power, re dispatch or other ancillary services" (2014: 16).
It is significant to adjust the optimal level of the minimum generation because it could lead to higher wholesale prices and the curtailments of the renewable power plants in low residual load and on the other hand, it could risk the energy security if it is intended to reduce minimum generation and so minimum generation should be reduced gradually (Green Paper, 2014). The Green Paper describes curtailment as "Wind and solar power installations, in turn, can reduce their generation if the residual load is very low or grid capacity is limited" (2014: 18).

2.3 Investment Decision

One of the biggest challenges to invest on renewable energy sources stems from being relatively an immature field compared with conventional energy investments. Masini and Menichetti (2012) point out that the investors are not eager to make investments on new technologies which cannot guarantee a certain amount of returns in the short-term and they prefer to invest in low risk-low income profiles with higher confidence. However, renewable energy sources will provide higher returns in the long-term.
The feedback loops driving the investment decisions of the investors should be known to shift the investments from conventional energy sources to renewable energy sources. Dangerman and Schellnhuber (2011) explain that the basic mechanisms of conventional and renewable energy systems with increasing return positive feedback loop. They state that to create this mechanism, appropriate

technology, large investments in research and development (R&D), demonstration, testing, and equipment should be made and it will lead to the starting of the virtuous loop which will change the system in the favor of relevant system. Thus, they suggest that resources should be allocated to renewable energy sources rather than conventional energy sources which have already the advantage of this virtuous loop over renewable energy systems that are still in their late-organization and early-exploitation (α-r) phase and lacking of critical mass.

Moreover, they emphasize the saturation of the investment on a specific technology. Abundant bureaucracy, scarcity of the resources or expensive resources and high competition among the actors in the sector lead to the saturation of the investments. They reveal the sources of the increasing returns loops as following; large set-up and fixed costs, learning effects, network effects and self-reinforcing expectations. Firstly, electricity generation requires high investments, including setting up plant, maintenance of plant and distribution of electricity. Secondly, accumulated experience on production and use of technology improves efficiency of plant and reduces production cost. Also, investors have a tendency to make investments on a technology which has already a spread-out network. Finally, when the more investments are made on a specific technology, investors develop a perception that this technology will be more dominant in the future.

Renewable energy investments could be supported by fiscal and non-fiscal policy options. Germany has mainly focused on the fiscal policy options to incentivize renewable energy investments so far. However, Masini and Menichetti (2012) discuss the role of the non-financial drivers on the renewable energy investments. They point out the importance of bounded rationality and behavioral finance for the topic against to the supporters of classical economical approach. Simon (1978) explains that bounded rationality emerges under uncertainty and missing information and it refers to the lack of human skills for processing data. It could be simply claimed that on the investment decisions of the investors on the renewable energy sources, uncertainty and missing information exist besides rational economical calculations for the returns and it proves the argumentation of Masini and Menichetti (2012).

2.4 Policy Options

The growth of the renewable energy sources in the electricity supply is incentivized by the German government with the implementation of specific tools and the market design and while it induces the boost of the renewable energy sources, it increases the burden on the end customers. Sprick et al. (2012) state that the network operators have to buy the electricity from the renewable energy plants and sell it in the stock exchange market .The difference between the market price and the Fixed-

Price FIT is passed on the end customers. Prognos, EWI and GWS claim that in the “Energy Reference Forecast” report in 2014, the EEG surcharges will increase remarkably until 2020 and finally, it will start to decline in 2025. Thus, it could risk the success of the implementation of the EEG in Germany until 2025. However, the Energiewende is backed by public support in Germany with 80-90% of the citizens who are positive about it despite the EEG surcharges (Federal Ministry for Economic Affairs and Energy, 2014).

The main financial policy instrument was the implementation of Fixed-Price Feed-in Tariff policy to support the renewable energy generation plants but the policy brought unwanted consequences for the electricity bills in Germany. Germany had one of the highest electricity costs in 2013 in the Europe and the electricity cost per kWh that the customers have to pay has been increasing continuously because of the incentives given to the renewable electricity plants (International Energy Agency, 2013). As a result, Germany is introducing new financial policy instruments, including FIT Premium payments and an auctioning system which are expected to liberalize the electricity market and decrease the EEG surcharge (International Renewable Energy Agency, 2015).

The energy transformation in Germany encompasses many aspects. Germany has been making lots of efforts to regulate the electricity market and achieve a successful energy transformation via the EEG, their reports and the energy institutions and generally the legal framework. The Energiewende is a continuously evolving process, involving many dynamics such as political parties in Germany, the EU and Germany’s neighbors, technological innovations, the electricity industry and the electricity market and finally German citizens (Federal Ministry for Economic Affairs and Energy, 2014). Legal framework for the German electricity market is the main driver for the investments and the market design and it influences many actors in the sector including investors, transmission and distribution operators, end customers, conventional electricity plant operators and the German economy in general. Thus, legal framework has been changed many times to balance out of the paradigms of the diverse actors but it increased uncertainty for the investor and the market actors. Moreover, digression of the Fixed-Price FIT, shift to Feed in Premium and Public Auctions bring new uncertainties for the investors and these new shifts in the legal framework are more complicating their investment decisions (Federal Ministry for Economic Affairs and Energy, 2014).

Jacobsson and Lauber (2004) pointed out their concerns about the sustainability of the legal support towards the renewable energy sources in Germany and they claimed that maintaining the supportive policy in favor of the renewable energy sources might be difficult in the long-term because of the actors in the favor of the

conventional energy sources who have a good and strong network and can impact the policy framework with their liberalization views and ambitions for short- term profitability over long-term benefits.
According to the calculations of the report of the Irena, “Remap 2030”, in 2015, USD 4.5 billion is required for new capital investment and USD 2.4 billion is required for redirection of investments from conventional sources to renewable energy sources to achieve the German targets for a successful energy transformation.

2.5 Previous SD Models

Kubli (2014) did a research about “The Impacts of Governmental Policies on the Investment Decision for Renewable Energies in the Swiss Electricity Market” through the System Dynamics Methodology. She tested how financial government policies impact renewable electricity plant investment and how different types of financial government policies impact renewable electricity plant investment by taking into consideration of renewable energy characteristics. She also compared the results of different types of financial government policies.
Osorio and Ackere (2014) conducted a research about “Security of Supply in the Swiss Electricity Market: A System Dynamics Approach”. They modeled the gap between supply and demand. This gap determines the market price through defining the level of capacity reserve and minimum generation from conventional plants which are crucial for the supply security due to the fluctuations of renewable energy sources but they increase the market price for the end customers due to their higher variable costs. They also modeled expected reserve margin, which is the ratio between expected supply and expected demand, and it is either increasing or decreasing the investments on the non-intermittent electricity plants depending on the abundance or lack of the ratio through market price signals. Expected residual load determines the investment rates on the peak units which are natural gases and storage hydro in the study through their capacity utilization rates. Thus, this study is based on guaranteeing supply security which is threatened by intermittency of renewable energy sources.
Jäger et al. (2009) did a research about “A system dynamics model for the German electricity market –model development and application”. The impacts of economic and environment related constraints on the German electricity market were analyzed in the study. They modeled technological process through the learning curves which reduce the investment costs in the model. Moreover, they modeled capacity factor through the ratio, which is electricity price over operational costs, and capacity factor impacts expected profitability of new capacity. Also, CO_2 tax rates in the model increase operational costs of the electricity plants in the model.

They made scenario analysis for CO_2 tax rates, nuclear phase-out, fuel prices, FIT prices and electricity demand. Then, they compared the results of different scenarios to figure out the impact of different economical and environmental constraints in the model. Besides installed capacity of the electricity plants and their electricity generation, CO_2 emissions from the electricity plants take place among the model results.

3. Research Strategy and Methodology

Quantitative experiment was conducted through the System Dynamics model in the case of “the German Renewable Energy Resources for Electricity Provision in Germany” as a research strategy in my master thesis. Kubli (2014) states that interplaying between physical, economic and natural system and major delays in the system make SD modeling a good approach to solve the problem. She also reveals that testing the impact and the validity of the variables by sensitivity analysis and making various scenario analyses and representing the results in the graphs and tables are other important benefits of using a SD model. Osorio and Ackere (2014) also assert that SD offers to visualize the interaction of different variables and their causal relationships. Thus, the System Dynamics Modeling was chosen as a proper method to conduct the quantitative experiment in the study.

I collected both qualitative and quantitative secondary data to accomplish the research. Qualitative secondary data include the elements of the electricity market, physical capacity, risk of electricity plant investments, the investor behaviors, organizational learning, supply security, the capacity factor of electricity plants and renewable energy characteristics. Quantitative secondary data include the past and current capacity level of the power plants, approval time for the investments and plant life times, the duration of the Feed-in Tariff policies and the amount of the incentives for each technology, the fluctuation level of intermittent renewable energy sources, the electricity demand, the costs for each technology and the desired targets of the German government for the share of renewable energy sources in electricity supply and CO_2 emission level.

It is important to define the boundaries of the system. Sterman (2000) reveals that our concern should be to investigate if any important feedback loops which will serve the purpose of the model have been omitted from the system and we can figure it out from literature review, expert opinions, interviews and archival materials. In the light of this, I built a conceptual stock and flow diagram for the electricity market of Germany, the physical capacity and the supply of the electricity plants, supply security of the electricity production in Germany, the investment mechanisms in the German electricity market on the electricity plants and the government polices embedded with other subsystems that I mentioned as a start of my modeling efforts. Turner et al. (2014: 261) state that “System dynamics models strive to represent the structure of a real system where the problem of interest is embedded. The more aligned a model structure is to the real system, the more confidence we can have in the model-generated behavior and its policy implications”. To represent the structure of the real system, I revealed the relationships within the subsystems and among the subsystems by using built SD models and SD articles on the topic and relevant articles from other disciplines.

After I structured the model, I conducted quantitative data collection to run the model. I used the reports of the International Renewable Energy Agency and the International Energy Agency, German Government and Private Institutions, the European Network of Transmission Operators for Electricity, German Energy Blog, German Energy Law, the European Commission and the Fraunhofer Institute. Also, I used the databases of the Fraunhofer Institute, the European Network of Transmission Operators for Electricity, the World Bank and the Information Platform of the four German Transmission System Operators. Additionally, I used the studies from the experts of the topic. By using all sources I enumerated above, I quantified the model variables.

Sterman (2000: 854) states: "Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values". Considering this, I estimated parameters for these kinds of variables that are functioning as the key decision points in my SD model. I used non-linear functions for the soft variables and estimated parameters for the variables that I could not find numerical data through numerical guess and equation guess in my model.

I explored the past policies applied in Germany to stimulate the renewable energy sources. Thus, I conducted the archival analysis of past the Renewable Energy Law (EEG) in Germany. Then, I inserted these policies in the model .The time frame in the model starts from 2006 because I found robust and meaningful data for my model from the related sources from 2006. Past policy options in favor of renewable energy sources both include qualitative and quantitative secondary data. Qualitative data include different types of policy options applied in Germany so far for example fixed - price feed-in tariff, feed-in premium, grid priority and tax exemption for the renewable energy plants. Quantitative data include the amount of years that the FIT policies will be valid and the amount of the incentives given to the renewable energy plants to finance their investments through the feed -in tariff policies. Moreover, the FIT types and the amount of incentives differ depending on the type of renewable energy sources such as Solar PV or Onshore and Offshore Wind energy.

After I structured and quantified the model, I ran the model to analyze the dynamics of the model. Taylor et al. (2010: 73) assert that "Changes in high-leverage parameters and structures can shift feedback loop dominance or constrain feedback loop strength and thereby dramatically alter system behavior". In order to take their insights about high-leverage parameters into consideration, I defined the key decision points for the success of the system and I also determined the central dynamics of the SD model.

After I ran the model, I compared the reference mode that I elicited from the databases with the dynamic behavior of my SD model to demonstrate how robust my model was to replicate the trends of actual data.
Additionally, I conducted Structure Verification and Parameter Verification Test and Dimensional Consistency Test to check out the validity of the system. The sensitivity analysis of the exogenous parameters was done during the validation process of the SD model as well.
Developing scenarios and inserting them to the SD model have been accomplished after the Validation part of the model. Four scenarios were developed based on the literature review and the analysis of the SD model. Then, the model results of four scenarios were compared with each other. Lastly, main conclusions were drawn from the scenario analysis for the policy implementation.

Following scenario analysis, I applied different Feed in Tariff policies which led the system to reach the targets set by German Government in the long-term compatible with the combination of particular two scenarios that I inserted in my model and calculated the overall costs of these policies from the German electricity consumer perspective. Then, I compared the overall costs of these policies and other simulation results such as CO2 emission and spot price. At the end of this analysis, I chose the best policy for the German electricity customers and the German Government.

From the research ethics perspective, I placed all sources of the knowledge that I learned and the data that I used in my model in the References section of the study. I did not manipulate the data and the model results to deceive the readers. I explained the shortcomings of the project to be honest and I was authentic on the topic and my work. Lastly, I am going to help new researchers in this area as much as I can.

4. Model

A Quantitative System Dynamic model was built in this study to gain insight about the German electricity system and to figure out about the dynamics of the system. After the system has been analyzed, the government policies leading the system to reach the German targets have been developed to give policy recommendations.
The simulation timeframe in the system is from 2006 until 2050 which is in line with the German targets for the share of renewable energy sources in electricity provision in Germany. From 2006 until 2015 represents the past state of the system and from 2016 until 2050 represents long-term planning of the system.
The System Dynamics software iThink 10.0.6 was tool to build and simulate the model in the system. The model results were exported and compiled in the Microsoft Excel to show the results in a better visualized way.
In the model, electricity generation sources and their related variables were distinguished by different arrays. Five different arrays were used in the model. They are intermittent technologies, other technologies, all technologies, renewable technologies and conventional technologies.
Table 1 shows the arrays and their dimensions.

Intermittent	Other	All	Renewable	Conventional
Solar Phovoltaic	Nuclear	Solar Phovoltaic	Solar Phovoltaic	Nuclear
Onshore Wind	Hard Coal	Onshore Wind	Onshore Wind	Hard Coal
Offhore Wind	Lignite	Offhore Wind	Offhore Wind	Lignite
	Natural Gas	Nuclear	Hydro	Natural Gas
	Hydro	Hard Coal	Biomass	
	Biomass	Lignite		
		Natural Gas		
		Hydro		
		Biomass		

Table 1: Arrays and their dimensions used in the model

I used different kinds of arrays in the model for specific purposes. The Green Paper (2014) defines Sun and Wind as intermittent sources for electricity generation and electricity generation from them can vary significantly depending on the season, day or the time of day. Also, residual load, minimum generation and curtailment of Solar PV and Wind Plants are crucial terms for the supply security in Germany and they are determined by the electricity production from Solar PV and Wind Plants (Green Paper, 2014). Thus, I modeled a particular array for intermittent technologies and it helped to represent the system more realistically and to emphasize the significance of the supply security in Germany for the model and its results. In correspondence with that, I included another array for other technologies.

In some parts of the model, I used the array of renewable technologies because the government policies such as FIT policies and grid priority in merit order are available for all kinds of renewable sources. Also, making a distinction between renewable and conventional sources is required due to the nature and objective of the study. In correspondence with that, I modeled another array for conventional technologies.

Grid priority and connection rights of renewable energy sources are one of the key elements of German Renewable Energy Sources Act (2014). The Economist (2014) defines grid priority as “Those renewable sources have grid priority, meaning they must by law be drawn upon before other energy sources, like electricity from coal, gas or nuclear plants”.[2]

[2] Available http://www.economist.com/blogs/economist-explains/2014/12/economist-explains-10

4.1 Model Overview

The model consists of fifteen sectors. To represent the model in more detailed and understandable level, the model is broken down into fifteen sectors and it helps the readers to grasp it piece by piece and to see the relationships of the sectors clearly to perceive the system as a whole. The Physical Capacity Other Sources Sector and the Physical Capacity Intermittent Sources Sector were combined as Physical Capacity Sectors in the Figure 1 for better visualization purpose.

Figure 1 shows the sectors and the relationships among the sectors in the model. The detailed explanation of the structure of the model sectors can be found in the Model Sectors section of the study.

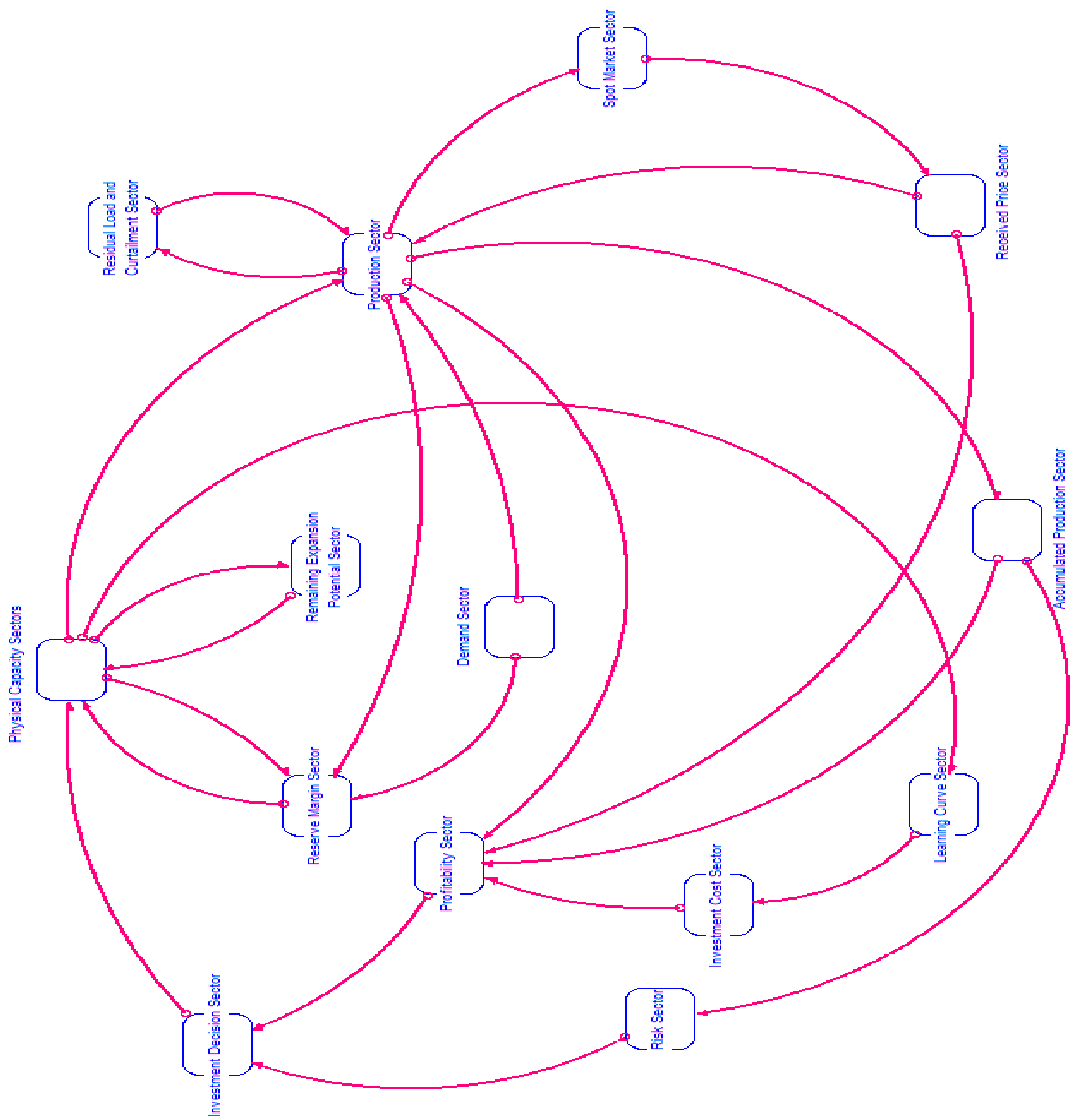

Figure 1: Overview of the sectors in the model

4.2 Causal Loop Diagram of the Model

The model consists of twelve feedback loops, which are five reinforcing loops and seven balancing loops. Bellinger (2004) defines a reinforcing loop as “One in which an action produces a result which influences more of the same action thus resulting in growth or decline” and he defines a balancing loop as” Representative of any situation where there is a goal or an objective and action is taken to achieve that goal or objective”.[3]

The Causal Loop Diagram of the system is represented on two diagrams to visualize the feedback loops clearly with the purpose of making it understandable for readers. These two diagrams can be found on Figure 2 and Figure 3 and the explanations of each loop are under the figures. The dynamic of each loop is articulated in a way that the share of renewable energy sources in electricity mix is increasing because of the historic data and the purpose of the study.

Some particular variables on the first Causal Loop Diagram were already defined in the study and some particular variables are defined explicitly below to make the diagram more comprehensible and clear:

Merit order guaranteed supply: It represents electricity production of all renewable energy sources that have grid priority rights to stimulate renewable energy investments.

Capacity factor: “The net capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time”.[4]

Remaining Expansion Potential: It represents economical and technical expansion potential of all technologies in GW.

Received Price: It is composed of market price and FIT incentives for renewable energy sources or subsidies for conventional energy sources.

[3] Available on http://www.systems-thinking.org/theWay/sba/ba.htm

[4] Available on https://en.wikipedia.org/wiki/Capacity_factor

Figure 2 illustrates first causal loop diagram of the model.

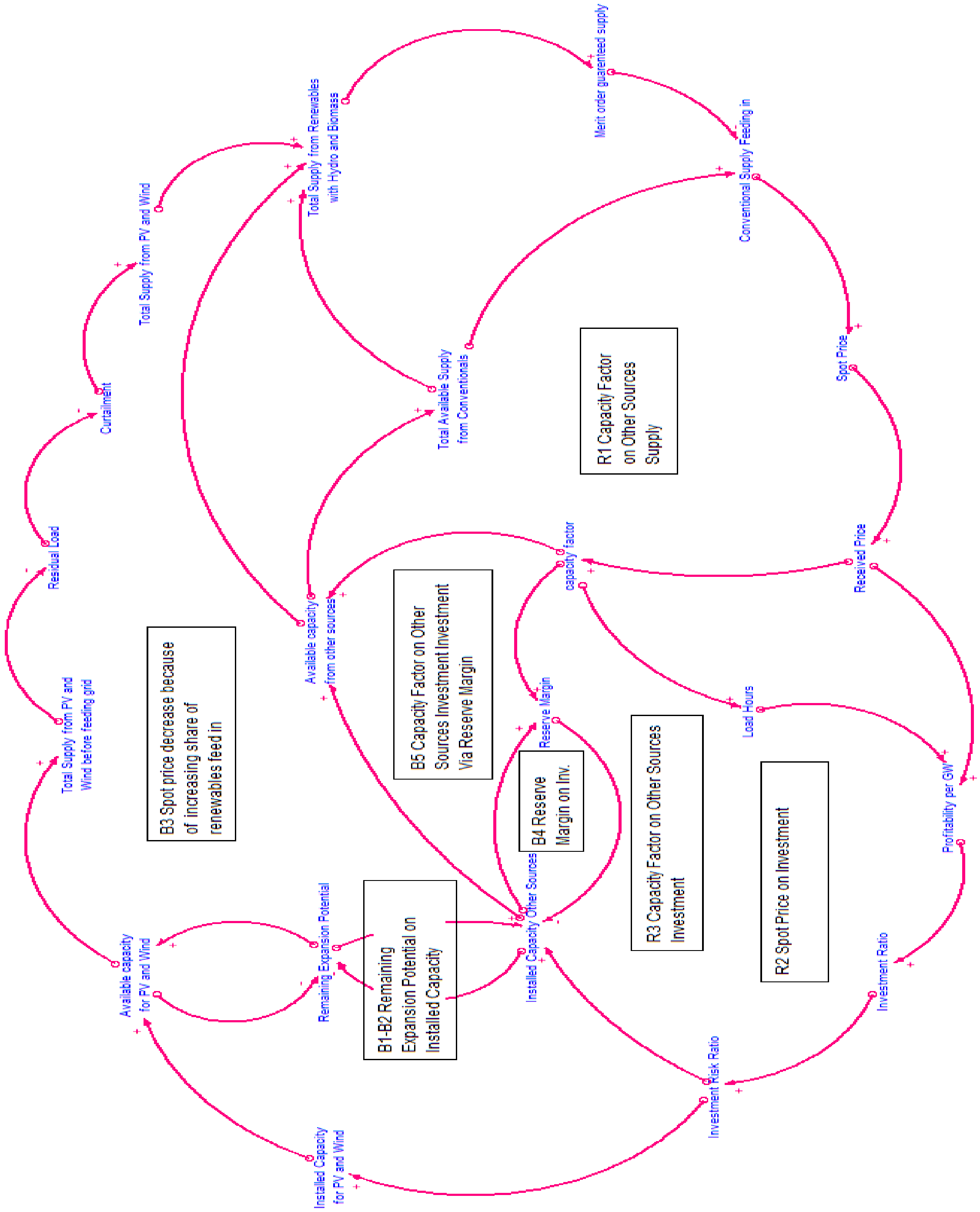

Figure 2: First Causal Loop Diagram of the Model

The first Causal Loop Diagram of the model has five balancing loops and three reinforcing loops.

The first and second balancing loops of the model are *Remaining Expansion Potential on Installed Capacity.* When installed capacity of all technologies increase, remaining expansion potential of all technologies decrease and investment rate of all technologies and so installed capacity of all technologies decrease in turn.

The third balancing loop of the model is *Spot price decrease because of increasing share of renewable sources feed in.* When installed capacity for Solar PV and Wind increase, Total Supply from Solar PV and Wind increase as well and it reduces the amount of total supply from conventional sources. Then, spot price diminishes because of lower variable cost of Solar PV and Wind plants. Afterwards, spot price reduction diminishes profitability of all technologies and so it decreases investment rate of all technologies and so installed capacity of all technologies decrease in turn.

The fourth balancing loop of the model is *Reserve Margin on Investments*. When investment rate of all technologies and installed capacity of all technologies increase, expected supply of the system in the future increases and so expected reserve margin increases. Then, investment rate of other sources and so installed capacity of other sources decreases because increasing reserve margin provides supply security and so investment on other sources is less required.

The fifth balancing loop of the model is *Capacity Factor on Other Sources Investment via Reserve Margin.* When installed capacity of other sources increase, total supply from conventional sources increase and it arises spot prices. When spot price increases, capacity factor of other sources increases and it boosts reserve margin through expected supply in the future. Then, it reduces investments on other sources with the mechanism of fourth balancing loop.

The first reinforcing loop of the model is *Capacity Factor on Other Sources Supply.* When available capacity from other sources increase, total supply from conventional sources increase and so spot prices rise. When spot price increases, capacity factor of other sources increases and it increases available capacity from other sources again.

The second reinforcing loop of the model is *Spot Price on Investment.* When installed capacity of other sources increase, total supply from conventional sources increase and it arises spot prices. Then, spot price increases profitability of all technologies and so investments on all technologies increase. Eventually, capacity of other sources rises again.

The third reinforcing loop of the model is *Capacity Factor on Other Sources Investment.* When installed capacity of other sources increase, total supply from conventional sources increase and it arises spot prices. Then, spot price increases capacity factor of other sources and so load hours of other sources increase. Afterwards, load hours of other sources rise profitability per GW for other sources. Eventually, investments on capacity of other sources increase and so capacity of other sources increase again.

Some particular variables on the second Causal Loop Diagram is defined explicitly below:

Accumulated Production: It represents how many “GW Hours” each technology generated electricity.

Ratio of PV and Wind Feeding in and **Ratio of Conventional Feeding in:** It shows the percentage of electricity generation feeding in the grids.

Load hours: It represents how many hours electricity plants work actively in a year depending on their capacity factor and their ratio of feeding in by technology.

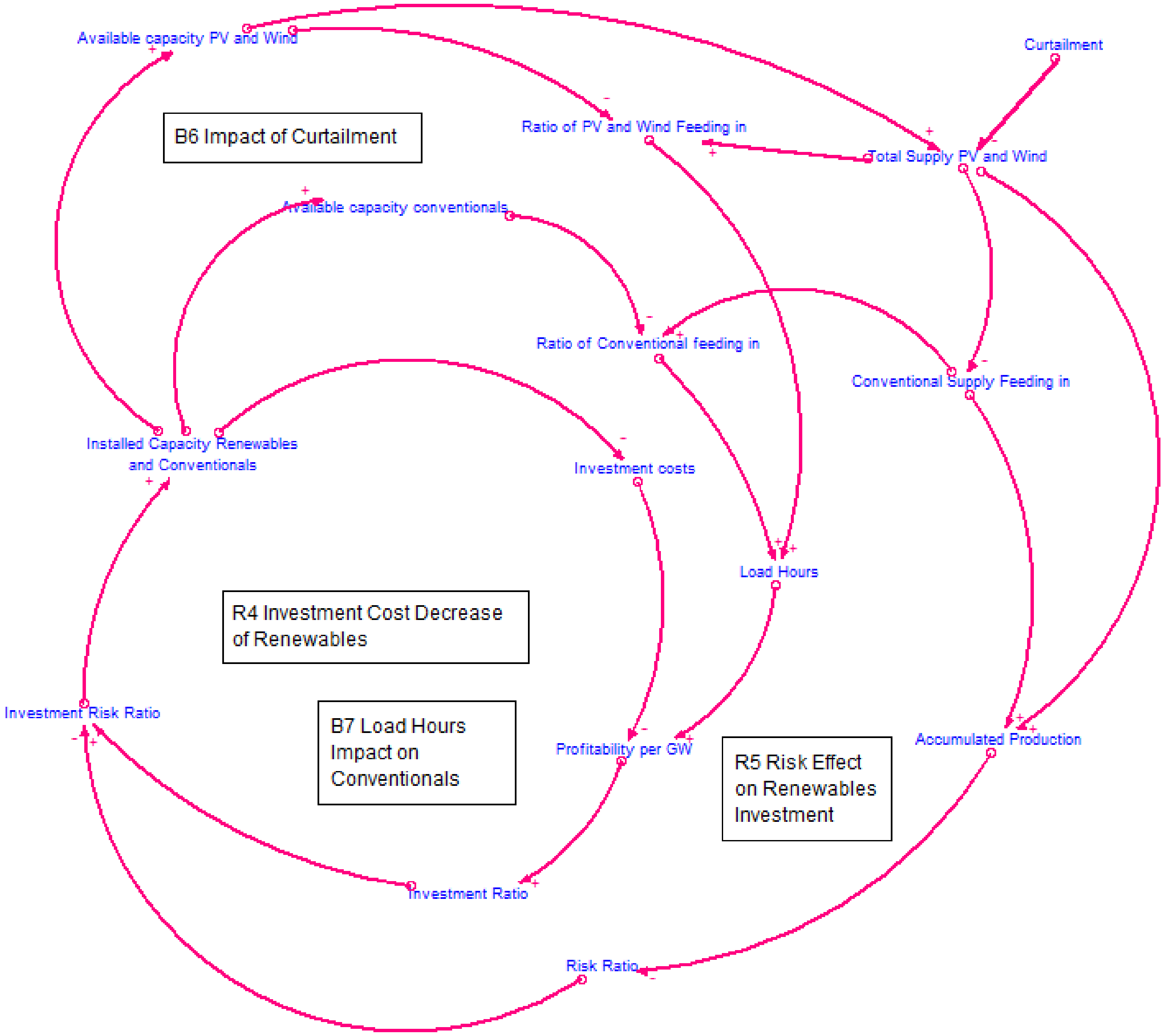

Figure 3: Second Causal Loop Diagram of the Model

The sixth balancing loop of the model is *Impact of Curtailment*. When installed capacity of Solar PV and Wind Plants increase, available capacity from Solar PV and Wind Plants increase as well. However, it reduces the ratio of Solar PV and Wind feeding in due to the curtailment of Solar PV and Wind Plants. Then, the ratio of Solar PV and Wind feeding in decreases load hours and so profitability of Solar PV and Wind Plants. Eventually, it reduces investments on Solar PV and Wind Plants and installed capacity of Solar PV and Wind Plants decrease in turn.

The seventh balancing loop of the model is *Load Hours Impact on Conventional.* When installed capacity of conventional sources increase, available capacity from conventional sources increases as well. However, it reduces the ratio of conventional sources feeding in due to grid priority of renewable energy sources. Then, the ratio of conventional sources feeding in decreases load hours and so profitability of conventional sources. Eventually, it reduces investments on conventional sources and installed capacity of conventional sources decrease in turn.

The fourth reinforcing loop of the model is *Investment Cost Decrease of Renewable.* When installed capacity of all technologies increase, investment costs of all technologies decrease due to the increasing learning rates. Then, decreasing investment costs rise profitability of all technologies. Eventually, it increases investments on all technologies and installed capacity of all technologies increase again. However, this loop mainly works for renewable energy sources because the learning rates of conventional energy sources are already too high.

The fifth reinforcing loop of the model is *Risk Effect on Renewable Investment.* When installed capacity of all technologies increase, total supply from all technologies increase as well. Then, accumulated production rises and increment on accumulated production reduces the risks for all technologies. Thus, it increases investments on all technologies and installed capacity of all technologies increase again. However, this loop only works for renewable energy sources because the risks of conventional energy sources are already minimum.

4.3 Model Sectors

In this section, the model sectors are explained in a detailed way. Some sectors are elaborated together because they have important relationships with each other.

4.3.1 Physical Capacity Sectors and Remaining Expansion Potential Sector

Physical Capacity Sectors and Remaining Expansion Potential Sector are elaborated together in this section of the study because they have significant relationships with each other.

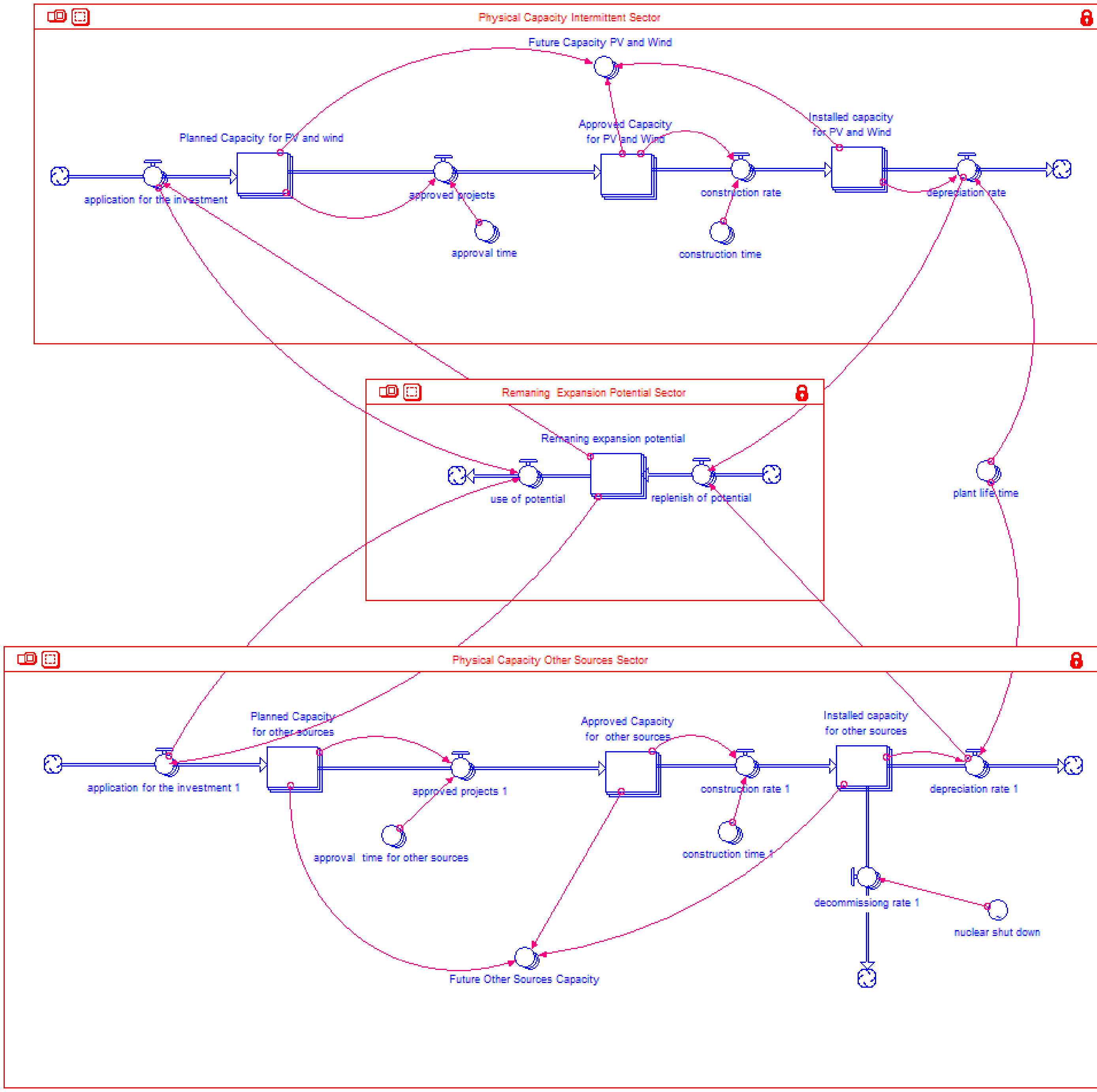

Figure 4: Stock and Flow Diagram of Physical Capacity Intermittent Sector, Remaining Expansion Potential Sector and Physical Capacity Other Sources Sector

A supply chain is made for the physical capacities of the electricity plants. The supply chain consists of the planned capacity and the approved capacity which eventually makes up the stock of the installed capacity (Sterman, 2000). In the chain, there is a delay whose duration changes depending on the type of the technology for both approval and construction. After the investment decision, it takes time for the legal authorities to approve the projects and then it takes time to construct the electricity plants until the electricity plants are ready to generate electricity.

Depreciation rate in the model depletes the stock of installed capacity. Baldwin et al. (2005) describe about the straight line depreciation of installed capacities. Thus, it is assumed in the model that the installed capacity is depreciated equally every year depending on the life time of electricity plants.

The equation for the depreciation rate of Solar PV is:

Depreciation_rate[Solar_PV]*=Installed_capacity_for_PV_and_Wind[Solar_PV]/plant_life_time[Solar_PV]*

The equation is applied for all technologies in the model except nuclear plants. Germany announced to decommission their all nuclear capacity until the end of 2022. The report of the Energiewende (2015) provides yearly the decommissioning rate of nuclear plants from 2000 until the end of 2022. Thus, decommissioning rate for the nuclear plants is constructed in the model and depreciation rate for the nuclear plants is ignored. The data for plant life time in years by technology is taken from the report of the Fraunhofer Institute in 2013.

The installed capacity of all technologies is one of the main stocks in the model. Initial capacity level of the installed capacities is taken from the database of the Fraunhofer Institute. I could not find the data for the initial capacity of planned capacity and approved capacity by technology. However, the initial total planned and approved capacities were found in the literature and they are taken from the report of the Capgemini (2007). These capacities are distributed to each technology except nuclear plants because there is no planned investment on nuclear plants due to the phase-out of nuclear technology. The initial total planned capacity is 33,250 GW and the initial total approved capacity is 13,659 GW in the report.

Table 2 illustrates Initial Planned Capacity, Initial Approved Capacity and Initial Installed Capacity by technology.

Table 2	Initial Planned Capacity	Initial Approved Capacity	Initial Installed Capacity
Solar PV	7,31	1,88	2,06
Wind Onshore	8,07	2,83	18,38
Wind Offshore	0,64	0,00	0
Nuclear	0,00	0,00	20,34
Hard Coal	5,31	2,97	27,64
Natural Gas	5,28	2,49	20,6
Lignite	3,93	2,23	20,68
Biomass	1,67	0,69	3,53
Hydro	1,04	0,57	5,21
Total	33,25	13,66	118,44

Table 2: Initial Planned Capacity, Initial Approved Capacity and Initial Installed Capacity by technology

As it can be seen in the stock and flow diagram of the sector, it takes time for the projects to be approved and constructed and there is a shift in the German electricity market that investments on renewable energy sources increase much faster than investments on conventional energy sources. Thus, the initial total planned capacity is distributed to each technology based on the share of each technology on the total installed capacity in ten years and the initial total approved capacity is distributed to each technology based on the share of each technology on the total installed capacity in five years. Ten years implies average time for a plant to start generating electricity after the investment decision is taken. Five years implies average time for a plant to start generating electricity after the project is approved by the German legal authorities.

Future Capacity in the model represents the sum of planned capacity, approved capacity and installed capacity. The equations for future capacity are:

Future_Capacity_PV_and_Wind[Interminent_technology]=*Approved_Capacity_for_PV_and_Wind+Installed_capacity_for_PV_and_Wind+Planned_Capacity_for_PV_and_wind*

Future_Other_Sources_Capacity[Other_technology]=*Approved_Capacity_for__other_sources+Installed_capacity_for_other_sources+Planned_Capacity_for_other_sources*

Future capacity is used for the calculation of reserve margin in the model and it is explained in the Reserve Margin Sector in the study.

Kubli (2014) modeled Remaining Expansion Potential explicitly. She stated that designing it explicitly in the research reports is common and this stock has an explanatory value that helps to communicate in order to show the potential of the technologies. Moreover, she asserted that the implications of the estimations for the potential of the technologies can be tested directly in these reports.

Remaining Expansion Potential is modeled as a stock in the model. This stock is depleted by the investment rate and it is replenished by the depreciation rate. The initial level of Remaining Expansion Potential is the difference between total potential and the initial installed capacity by technology.

Total potential level by technology is taken from the joint report of the Fraunhofer Institute, DLR, Stuttgart Institute, IFNE and Teltow in 2012. The values for the potential of each technology are taken from the “Scenario 2011 A” in the report. However, the potential value for Onshore Wind is very pessimistic in this scenario and so the upper limit at the “Scenario THG95” is used for Wind. Then, the difference between the upper limit of Wind and the potential for Offshore Wind at the “Scenario 2011 A” is calculated for the potential of Onshore Wind in the model.

There are two common values representing the potential capacity feeding in the EU power grid for the category of solar-thermal plants and for the category of wind-other renewable in the “Scenario 2011 A”. The potential capacity value for the category of solar-thermal plants is distributed to the thermal plants because electricity generation from the Solar PV feeds in the national grids almost fully due to grid priority and its low variable cost. The potential capacity value for the category of wind-other renewable is distributed to the Biomass because electricity generation from the Wind feeds in the national grids almost fully due to grid priority and its low variable cost and Biomass has much more expansion potential than Hydro as it is suggested by the study. Table 3 presents total potential and initial remaining expansion potential.

Table 3	Total Potential	Remaining Expansion Potential
Solar PV	67,3	65,24
Wind Onshore	83,3	64,92
Wind Offshore	32	32
Nuclear	20,43	0
Hard Coal	30,1	2,46
Natural Gas	38	17,4
Lignite	26,4	5,72
Biomass	14,3	10,77
Hydro	5,2	0
Total	317,03	198,51

Table 3: Total Potential and Initial Remaining Expansion Potential

4.3.2 Residual Load and Curtailment Sector, Production Sector and Demand Sector

The relationships of the variables in these sectors are shown in the Figure 5.

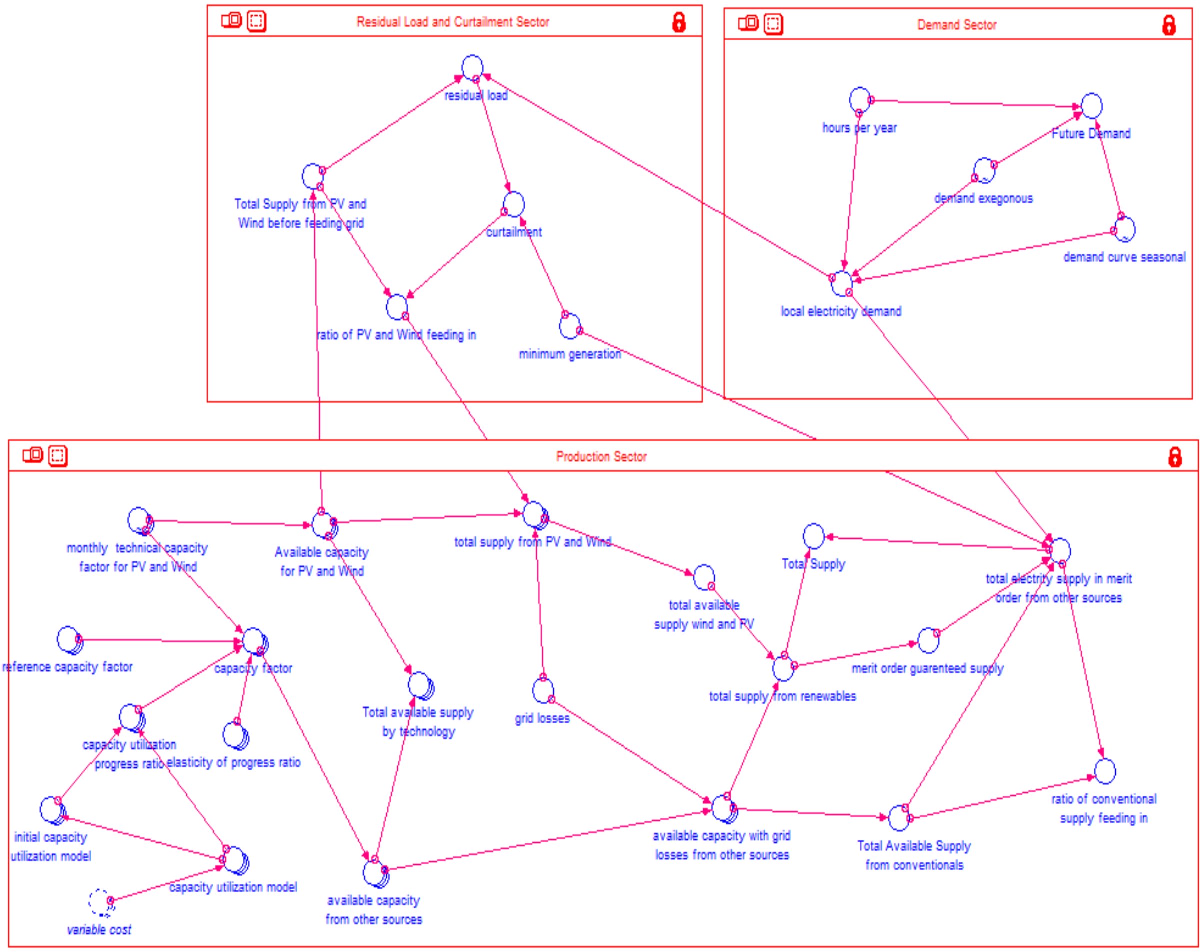

Figure 5: Relationships of the variables of Residual Load and Curtailment Sector, Production Sector and Demand Sector

Production sector is one of the main sectors in the model with the sector of physical capacity because they determine the amount of the electricity feeding in the national grids together. Residual Load and Curtailment Sector is also important to portray the supply security related variables in the model.

The installed capacity of power plants imply maximum amount of electricity generation if they work in a full capacity but any type of power plants do not work in a full capacity. Thus, the unit of installed capacity in the model is GW and the unit of electricity generation is GW Hours. In the literature, the ratio of running an electricity plant is called as capacity factor. Kubli (2014) describes two components for the capacity factor, which are the seasonal availability implying if power plants are ready to produce electricity technically and capacity utilization implying if it is profitable to generate electricity for a power plant.

Solar PV and Wind Plants suffer from the technical availability because sun and wind are not always present to generate electricity. However, their economic availability is always maximum because their variable cost is close to zero. Thus, the only restriction to generate electricity is stemming from the intermittency of the presence of sun and wind for Solar PV and Wind plants and technical availability presents it in the model.

It is impossible to predict daily fluctuations of Solar PV and Wind and it is beyond of the purpose of this study. That is why monthly technical availability ratios are used in the model to represent the fluctuations of the intermittent sources.
The monthly technical availability for Solar PV and Onshore Wind is taken from the reports of the European Network of Transmission Operators for Electricity in 2014 and 2015. However, the monthly technical availability for Offshore Wind could not be found in the literature. However, placing the monthly technical availability for Offshore Wind is significant for this study so historic electricity generation data from Offshore Wind in 2015 and in the beginning of 2016 is used to calculate the monthly technical availability. This dataset is taken from the database of the Fraunhofer Institute.
The formula to calculate available capacity for Solar PV and Wind before feeding in the grids is:
Available_capacity_for_PV_and_Wind[Solar_PV]*=monthly__technical_capacity_factor_for_PV_and_Wind[Solar_PV]*Installed_capacity_for_PV_and_Wind[Solar_PV]*
This formula is applied for all intermittent sources in the model.
The technical availability for other sources can be found in the report of the Generation Consulting Services in 2013. The technical availability for all other sources is over 80% in the report. Kubli (2014) modeled the economic availability as the ratio between received price and variable cost and Jäger et al. (2009) modeled capacity factor as the ratio between market price and operational cost. However, how much this ratio impacts the capacity factor or the economic availability for each technology could not be found in the literature.
Thus, the capacity factor of other sources is calculated as a linear function in the study. $f(x) = ax + b$ is the formula used in the model to calculate the capacity factor for other sources.[5]
The amount of electricity generation by technology in 2005 in GW Hours is taken from the report of DBEW and the capacity factor for each technology is computed by using the installed capacity by technology in 2005 and hours in a year. The capacity factor in 2005 is used in the model as a reference capacity factor which refers "*b*" in the main formula. It includes both technical and economical availability of each source. Then, the capacity utilization by each technology is modeled as a ratio between received price and variable cost. Afterwards, the capacity utilization progress ratio is modeled to calculate how much the capacity utilization progresses compared with its initial level. It refers *"x"* in the main formula. Elasticity of progress ratio in the model refers to *"a"* in the main formula. The assumptions based on the report of the European Copper Institute in 2014 are made for the elasticity of progress ratio. The elasticity of progress ratio comes from the flexibility of each

[5] Available on https://en.wikipedia.org/wiki/Linear_function

technology to start and shut down electricity production based on the report. The sensitivity analysis of capacity factor for other sources is conducted in the Validation section of this study.
The equations to calculate capacity factor for other sources are:
Capacity_utilization_progress_ratio[Other_technology]=*capacity_utilization_model/initial_capacity_utilization_model-1*
Capacity_factor[Hydro]=*reference_capacity_factor[Hydro]+elasticity_of_progress_ratio[Hydro]*capacity_utilization_progress_ratio[Hydro]*
The reason to subtract 1 in the first formula stems from how many percent the capacity utilization increased or decreased compared with the initial level. The capacity utilization progress ratio is negative for conventional technologies in the model and positive for Hydro and Biomass based on the simulation results.
The equation for capacity factor Hydro is applied for all other sources in the model.
Available capacity from other sources before feeding in the grids is calculated with this formula:
Available_capacity_from_other_sources[Nuclear]=*Installed_capacity_for_other_sources[Nuclear]*capacity_factor[Nuclear]*
The formula is applied for all other sources.
In the production sector, supply from the power plants are measured in GW because the supply represents a flexible time span and electricity demand is measured in GW to be compatible with unit of supply (Kubli,2014). Historic electricity demand in GW Hours is taken from the report of the Agora Energiewende in 2016. To forecast the electricity demand from 2016 until 2050, the reduction targets set by the German government for 2020 and 2050 are used (Energiewende, 2015). The electricity demand is reduced equally per year until 2020 compatible with the target for 2020. Then, the electricity demand is reduced equally per year compatible with the target for 2050 from 2020 until the end of simulation time frame.
Electricity demand in a year fluctuates depending on the seasonality so monthly demand curve is used to calculate the monthly electricity demand in the model. Historic monthly electricity consumption data is taken from the database of European Network of Transmission Operators for Electricity and then it is transformed into the monthly demand curve.
Hours per year variable is used in the model to transform electricity demand from GW Hours to GW to correspond with unit of the supply in the model. Net electricity trades with the neighbor countries are ignored not to complicate the model. Thus, total supply and total demand cover only local levels in the study.
The equation for local electricity demand is:
Local_electricity_demand=*(demand_curve_seasonal*demand_exegonous)/hours_per_year*

Residual Load in the model is calculated correspondingly with the definition made in the theoretical background of the study. The equation is:

Residual_load *= local_electricity_demand-Total_Supply_from_PV_and_Wind_before_feeding_grid*

Curtailment of Solar PV and Wind Plants is substantial to figure out how many percent of electricity generation from Solar PV and Wind Plants feed in the national grids in Germany and it is highly related with the minimum generation from the conventional power plants.

Conventional power plants in Germany should not produce electricity less than a particular level for supply security reasons and it is called minimum generation in the study. Minimum generation level is assumed constant in the model in GW and the amount of minimum generation is taken from the Green Paper in 2014.However, minimum generation level is changed in the model for scenario analysis in the Scenario Analysis section of this study. Minimum generation is main variable to compute the curtailment in the model and there is no curtailment if residual load is bigger than minimum generation. The equation for the curtailment is:

Curtailment*=IF(residual_load>minimum_generation),THEN(0) ELSE(minimum_generation-residual_load)*

As a simplification in the model, it is assumed in the model that curtailment impacts Solar PV, Onshore Wind and Offshore Wind equally.

The formula of the ratio of Solar PV and Wind feeding in is:

Ratio_of_PV_and_Wind_feeding_in*=(Total_Supply_from_PV_and_Wind_before_feeding_grid-curtailment)/Total_Supply_from_PV_and_Wind_before_feeding_grid*

When electricity is transmitted and distributed, it cannot reach to end customers completely so grid losses of electricity occur in the reality. Thus, the ratio for grid losses is constructed in the model and the data is taken from the database of the World Bank. As a result, supply from Solar PV and Wind Plants is calculated with the grid losses and curtailment by this formula:

Total_supply_from_PV_and_Wind[Interminent_technology]*=ratio_of_PV_and_Wind_feeding_in*(1-grid_losses)*Available_capacity_for_PV_and_Wind*

Total available capacity from other sources is calculated in the model by taking the grid losses into account. This variable represents supply from conventional technologies if their all electricity generation were fed in the grids. However, it represents real supply for Hydro and Biomass plants in the model because all of their electricity generation is fed in the grids.

Total available capacity from other sources for Biomass and Hydro and total available supply from Solar PV and Wind make up total supply from renewables in the model. The formula for this variable is:

Total_supply_from_renewables=*total_available_supply_wind_and_PV+available_capacity_with_grid_losses_from_other_sources[Biomass]+available_capacity_with_grid_losses_from_other_sources[Hydro]*

Renewable power plants have grid priority in the grids in Germany so total supply from renewable sources make up merit order guaranteed supply variable. It is important for the communication of the model to punctuate the priority of renewable power plants in the merit order to sell electricity.

Local demand which cannot be met by the renewable energy sources is provided by the conventional energy sources in Germany and it is compatible with the real state of the system. However, the conventional energy sources in Germany should produce electricity at least in minimum generation level even if it is not necessary to meet local demand. Also, the conventional energy sources cannot meet local demand more than their available capacity with the grid losses.

These considerations are taken into account in the formula for total electricity supply in merit order from conventional energy sources and the formula is:

Total_electrity_supply_in_merit_order_from_conventionals=*MIN(Total_Available_Supply_from_conventionals,(MAX(minimum_generation,local_electricity_demand-merit_order_guarenteed_supply)))*

The variable of ratio of conventional supply feeding in is crucial for other parts of the model and it is calculated in the production sector of the model. As a simplification, this ratio is assumed equal for Natural Gas, Lignite and Hard Coal technologies although they have different variable costs and it is assumed that the electricity generation from the nuclear plants feed in the grids completely due to their low variable cost.

4.3.3 Spot Market Sector and Received Price Sector

Spot Market Sector and Received Price Sector are elaborated together in this section because they are highly connected sectors of the model.

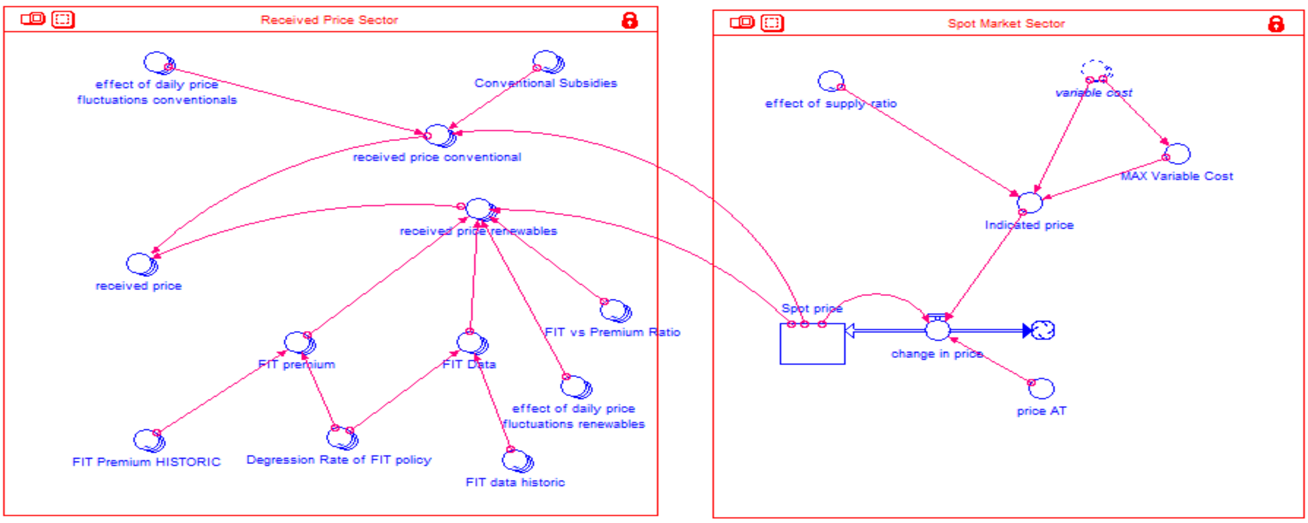

Figure 6: Stock and Flow Diagram of Received Price Sector and Spot Market Sector

Spot price of electricity is determined on the power wholesale market.[6] Thus, it does not include the cost of grid operators, electricity distributors and the tax of end customers. Therefore, only the variable costs of the power plants are taken into account in the model to calculate the electricity spot price and it is compatible with the knowledge given in the Theoretical Background of the study about the merit order.

The spot price in the model is modeled as a stock in order to avoid circular connections for the capacity utilization and it is a goal-seeking process between indicated price and spot price (Kubli, 2014). The idea to construct the indicated price comes from the generic price structure of Sterman (2000). However, the formula for the indicated price in this model is different from the formula of generic price structure of Sterman(2000) to represent the structure of electricity market in Germany more realistically.

Effect of conventionals supply ratio variable is used to calculate the indicated price in the model and the effect depends on the variable of ratio of conventional supply feeding in .Indicated price decreases when the ratio of conventional supply feeding in decreases. The graphical function for the effect of conventionals supply ratio is illustrated below:

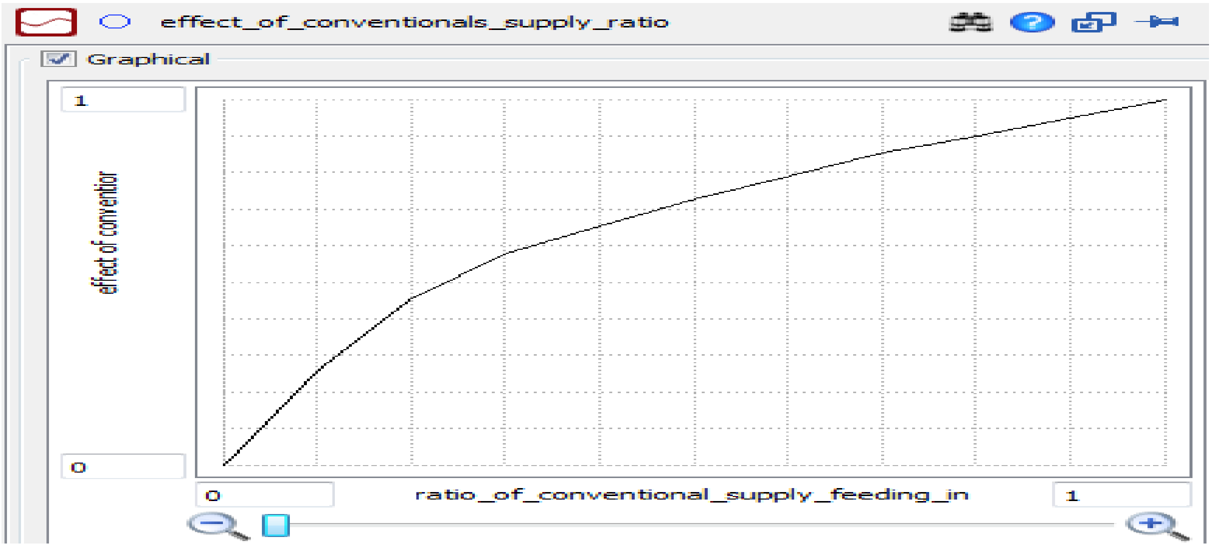

Figure7: Graphical function for effect of conventionals supply ratio

In the graph, the effect changes slowly when the ratio of conventional supply feeding starts to decrease from 1 and the effect changes increasingly when the ratio of conventional supply feeding approaches to zero. The effect represents the impact of supply from conventional sources to raise the spot price in the model so spot price decreases as well when the ratio of conventional supply feeding decreases. The sensitivity analysis of this variable is conducted in the Validation section of this study.

[6] Available on https://www.epexspot.com/en/company-info/basics_of_the_power_market/negative_prices

The variable cost of Biomass plants is the highest among renewable energy sources and so if no electricity from the conventional plants feed in the electricity system, electricity spot price is equal to the variable cost of Biomass plants. Also, if all electricity generation from the renewable power plants feed in the electricity system, electricity spot price is equal to the highest variable cost of conventional technologies. Therefore, indicated price in the model varies between the variable cost of Biomass plants and maximum variable cost of the conventional plants depending on the effect of conventionals supply ratio. The formula for indicated price in the model is:

Indicated_price *= (MAX_Variable_Cost*effect_of_conventionals_supply_ratio)+(1-effect_of_conventionals_supply_ratio)*variable_cost[Biomass]*

Spot price is assumed to adjust to the indicated price monthly to be compatible with the demand curve and the technical availability for Solar PV and Wind in the model. Power plant investments are stimulated with the different tools for renewable energy sources and conventional energy sources in Germany. Renewable electricity plant investments are supported by the financial FIT policies and conventional electricity plant investments are supported by the subsidies. Thus, received price for renewable and conventional energy sources are modeled distinctly in the study. The unit for spot price, received price, subsidies and FIT policies is Euro/GW Hours.

Electricity generation from power plants by technology varies during a day because of the technical barriers of Solar PV and Wind Plants. Therefore, power plants by technology sell their electricity generation by different average spot price. This aspect is captured in the model with the variable of daily price fluctuations. The data to compute daily price fluctuations variable is taken from the report of the Fraunhofer Institute in 2016. The spot price received by each technology is divided to the average spot price in the report to calculate daily price fluctuations variable in the model. The data for conventional subsidies is taken from the joint report of the Greenpeace Energy EG and the German Wind Energy Association BWE in 2012. However, the subsidies for natural gas are too low in the report so the subsidies data for natural gas is taken from the report of European Commission in 2014. Received price for conventional energy sources is formulated as:

Received_price_conventional[Conventional]*=Spot_price*effect_of_daily_price_fluctuations_conventionals+Conventional_Subsidies*

Two types of financial FIT policies are applied in Germany to stimulate renewable energy sources. Only Fixed-Price FIT policy was applied until 2012 in Germany but Fixed-Price FIT policy and FIT Premium policy have been applied together since 2012 in Germany. Therefore, FIT vs Premium Ratio variable in the model is constructed to determine the amount of electricity generation for received Fixed-Price FIT and FIT Premium by technology. The data to calculate the financial FIT prices and the FIT vs Premium Ratio is taken from the reports of the Information Platform of the 4 German Transmission System Operators from 2006 until 2015. Total payments for Fixed-Price FIT and FIT Premium by technology and total electricity generation for Fixed-Price FIT and FIT Premium by technology are presented in the report and they are used to calculate related variables in the model.

Financial FIT rates are decreasing annually in Germany from 2016 to lower the EEG surcharge on the electricity customers (IRENA, 2015). The digression rates by technology on the FIT rates are taken from the Irena, “Remap 2030”, in 2015 to capture the phenomena in the model.

FIT refers to Fixed-Price FIT in the model. FIT Premium and FIT Data in the model are calculated by the digression rates and the historical data. The equation is:

FIT_Data[Renewables] *= IF(TIME<2016),THEN(FIT_data_historic) ELSE(FIT_data_historic*(1-Digression_Rate_of_FIT_policy))*

Electricity plants benefiting from Fixed-Price FIT receive fixed price for their electricity generation and electricity plants benefiting from Fixed Premium receive premium price on spot price for their electricity generation. Thus, the equations for these two policies to calculate received price are different. Moreover, the FIT vs Premium Ratio is used to calculate the final received price for renewable energy sources by technology and it is assumed constant in the model from 2015.

The formula for the received price renewables variable is:

Received_price_renewables[Renewables]*=((FIT_Data*FIT_vs_Premium_Ratio)+(Spot_price*effect_of_daily_price_fluctuations_renewables+FIT_premium))/(1+FIT_vs_Premium_Ratio)*

4.3.4 Investment Cost Sector and Learning Curve Sector

The stock and flow diagram of this section in the study is shown in the Figure 8.

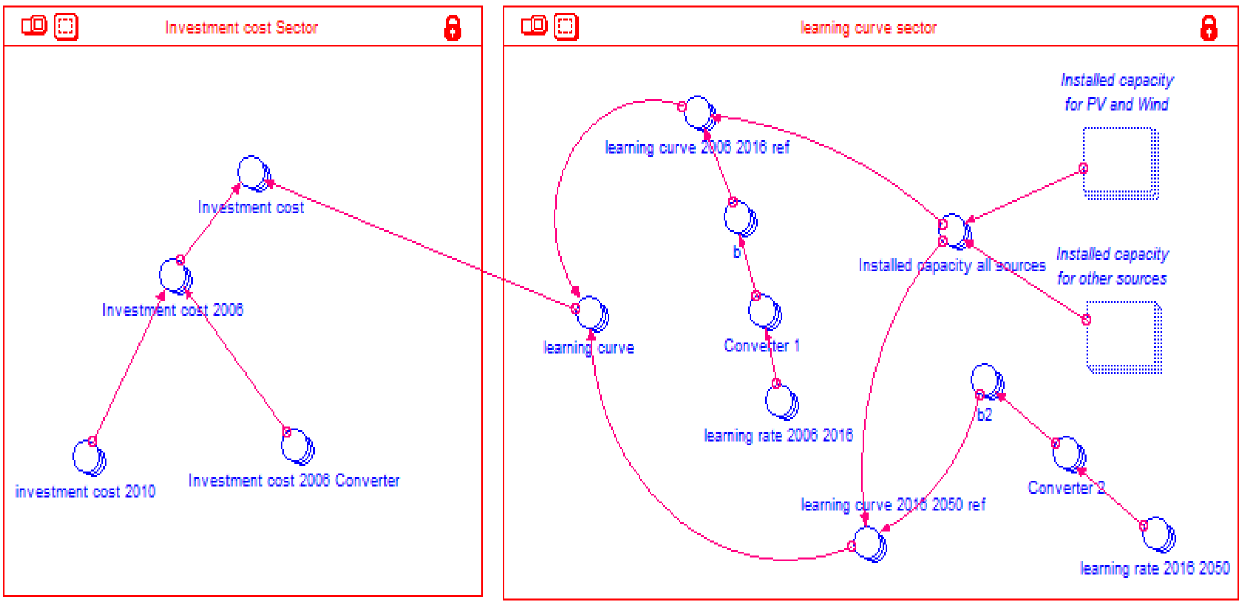

Figure 8: Stock and Flow Diagram of Investment Cost Sector and Learning Curve Sector

The report of the IRENA in 2015, “Renewable Power Generation Costs In 2014”, states that investment costs of renewable technologies decrease by the high learning rates of these technologies and the learning curve for these technologies is a function of cumulative installed capacity. Thus, the learning curve variable in the model is the function of installed capacities by technology.
The formula to calculate the learning curve is taken from the study of Stump (2014). The learning rates by technology are taken from the study of Azevedo et al (2013). The learning rates by technology between 2006 and 2015 are taken directly from the study of Azevedo et al. (2013). The learning rates by technology after 2015 are assumed to have constant values yearly for the simplification reason of the model and so constant learning rates by technology after 2015 are calculated with the geometric mean formula by using different learning rates for different time span in the study. The formulas to calculate the learning curve are:
Converter_1[All_technology] *= 1-learning_rate_2006_2016*
b[All_technology] *= (LN(Converter_1)/LN(2))*-1*
Learning_curve_2006_2016_ref[All_technology]*=(Installed_capacity_all_sources/INIT(Installed_capacity_all_sources))^-b*
Same formula is applied in the model to calculate the learning curve after 2015 with the different learning rates. Then, a general learning curve variable is constructed in the model to cover these two learning curves. In the formula for the variable of learning curve, the multiplication of these two learning curves is divided into the historical value of the second learning curve in 2016 to prevent the double effect of it.
Learning_curve[All_technology]*=IF(TIME>2016)*
*THEN(learning_curve_2016_2050_ref*HISTORY(learning_curve_2006_2016_ref,2016))/(HISTORY(learning_curve_2016_2050_ref,2016))*
else(learning_curve_2006_2016_ref)
In the literature, I could not find meaningful data for the investments costs by technology in 2006. However, the investments costs by technology in 2010 are found in the report of the DIW Berlin in 2013. The learning rates in the model and historic installed capacities are used to calculate the investment costs in 2006 by technology to be coherent in the study.
Initial value for the learning curve in the model is 1 for all technologies because of the nature of the formula for learning curve. When installed capacity by technology increases in the model, the learning curve decreases and it reduces the investment costs by technology. However, installed capacity of conventional energy sources might decrease in the model so the learning curve is restricted not to work in the model if it is bigger than 1 to prevent increment on the investment costs. Also, the investment cost variable is divided to 1 million to convert the unit of investment costs into Million Euros/GW.

Investment_cost[All_technology] = IF(learning_curve<1) then((Investment_cost_2006*learning_curve)/1000000) ELSE(Investment_cost_2006/1000000)

4.3.5 Profitability Sector

Profitability Sector is one of the main sectors in the model because this sector drives the investments in the model.

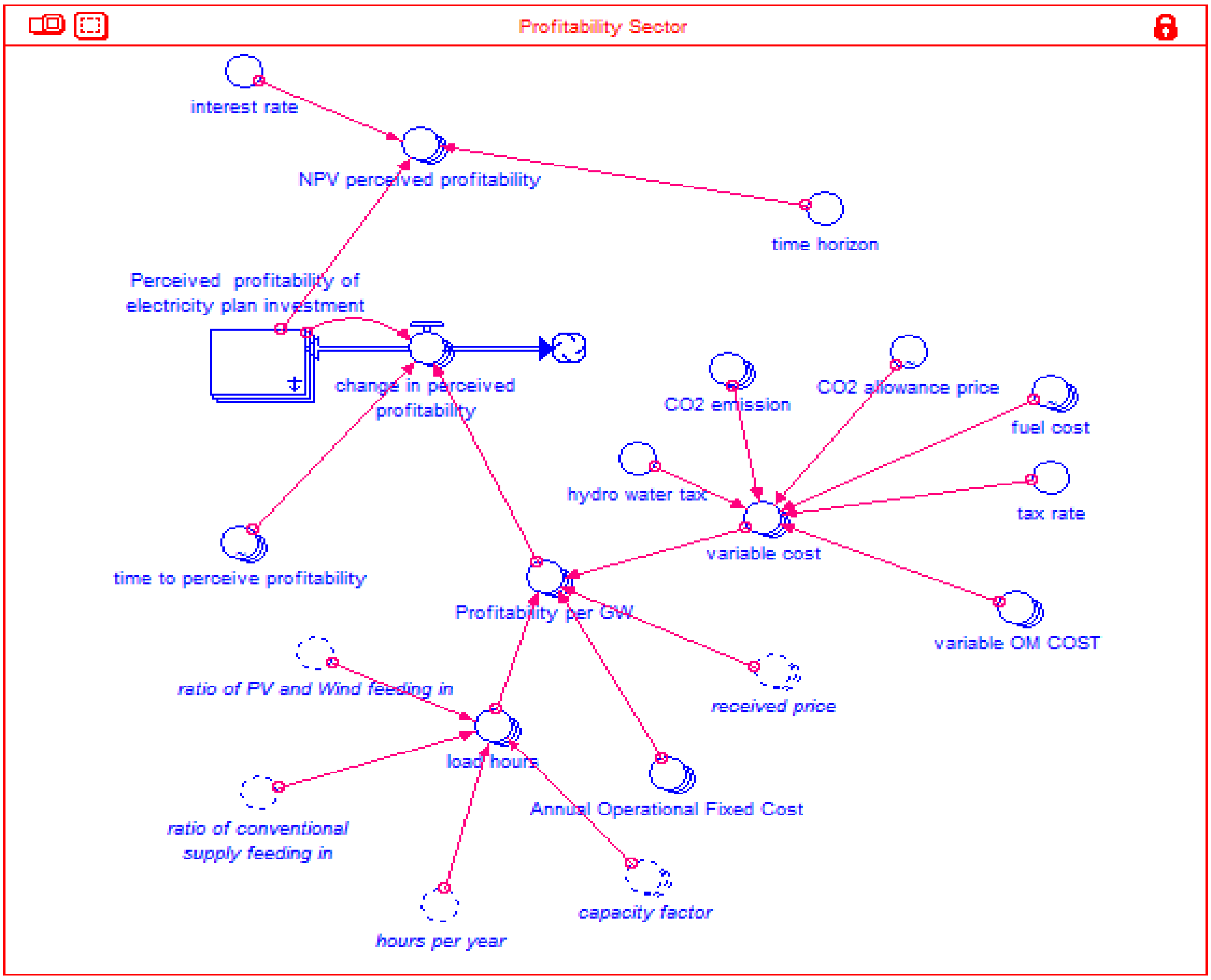

Figure 9: Stock and Flow Diagram of Profitability Sector

Variable costs of the technologies have different components in the model. Fuel cost is one of the components of variable cost in the model. All conventional technologies and Biomass plants have fuel cost and the data for fuel cost is taken from the report of the Fraunhofer Institute in 2013.

Power plants emitting CO2 have to pay CO2 tax in Germany. The cost of CO2 tax and CO2 emissions by technology are taken from the report of the Fraunhofer Institute in 2013 to calculate total CO2 emission cost per technology in the model. Only Lignite, Hard Coal and Natural Gas have CO2 emission costs in the model because CO2 emissions from renewable energy sources and nuclear plants are very low so they are ignored in the model. Fuel cost by technology and CO2 tax rate are variable in the model and they include the projections until 2050.

Another component for the variable cost is variable operation and maintenance cost. The data for variable operation and maintenance cost by technology is taken from the report of the DIW Berlin in 2013. Renewable energy sources do not have variable operation and maintenance cost in the model and their maintenance costs are covered on their fixed costs in the model. Variable operation and maintenance costs of conventional energy sources are constant in the model.

The tax rate for electricity sales in GW Hours is taken from the EEG Law in Germany. According to the Law, renewable energy plants are exempted from paying tax for electricity sales. Also, hydro plants have to pay hydro water tax and the rate is taken from the EEG law. Both tax rates are constant in the model.

All variable cost components make up variable cost by technology and the unit of variable cost is Euro/ GW Hours in the model.

The unit of Profitability in the model is Million Euros/GW so the variable cost and the received price must be converted into Euro/GW. Moreover, no power plants run in a full capacity so load hours by technology should be calculated in the model.

In previous studies, load hours are computed by the multiplication of capacity factor and hours in a year. However, not all electricity generation from the power plants feed in the grids to be used by the end customers. Thus, the ratio of Solar PV and Wind feeding in and the ratio of conventional feeding in are used in the model to calculate load hours for related technologies besides capacity factor and hours in a year.

The data for annual fixed costs in GW by technology is taken from the report Fraunhofer Institute in 2013. Eventually, all this variables compose the variable of Profitability and the equation for Profitability is:

Profitability_per_GW[All_technology] *= ((received_price*load_hours)-(variable_cost*load_hours)-(Annual_Operational_Fixed_Cost))/1000000*

As it is mentioned in the Theoretical Background of this study, investors have bounded rationality and humans make their decisions based on their perceptions (Kahneman 2003, Sterman 2000). Therefore, electricity plant investments are driven by the Perceived Profitability in the model. Perceived Profitability is having an adjustment process based on the Profitability in the model with the insights gained from Sterman(2000). Moreover, adjustment time to perceive profitability is modeled as a non-linear function of Accumulated Production according to Kubli (2014).

Net Present Value (NPV) is a concept widely used in the industry for investment decisions. Thus, NPV of Perceived Profitability is constructed in the model and the equation is formulated according to Kubli(2014). Other inputs are interest rate and time horizon in the model to calculate NPV of Perceived Profitability. The interest rate is chosen 5% per year and the time horizon is assumed 20 years that are compatible with the time duration of the financial FIT policies.

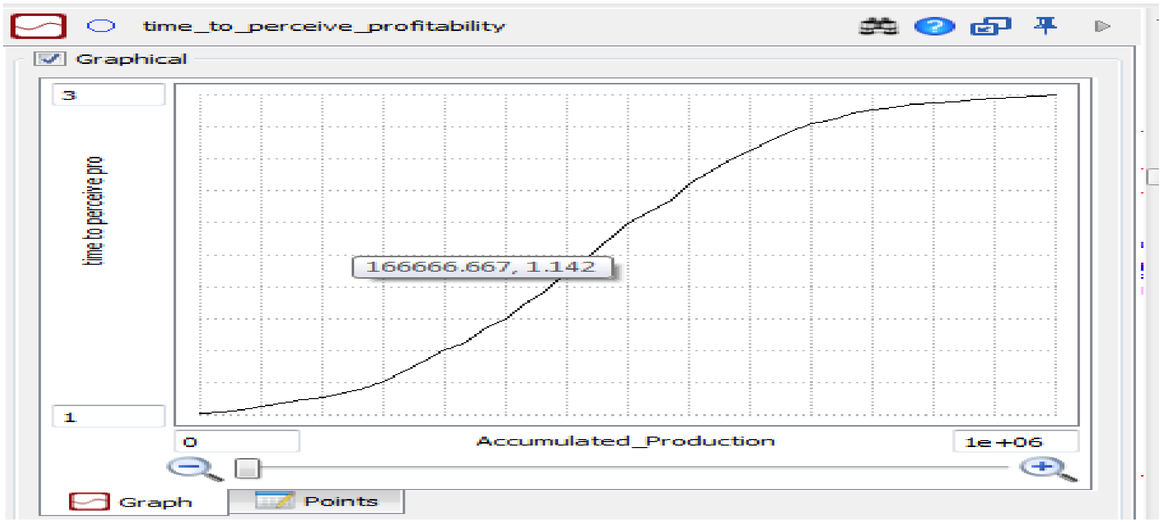

Figure10: Graphical function for adjustment time to perceive profitability

The equation for NPV of Perceived Profitability is:

NPV_perceived_profitability[All_technology] =

(Perceived__profitability_of_electricity_plan_investment(((1+interest_rate)^time_horizon)-1)/(((1+interest_rate)^time_horizon)*interest_rate))*

4.3.6 Accumulated Production Sector, Risk Sector and Investment Decision Sector

Accumulated Production Sector, Risk Sector and Investment Decision Sector are elaborated together in this section because of the interrelationships among the sectors.

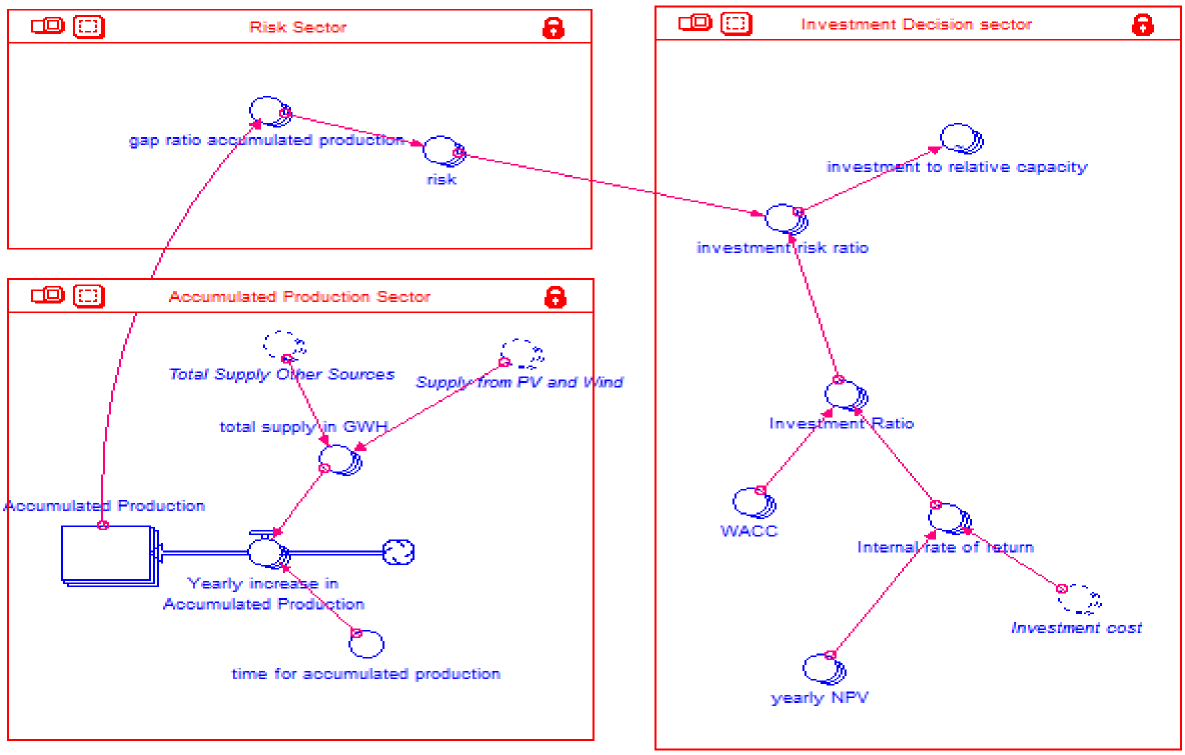

Figure 11: Stock and Flow Diagram of Accumulated Production Sector, Risk Sector and Investment Decision Sector

Masini and Menichetti (2012) state that investment decision of investors depends on how much risk they want to take because renewable energy sources are relatively new technology including risks but with big potential to provide high profit margins. Therefore, it is required to model the risk by technology in the model in order to represent the reality in the German electricity market.

Blumberga et al. (2011) decreased the risk of renewable energy sources by the accumulated production. Accumulated production in this model is used to model the risk variable correspondingly. However, different equation is used in this model to formulate the risk variable.

Initial accumulated production values by technology are taken from the report of DBEW. Accumulated production by technology increases in the model consistently due to electricity generation of all technologies. In this study, the initial risk of Hydro is assumed 1 because it is a mature technology. Thus, reference accumulated production for the risk variable in the model is the initial accumulated production of Hydro. When other renewable energy sources generate electricity, the gap is shrinking and the risk to be invested on them decreases. Furthermore, the risk in the model starts to decrease from the value of "e" with goal-seeking process until 1 due to the risk formula. Sensitivity analysis of the risk variable is conducted in the Validation Section of the model.

The equation for the risk variable is:

Risk[All_technology] *= MAX(1,EXP(gap_ratio_accumulated_production))*

The risk value by technology cannot be lower than 1 so max function is used in the formula.

Internal Rate of Return (IRR) and Weighed Average Cost of Capital (WACC) are widely used in the investment decisions in the industry. IRR is defined as "Internal rate of return is a metric used in capital budgeting measuring the profitability of potential investments. Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero".[7] With this knowledge, internal rate of return is modeled in the study. WACC is defined as "Weighted average cost of capital (WACC) is a calculation of a firm's cost of capital in which each category of capital is proportionately weighted".[8]

The values for WACC by technology in the model are taken from the report of the Fraunhofer Institute in 2013 and they are constant.

As a basic rule for investment decisions to be profitable, IRR should be bigger than WACC. Therefore, Investment ratio refers the ratio between IRR and WACC. The bigger the ratio is, the more profitable the project is. Then, investment risk ratio is calculated in the model to take the risk into account and it is a ratio between

[7] Available on http://www.investopedia.com/terms/i/irr.asp
[8] Available on http://www.investopedia.com/terms/w/wacc.asp

investment ratio and risk. The bigger the ratio is, the more feasible the project is to invest on.
Kubli (2014) used the variable of investment to relative capacity which refers to the ratio by technology to invest and the investment rate is the multiplication of this variable and future capacity by technology. However, remaining expansion capacity is used as a basis for investment rate instead of future capacity in this study as it was done in the study of Kılanc and Or (2006).
The variable of investment to relative capacity is a non-linear function of the investment risk ratio and the graphical function is illustrated in the Figure 12.

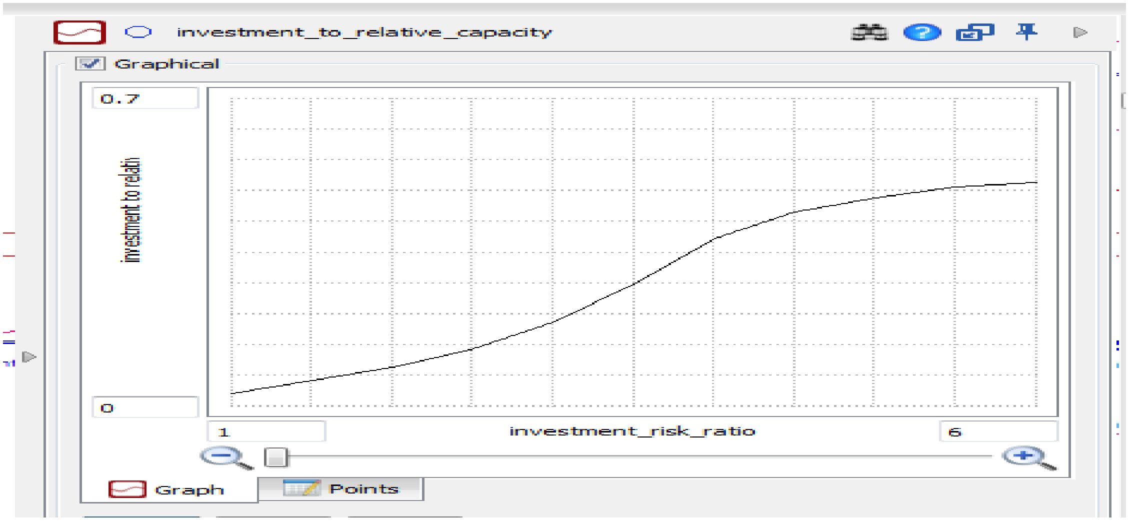

Figure12: Graphical function for investment to relative capacity

Sensitivity analysis of Investment to Relative Capacity is conducted in the Validation section of the model.
The formula of the investment rate for Solar PV and Wind is:
Application_for_the_investment[Solar_PV]=*investment_to_relative_capacity[Solar_PV]*Remaning_expansion_potential[Solar_PV]*
It is applied for Onshore Wind and Offshore Wind as well in the model.
The formula of the investment rate for other sources is:
Application_for_the_investment_1[Hard_Coal]=*investment_to_relative_capacity[Hard_Coal]*Remaning_expansion_potential[Hard_Coal]*effect_of_reserve_margin_on_investments*
It is also applied for other technologies in the array of the Other Sources except nuclear plants because there is no investment on the nuclear plants in the reality so the investment rate for the nuclear plants is zero in the model.
Effect of reserve margin on investments is explained in the next section of the Model Sectors.

4.3.7 Reserve Margin Sector

Figure 13 shows the stock and flow diagram of Reserve Margin Sector.

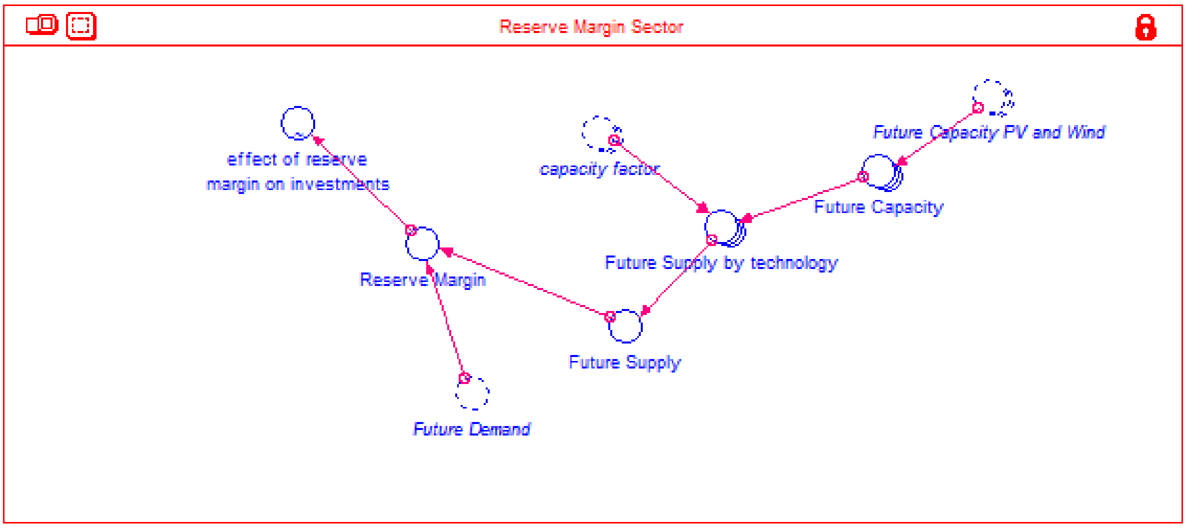

Figure 13: Stock and flow diagram of Reserve Margin Sector

Reserve margin is a crucial term for supply security. It is defined as “A measure of available capacity over and above the capacity needed to meet normal peak demand levels”[9]. It is stated that a negative relationship exists between reserve margin and capacity investments in the report of the European Commission in 2015. Moreover, the report asserts that low reserve margins trigger the capacity investments while high reserve margins lower the capacity investments.

Osorio and Ackere (2014) modeled reserve margin as a ratio between expected demand and expected supply. In this study, future demand is the electricity demand in 10 years to be compatible with the assumption in the model that it takes ten years in average for a power plant to start generating electricity after the investment decision is taken. Future supply is the multiplication of future capacity and capacity factor because during peak demand times, all electricity generation would feed in the grids to meet the electricity demand. The formula for reserve margin in the model is:

Reserve_Margin = *Future_Supply/Future_Demand*

Any data providing the effect of reserve margin on the investments could not be found in the literature. Thus, a non-linear function of reserve margin is made for the effect of reserve margin on the investments with the insights gained from the report of the European Commission in 2015.

This variable influences the investments only on the other sources because the intermittent sources are not reliable to provide supply security. Sensitivity analysis of Effect of Reserve Margin on Investments is conducted in the Validation Section of the model.

[9] Available on https://www.energyvortex.com/energydictionary/reserve_margin__reserve_capacity.html

Figure 14 illustrates the non-linear function of effect of reserve margin on investments.

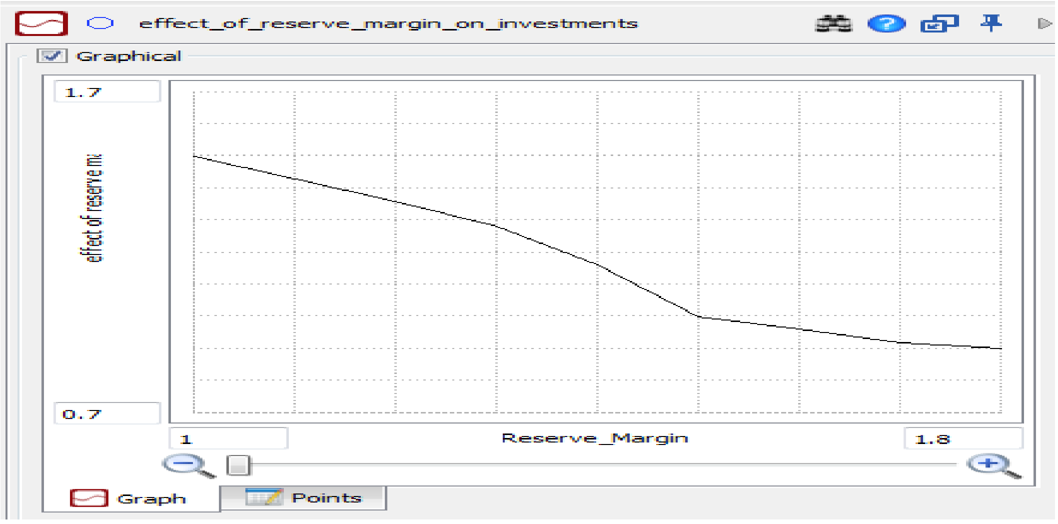

Figure14: Graphical function for effect of reserve margin on investments

4.4 Model Validation

Barlas (1996) states that the validity of a System Dynamics model significantly determines the validity of model results. Various validation tests are offered by Barlas under the categories of direct structure tests, structure oriented behavior tests and behavior pattern tests. Not all tests are conducted in this study because of the limited time and the purpose of the study.

Structure Verification and Parameter Verification Test, Dimensional Consistency Test, Behavior Pattern Test and Behavior Sensitivity Test are conducted in this study to test the validity of the model.

4.4.1 Structure Verification and Parameter Verification Test

This test is a part of direct structure test according to Barlas (1996). He states that the real system structure is compared with the model structure to conduct this test and qualitative and quantitative relationships in the model are tested based on the available knowledge about the real system.

Causal relationships are based on the extensive literature review in this study and it is illustrated by the causal loop diagrams in the model. This literature review includes both the SD studies and the other studies by different methodologies on the topic. To represent the real state of the system, the sectors that have been modeled in the different previous SD studies are put together in this model such as Reserve Margin Sector, Risk Sector and Learning Curve Sector. Also, residual load and curtailment sector that has not been modeled in the previous SD studies is added to the model because it is an important term in the real system structure for the supply security reasons. As a result, the structure of the model is encompassing the previous SD studies and the real state of the system that has been learned through the reports of the German and international institutions.

Some equations used in the model are gained from the study of Kubli (2014). Some equations like curtailment and merit order guaranteed supply are formulated by the definition of these terms. The equations of the capacity factor for other sources and the learning curve are gained by the previous studies on the related fields. Some equations are inferred by the knowledge about the real system for example the equations of spot price, investment risk ratio, application for investment, received price, ratio of conventional feeding in. Also, the stock adjustment process is learned from Sterman (2000) and the past SD studies discussed in the previous sections of the study are used to formulate the equations in the model such as risk and reserve margin.

Numerical values of the variables are taken from the report of the German Institutions and International Organizations. The official values are preferred to insert to the model and the assumptions based on the real system structure are made in the model when any values cannot be found for the related variables. The planned and approved capacities by technology are the examples of the numerical assumptions and the logic for the assumptions is already explained in the study.

4.4.2 Dimensional Consistency Test

The dimensional consistency of the units of the variables in the model was provided and checked when the model was constructed. After the model was finalized, the dimensional consistency was tested through the “Check Units” button of the iThink modeling program. The dimensional consistency errors were analyzed and they come from either writing same concept with different names or dividing 1 million to convert Euro to million Euros. Thus, dimensional consistency was provided in the model.

4.4.3 Behavior Pattern Test

Barlas (1996: 193) states about the behavior pattern test that “It is crucial to note that the emphasis is on pattern prediction (periods, frequencies, trends, phase lags, amplitudes, ...), rather than point (event) prediction”. In order to take his remarks into consideration, the reference modes and the simulation results of four main variables in the model are compared in this section. The reference modes represent historical data from 2006 until 2015 in the study.

The share of renewable energy sources in the German electricity supply is the most important consideration in the model. Its behavior pattern test is shown in the Figure 15.

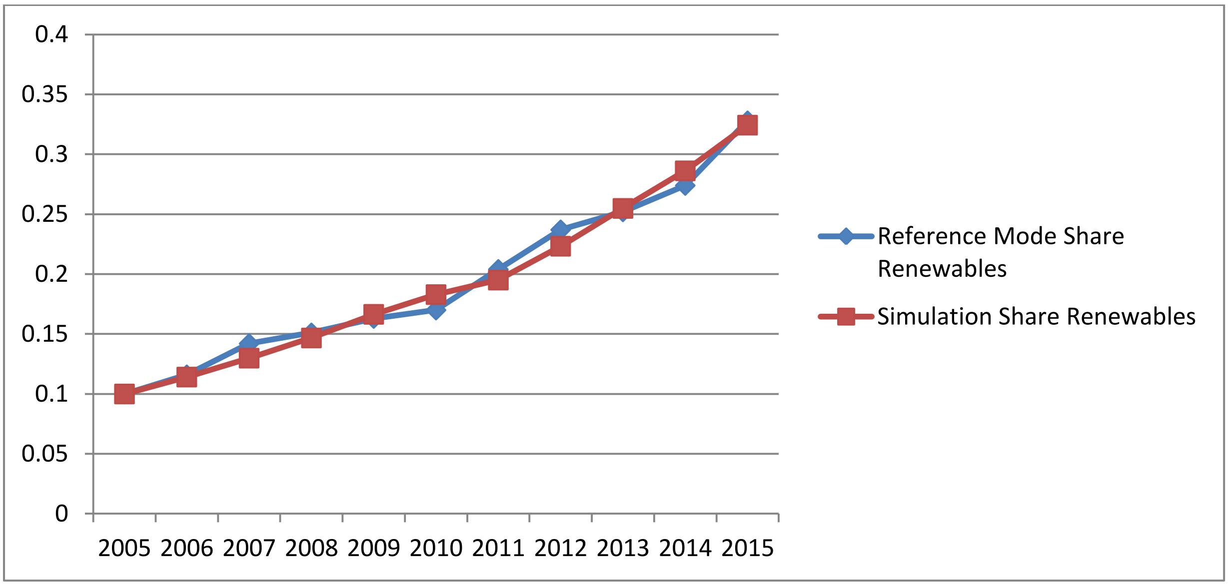

Figure 15: Behavior pattern test of share of renewable energy sources in the German electricity supply

The model is able to replicate historical data for the share of renewable energy sources in the German electricity supply.
As it is emphasized in the Theoretical Background of this study, environmental concerns are one of the main drivers for the energy transformation in Germany. Thus, behavior pattern test is applied for CO2 emissions. However, historical data for CO2 emissions from the power plants could not be found so initial value of CO2 emissions in the model and the reduction targets from 2006 until 2015 are used to calculate the reference mode for CO2 emissions.[10] Its behavior pattern test is shown in the Figure 16.

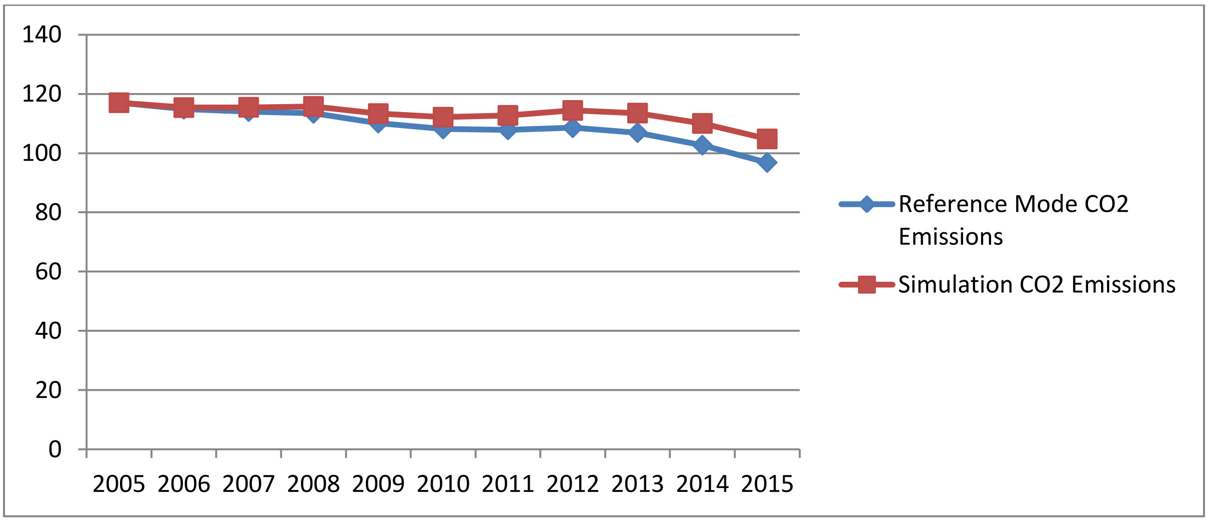

Figure 16: Behavior pattern test of CO2 emissions

The unit for CO2 emissions is Million Tones. The model is able to replicate historical data for CO2 emissions. The reason why the simulation results are higher than the

[10] Available on https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets CO2

reference mode comes from overcapacity of natural gas compared with historical capacity of natural gas.

Most important variable to determine the share of renewable energy sources and C02 emissions in the model is installed capacity of the technologies. Thus, behavior pattern test is conducted for installed capacity of renewable energy sources and installed capacity of conventional energy sources. The unit of them is GW and the behavior pattern tests are shown in the Figure 17 and Figure 18.

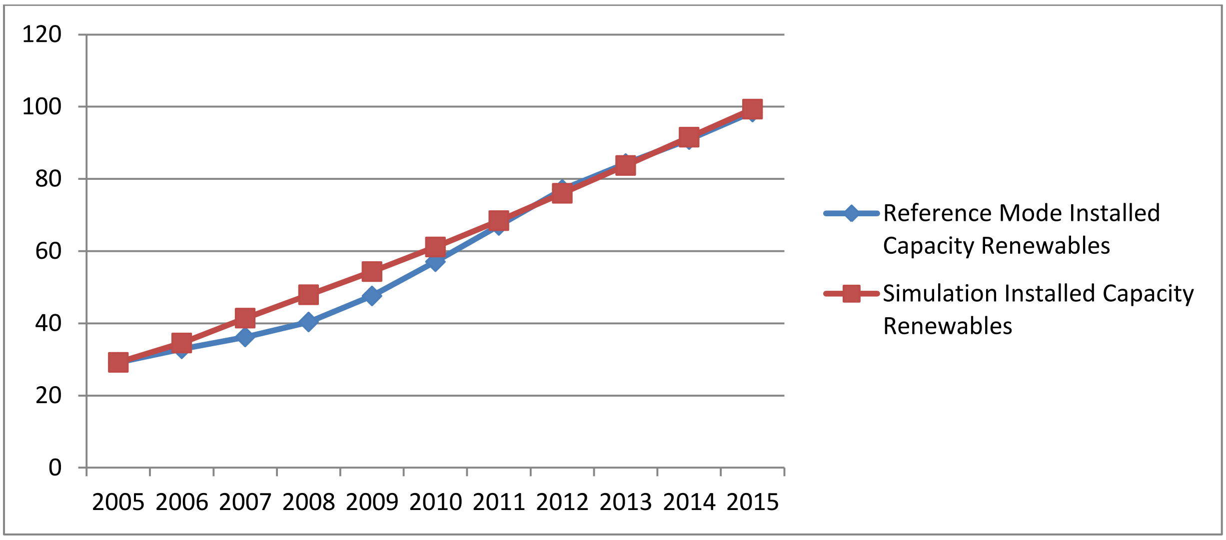

Figure 17: Behavior pattern test of Installed Capacity Renewable Energy Sources

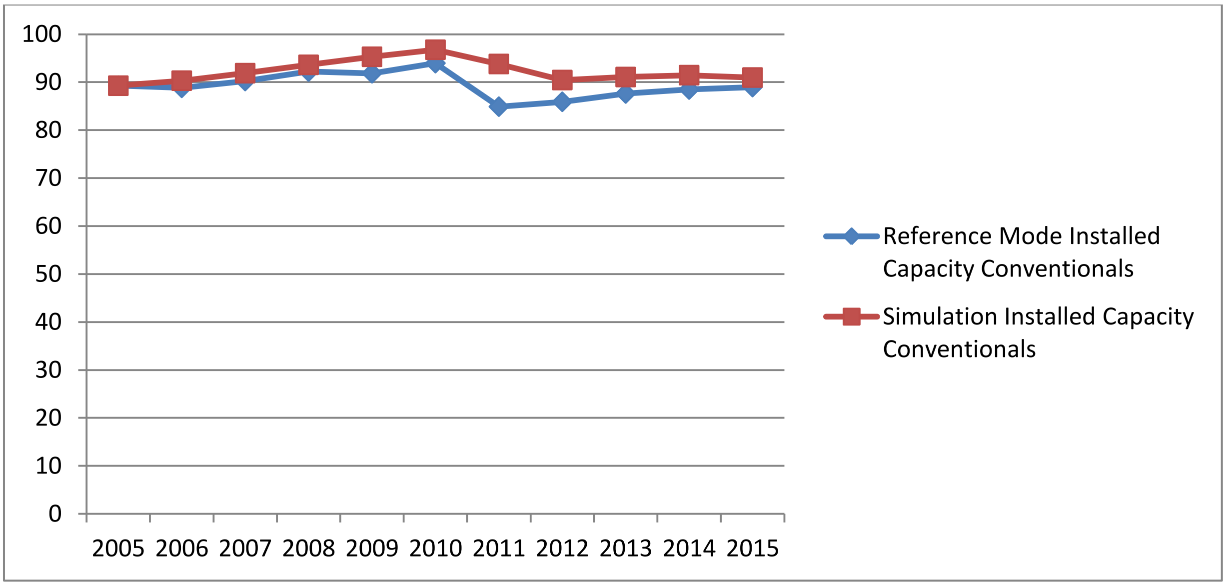

Figure 18: Behavior pattern test of Installed Capacity Conventional Energy Sources

The model is able to replicate historical data for Installed Capacity Renewable Energy Sources and Installed Capacity Conventional Energy Sources. However, installed capacity of renewable energy sources is increasing faster than the reference mode in the beginning of the simulation period because the risk for renewable energy sources in the model is reducing faster than the real risk perception of the investors.

4.4.4 Behavior Sensitivity Test

Sensitivity analysis of five variables is performed to figure out how the variables constructed based on the assumptions impact the main variables in the model. These variables are already mentioned in the previous section of the study. Three of them are non-linear functions and two of them are based on a formula.

Investment to Relative Capacity: It is a central variable to determine the investment rates of all technologies so it significantly impacts the installed capacity by technology. The height, base and shape of the non-linear function could be changed for the sensitivity analysis. In this analysis, changing the base value is preferred to perform sensitivity analysis. The base value refers to the investment risk ratio. Only the end values of it are played out for the sensitivity analysis because the starting value for the base is 1 and it is not profitable to make investment on a technology whose investment risk ratio is under 1.

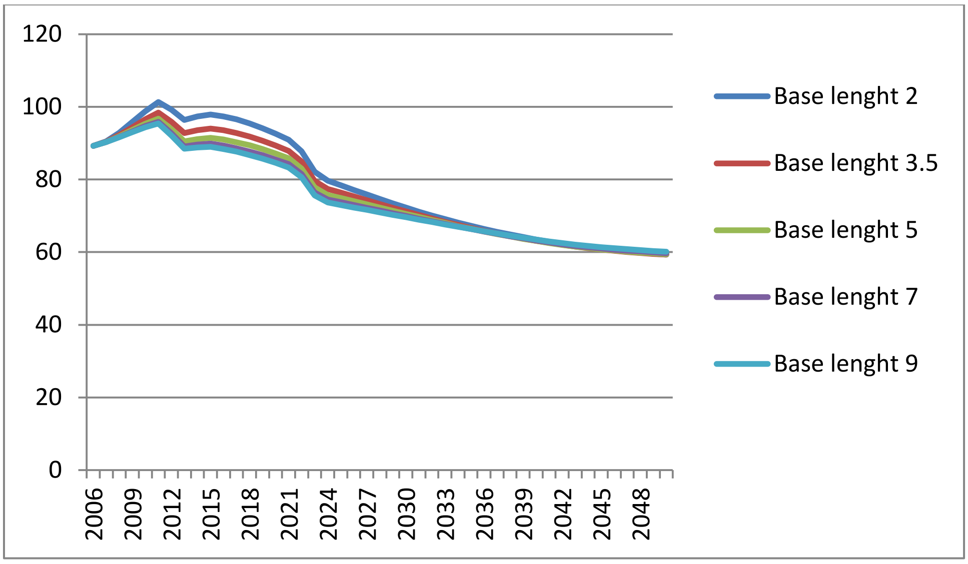

Figure 19: Sensitivity analysis of "investment to relative capacity" on installed capacity of conventional energy sources

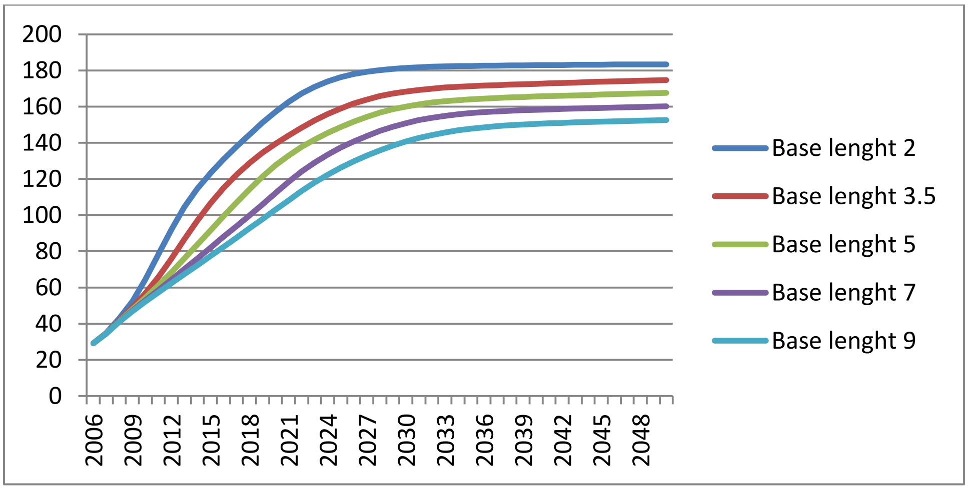

Figure 20: Sensitivity analysis of "investment to relative capacity" on installed capacity of renewable energy sources

The trend of the installed capacity for different base end values does not change significantly and it proves the validity of the non-linear function.

Effect of Conventionals Supply Ratio: It is a central variable to determine spot price in the model. The shape of the non-linear function is altered for the sensitivity analysis to figure out the power of the variable to arise spot prices.

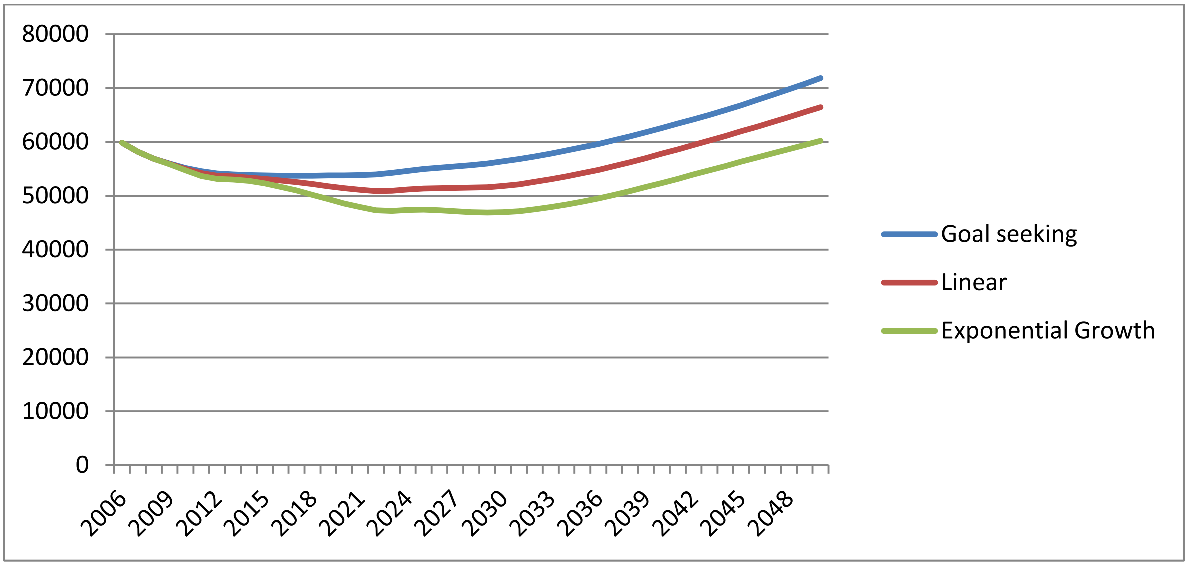

Figure 21: Sensitivity analysis of "effect of conventionals supply ratio" on spot prices

The trend is similar for different shapes of the function and only the values are varied due to different power of the shapes of the function to arise spot prices.

Effect of Reserve Margin on Investments: It is an important variable impacting the installed capacity for other technologies in the model. Secure reserve margin point defines the point that total installed capacity in the system is in the optimum level and so it is neither lacking for supply security nor implying excessive capacity. It is determined 1,5 in the base model and it is altered for sensitivity analysis of effect of reserve margin on investments.

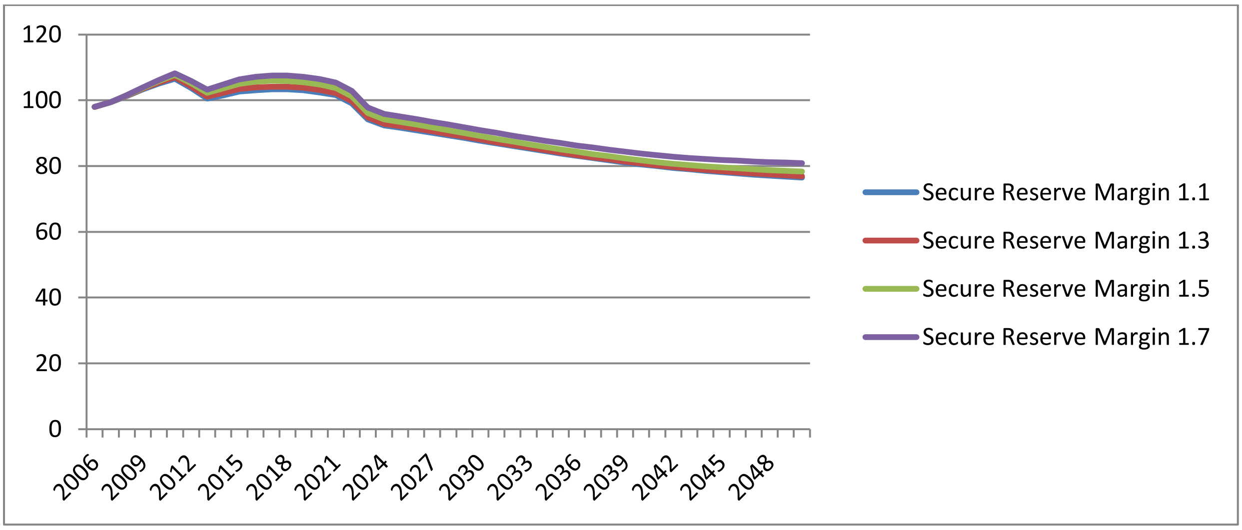

Figure 22: Sensitivity analysis of "effect of reserve margin on investments" on the installed capacity for other technologies

The trend and the simulation results for different values of secure reserve margin point on the installed capacity for other technologies are very similar.

Risk: It is one of the central variables to determine the investment rates for renewable energy sources. In the base model, reference technology for the risk variable is chosen Hydro technology and it implies that initial risk for the Hydro plants and other technologies whose initial accumulated production is more than Hydro technology is 1 and minimum. The risk for other renewable energy technologies is above 1 because their initial accumulated production is lower than Hydro technology and the risk for them is decreasing by time. As a result, the reference technology is altered for the sensitivity analysis of the risk variable. The sensitivity analysis does not impact the risk of conventional energy sources due to their initial accumulated production.

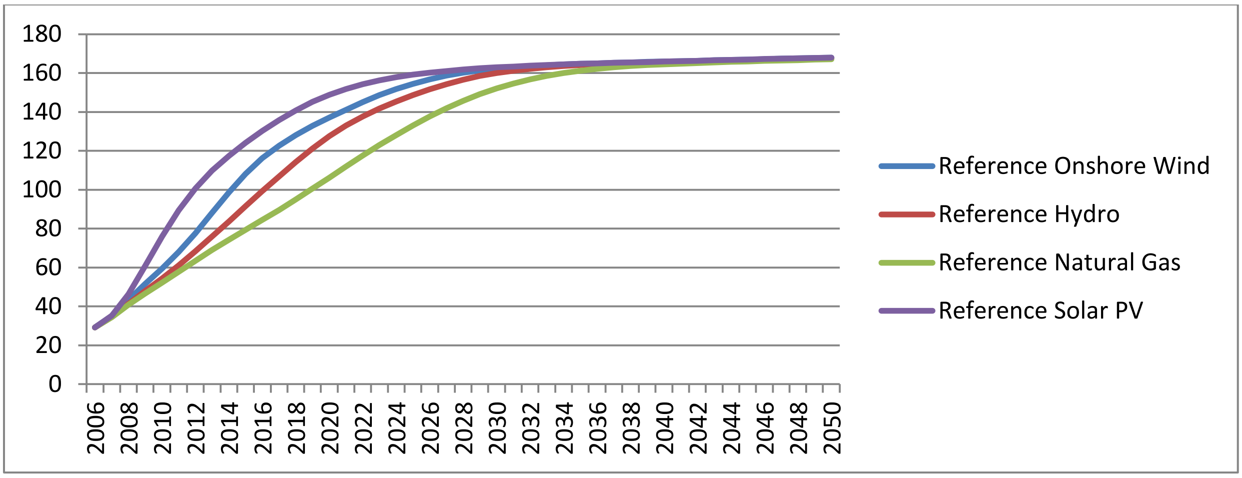

Figure 23: Sensitivity analysis of "risk" on the installed capacity of renewable energy sources

The trend is similar for different reference technologies and the increment rates on the installed capacity are varying based on if the reference technology is relatively mature or new technology.

Capacity Factor for Other Sources: Capacity factor is an important variable for the share of renewable energy sources in the German electricity supply because the capacity factors for conventional energy sources are decreasing in the model and it is increasing the share of renewable energy sources in the German electricity supply. Sensitivity analysis of capacity factor for other sources is conducted by multiplying the elasticity ratios by technology with different values to change the capacity factors.

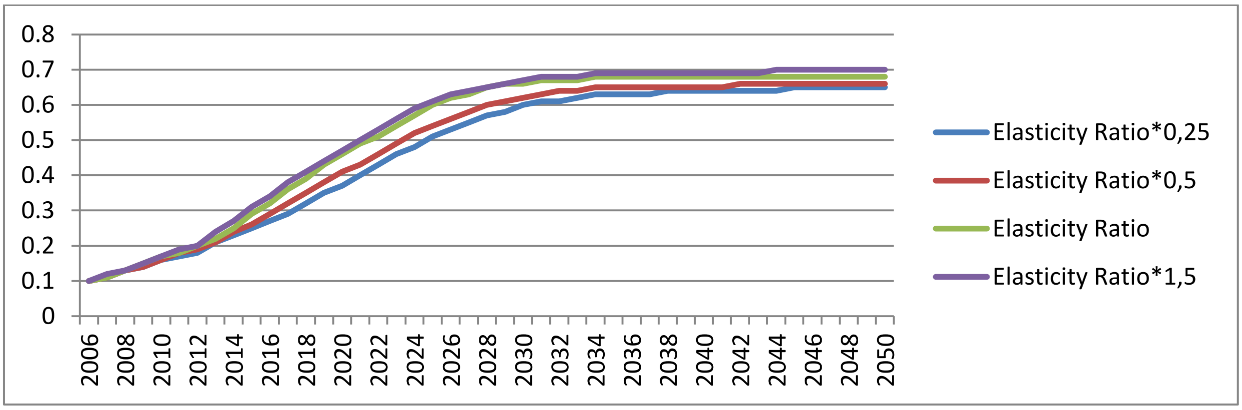

Figure 24: Sensitivity analysis of "capacity factor for other sources" on the share of renewable energy sources in the German electricity supply

The trend is similar for different values of the capacity factors and the increment rates on the share of renewable energy sources are varying based on the multiplier.

4.5 Model Results

Model results are communicated in this section of the study to give insights about the dynamic behavior of the model driven by the model structure that has been already explained in this study. The model is running until 2050 because it is the end year for the desired targets of the German government. Moreover, time span in the model is long enough to uncover the dynamics of the model and the financial FIT policies. The model is filled with real data and the procedure has been articulated in the previous sections of the study. The following assumptions are made from 2016 for the related variables in the model and they are:

- Fixed- Price FIT by technology and FIT Premium by technology are constant from 2016 until 2050.
- FIT vs Premium Ratio by technology is constant from 2016 until 2050.
- Different types of FIT financial policies are not introduced.
- The tax rates are constant.
- Grid priority of renewable energy sources is valid in the all simulation period.

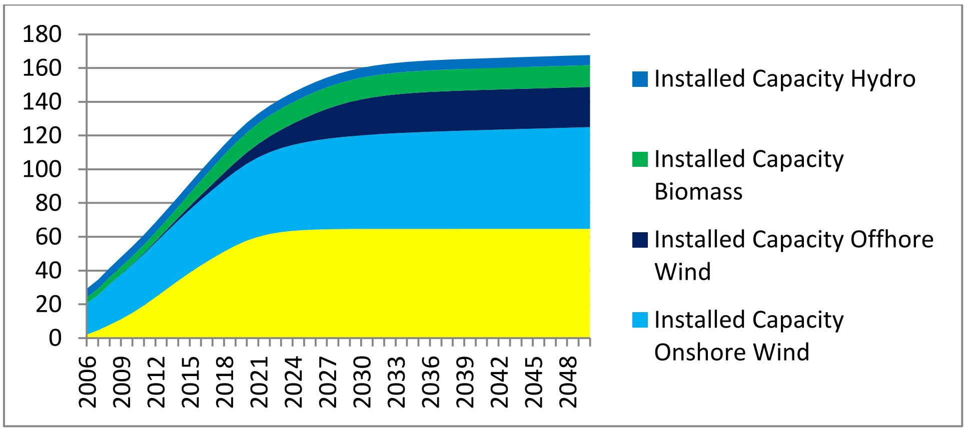

Figure 25: Simulation results of installed capacity of renewable energy sources by technology in the base model

Installed capacity of renewable energy sources is increasing decreasingly or in other words, it is having a goal-seeking process because the renewable energy sources are approaching their capacity limits. It can be explained by the balancing feedback loop mechanism of remaining expansion potential.

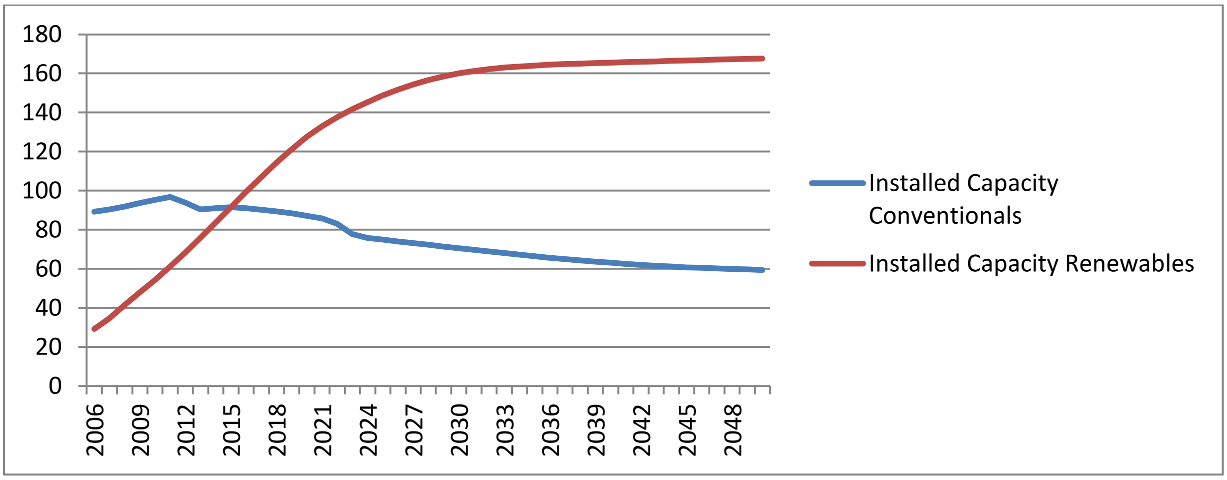

Figure 26: Simulation results for installed capacity of conventional energy sources and installed capacity of renewable energy sources in the base model

Installed capacity of conventional energy sources are decreasing because of their low investment risk ratios and lowering load hours stemming from mainly the grid priority of renewable energy sources. However, it is decreasing decreasingly due to increasing remaining expansion potentials of the conventional energy sources.

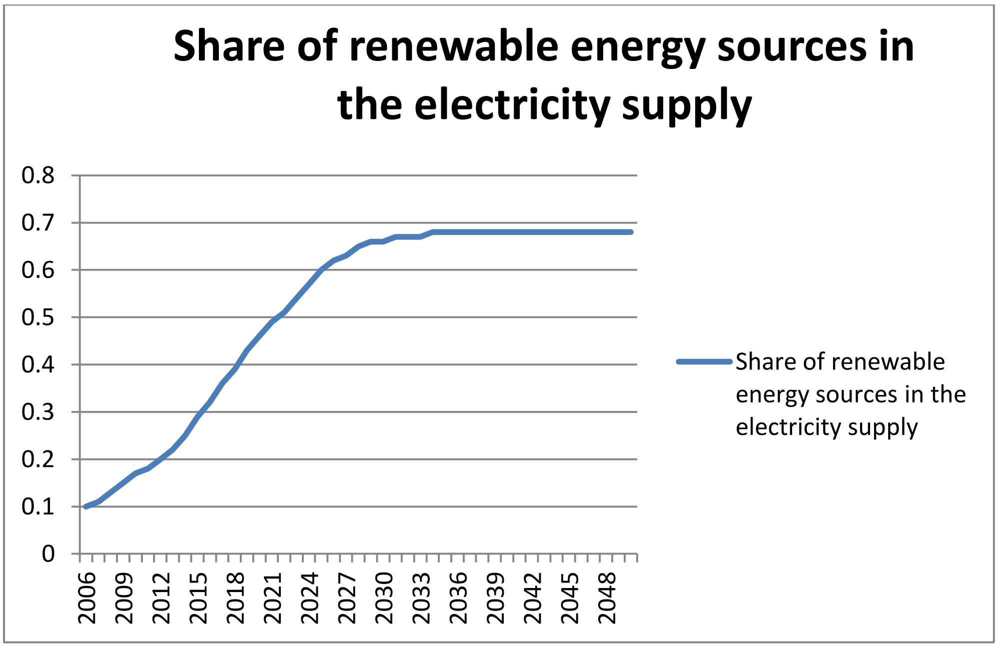

Figure 27: Simulation result of the share of renewable energy sources in the German electricity supply in the base model

The share of renewable energy sources in the German electricity supply is having an S-shaped growth because installed capacities of renewable energy sources by technology in the model are reaching their limits. Also, the minimum generation prevents the electricity generation from conventional energy sources to decrease further.

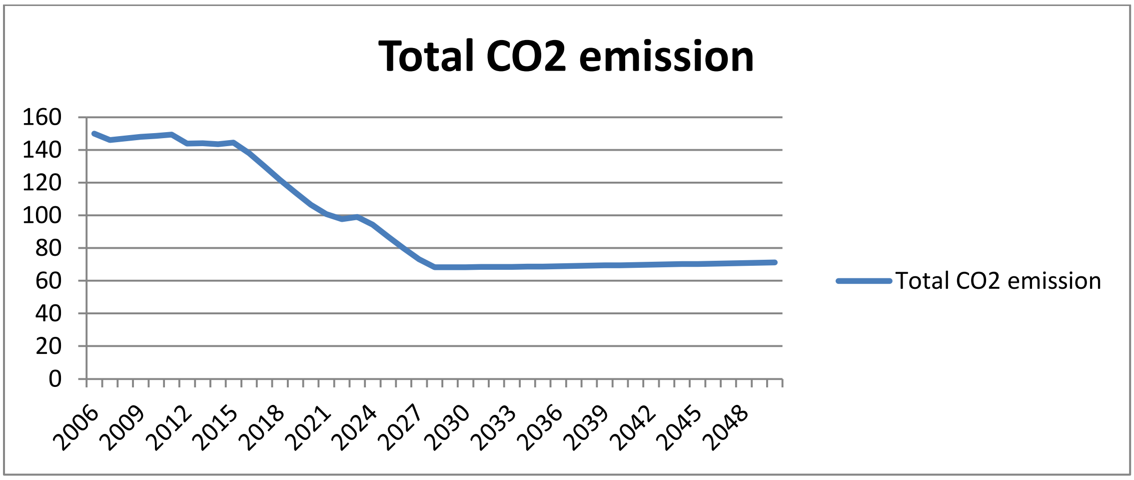

Figure 28: Simulation result of Total CO2 emission in the base model

The growth of electricity generation from renewable energy sources enables total CO_2 emissions to lower until 2027. From 2027, total CO_2 emissions start to increase slightly due to increasing ratio of conventional supply feeding in that basically results from the impact of the minimum generation variable in the model.

4.6 Model Scenarios

Various scenarios are applied in this section of the study to see how the system reacts to the possible changes in the future. The scenarios are inserted to the model after 2015. Only related variables in the all scenarios are altered and all other variables in the model remain same to figure out the exact effect of the possible shift in the future. Four scenarios are applied separately from each other and they are:

1. CO_2 Tax Rate remains constant after 2015.
2. Financial FIT policies for renewable energy sources and subsidies for conventional energy sources are canceled completely after 2015.
3. Subsidies for conventional energy sources are canceled completely after 2015.
4. Minimum generation from conventional energy sources is reduced gradually.

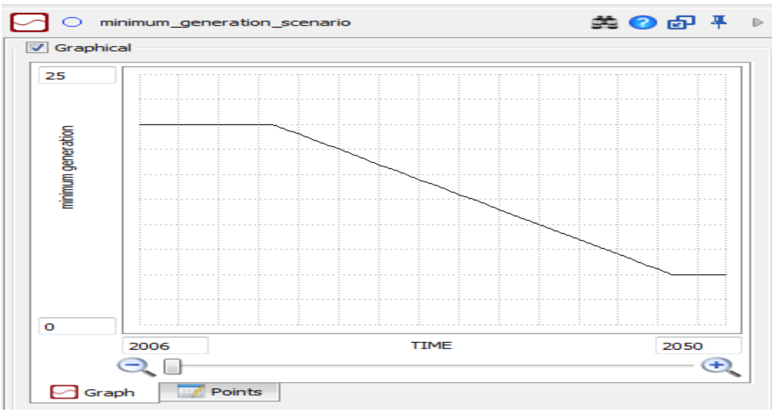

Figure 29: Graphical function of the scenario of minimum generation

The model results of the scenarios are shown in the Figure 30.

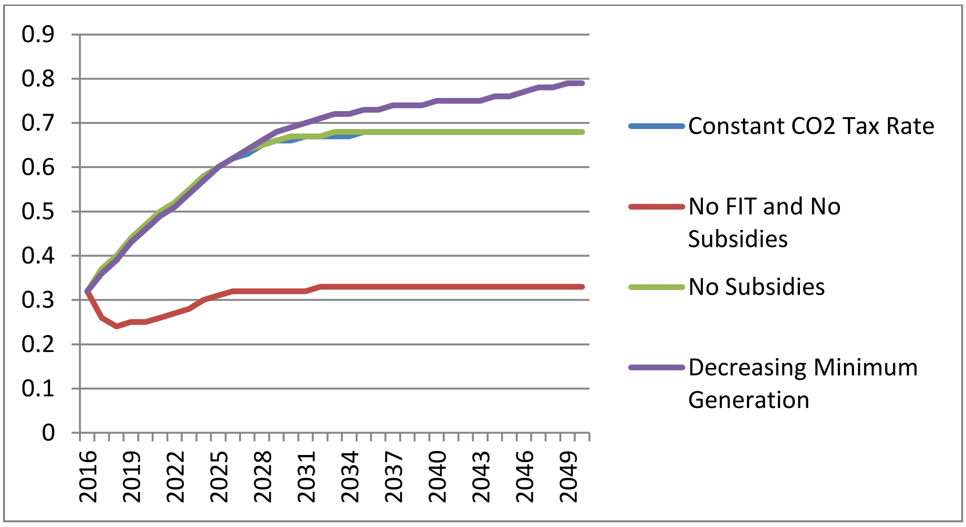

Figure 30: Model results of the scenarios on the share of renewable energy sources in the German electricity supply

The level of CO2 tax rate and the presence of conventional subsidies do not have a major impact on the share of renewable energy sources in the German electricity supply. However, the presence of financial FIT polices is necessary to reach out the German targets and the gradual reduction of minimum generation provides the system to reach the targets at the end of the simulation period because it prevents the electricity generation from conventional energy sources to decrease further and installed capacity of renewable energy sources get saturated after 2030.

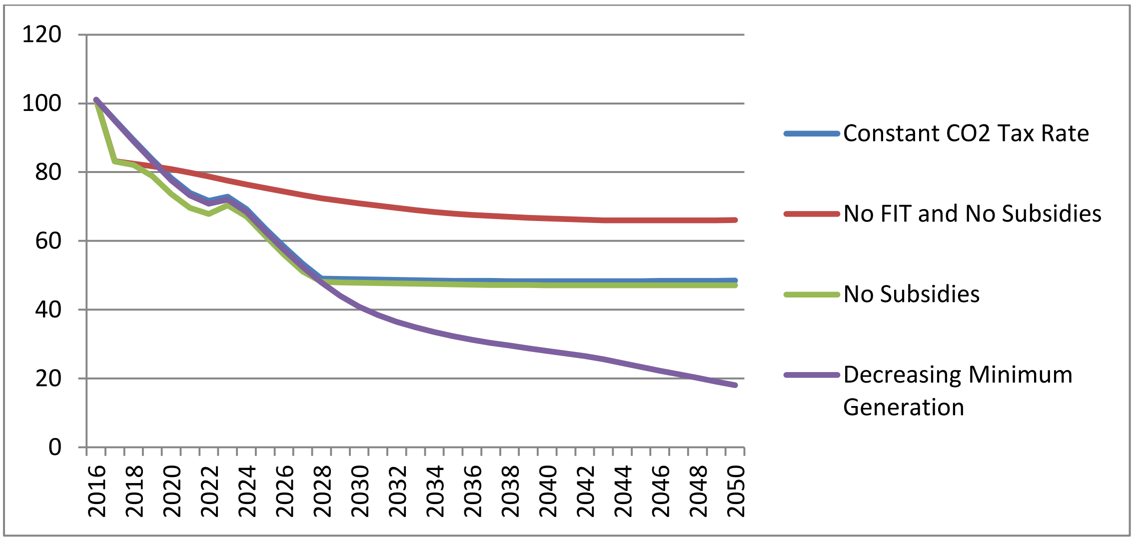

Figure 31: Model results of the scenarios on total CO2 emissions

Total CO2 emissions are highly negative correlated with the share of renewable energy sources in the German electricity supply. Thus, the reasons boosting the share of renewable energy sources reduce total C02 emissions.

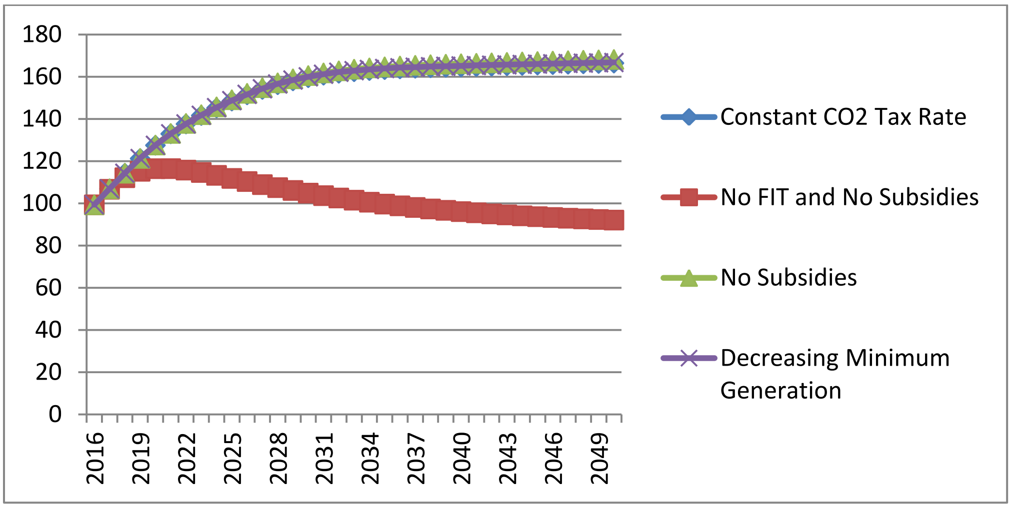

Figure 32: Model results of the scenarios on installed capacity of renewable energy sources

Financial FIT policies are main driver for installed capacity of renewable energy sources and other variables in the scenarios have minor effects on it.

4.7 Policy Analysis

Policy making is crucial to help the decision making process of the actors in the system. Therefore, four government policies leading the model to reach the German targets are introduced in the model. The minimum generation scenario defined in the previous section is used in the all policies because it is impossible to get the targets without the gradual reduction of minimum generation from conventional energy sources. Also, cancellation of the subsidies for conventional energy sources is applied for all policies because it does not have a major impact on the model results and it reduces total customer costs. Four government policies are introduced separately from each other after 2015 for the policy analysis and they are:

1. Existing FIT financial policies are multiplied with 1,01 and the digression rates of FIT financial policies are cancelled.
2. FIT premium is cancelled and only Fixed-Price FIT is applied by being multiplied with 1,12.
3. Fixed-Price FIT is cancelled and only FIT premium is applied by being multiplied with 1,07.
4. Existing FIT financial policies are cancelled and the policy of FIT Percentage of Market Price is introduced.

The reason why the financial FIT policies are multiplied with different values comes from equalizing the share of renewable energy sources in the German electricity supply for all policies to make better comparisons of the performance indicators of the policies.

FIT percentage of market price is another type of FIT financial policies in which FIT prices are paid as a percentage of market prices. The percentages for different kinds of renewable energy sources are defined distinctly in the model based on the level of FIT premium and fixed-price FIT by source of renewable energy.

4.7.1 Policy Comparisons and Policy Conclusions

The model results of four government policies mentioned above at the end of the simulation period are discussed in this section.

Model Results of the German Targets	Existing financial FIT policies*1,01(No digression rates)	Only Existing Fixed-Price FIT *1,12	Only Existing FIT Premium Tariff*1,07	Only FIT Percentage of Market Price
Share of Renewable Energy Sources	80,2%	80,2%	80,3%	80,3%
Total CO2 Emissions(in million tones)	21,82	25,6	21,25	20,62

Table 4: Model results of the German targets in 2050 for the government policies introduced in the model

The shares of renewable energy sources in the German electricity supply are almost same for all policies. However, minor differences in total CO2 emissions come from the composition of electricity generation from conventional sources because Lignite, Hard Coal and Natural Gas have different CO2 emissions per GWH.

Model Results of the Performance Indicators	Existing financial FIT policies*1,01(No digression rates)	Only Existing Fixed-Price FIT *1,12	Only Existing FIT Premium Tariff*1,07	Only FIT Percentage of Market Price
Average Weighted Spot Price(Euro/GWH)	58.238	58.371	58.336	58.854
Accumulated Supply Deficit(GWH)	202.150	204.786	203.602	244.129
Accumulated Investment Costs of Renewables(Million Euros)	547.118	522.740	550.939	554.553
Accumulated Customer Spot Price Spendings(Million Euros)	1.394.354	1.397.538	1.396.689	1.409.107
Accumulated Financial FIT Policies Cost(Million Euros)	1.920.892	2.284.432	1.524.724	1.346.701
Accumulated Total Customer Costs(Million Euros)	3.315.246	3.681.970	2.921.413	2.755.808

Table 5: Model results of the performance indicators in 2050 for the government policies introduced in the model

Average weighted spot price does not differ significantly for the policies. However, accumulated supply deficit is higher for the FIT percentage of market price than other policies. Accumulated investment costs of renewable energy sources are lower for the existing fixed-price FIT than other policies. Accumulated customer spot price spending does not vary considerably for the policies because of similar average weighted spot prices of the policies. On the other hand, accumulated financial FIT policies costs for the policies are significantly different from each other. The FIT percentage of market price has the lowest policy cost, followed by the FIT premium and then the existing FIT policies that is the mix of FIT premium and fixed-price FIT.

Therefore, the fixed-price FIT policy has the highest policy cost. The explanation for accumulated total customer costs is clearly in line with the explanation for accumulated financial FIT policies costs because accumulated customer spot price spending ,that is another component of accumulated total customer cost , is nearly same for all policies introduced in the model.

It can be concluded that the ratio of FIT Premium among the financial FIT policies is increasing for all kinds of renewable energy sources in the German electricity market when the historical data until 2015 is analyzed. Also, the simulation results suggest that the FIT Premium policy is cheaper than the Fixed-Price FIT policy. Therefore, the ratio of FIT Premium should keep rising in order to reduce the EEG surcharge in Germany as long as it does not boost the risk perception of the investors. However, Fixed-Price FIT policy is perceived more secure than FIT Premium because it guarantees a specific price for electricity generation.

The FIT Percentage of Market Price is the best policy in the study to implement because it is clearly the cheapest policy offer among the policies implemented in the model. However, Kubli (2014) states that this policy stimulates power plants to generate electricity when high market prices are formed in the electricity market. Therefore, accumulated supply deficit is higher for the FIT percentage of market price than other policies in the study and it might threaten electricity supply security in Germany. Also, daily fluctuations of the intermittent sources are not modeled in the study and it might accelerate the concerns about the electricity supply security.

Finally, applying a financial FIT policy is vital to reach the German targets as it is proved in the Scenario and Policy analysis of this study. However, which financial FIT policy must be applied is a multi-dimensional decision including many aspects such as risk perception of the investors, total policy cost, supply security. Also, Masini and Menichetti (2012) emphasize negative impact of uncertainty of government policies on private sector investments and they prove it with the downturn investments stemming from changing the legal framework in Germany, Denmark and the US. Therefore, a detailed policy analysis encompassing all important concerns in the German electricity system is required to be performed for effective decision making.

5. Discussion

The German Government set ambitious targets for the share of renewable energy sources in the German electricity supply and the reduction of CO2 emissions. Germany has had a successful energy transformation so far. However, they are facing the following challenges; the phase-out of nuclear plants, the intermittency of Solar PV and Wind Plants and the burden on the end customers which results from increasing electricity bill costs (Irena, 2015).

Providing electricity supply security is an important concern in Germany. Therefore, supply security is modeled by monthly technical availability of the intermittent sources, residual load, minimum generation, and curtailment in this study. However, daily fluctuations of the intermittent sources are not included out in the model and it would be useful to construct it in the model in the sense of supply security. Moreover, the investment costs of renewable energy sources are decreasing by the learning curve in the model. Also, the capacity factors and load hours of conventional energy sources are constructed with increasing CO2 tax rates in the model. The nuclear phase-out is included out on the physical capacity of Other Sources. Furthermore, the risk of investments on renewable power plants is modeled through the Accumulated Production in the model. Also, spot market price is modeled by the variable costs of power plant technologies and the ratio of conventional supply feeding in. Lastly, total potential capacities of all technologies are modeled exogenously to determine the investment rates on each technology. However, it would be interesting to model it endogenously in this study. All these efforts are performed to represent the real structure of the system addressing Research Question 1.

The main policy instrument to stimulate renewable energy sources is financial FIT policies in Germany. The German government is applying two financial FIT policies: Fixed-Price FIT and FIT Premium. They defined the digression rates for the financial FIT policies after 2015 by source of renewable energy to lower the policy costs. Also, there is a shift from fixed-price FIT to FIT premium in Germany. They are all included out in the model to address Research Question 2.

The SD model results also prove that financial FIT policies are the most essential variable in the model to boost the investments on renewable electricity plants. When the financial FIT policies are cancelled in the study, installed capacity of renewable electricity plants decreases dramatically and it blocks to reach out the German targets and to have a successful energy transformation. However, accumulated

financial FIT policies costs are too high according to the model results. The digression rates for the financial FIT policies by source of renewable energy do not reduce the policy costs considerably according to the model results. Also, installed capacity of renewable energy sources gets saturated after 2030 and so their capacity is increasing slightly in the model after 2030. The saturation of installed capacity of renewable energy sources comes from the rigid total potential capacity of renewable energy sources in the model. Moreover, minimum generation from conventional energy sources is another challenge preventing the system to achieve the German targets according to the model results. Although the financial FIT policies are boosting investments on renewable energy sources, the minimum generation leads to curtailment of the intermittent sources. Also, the minimum generation forces the grid operators to buy electricity from the conventional energy sources even if it is not necessary to meet the electricity demand.
The nuclear phase-out does not cause any obstacles on electricity supply security in Germany according to the model results because installed capacity of renewable power plants increases radically and they substitute the decommissioned nuclear plants. Also, the reserve margin mechanism in the model stimulates investments on other technologies. Thus, supply security is not a problem in the long-term according to the model results. Lastly, the capacity factors and load hours of conventional energy sources decrease steadily in this study. It leads to the increment on the spot price in the long-term because decreasing capacity factors and load hours boost the variable costs of conventional energy sources with increasing CO2 tax rates. Thus, increasing spot price gives a rise on the electricity costs of the end customers in the long-term and it creates another challenge for the German authorities. These explanations intend to answer Research Question 3.

Four different scenarios are introduced in the model after 2015 to see the dynamic behavior of the system. The scenarios which stabilize CO2 tax rates and cancel conventional subsidies have minor impacts on the system. However, the scenario which cancels the financial FIT polices leads to major impact on the system. Thus, this scenario suggests that it is essential to sustain the financial FIT policies in the system because if the financial FIT policies reduce significantly after 2030, installed capacity of renewable energy sources decreases dramatically in the model. Also, the scenario which reduces the minimum generation gradually suggests that the minimum generation should be reduced gradually to achieve the targets as installed capacity of the intermittent sources and other renewable energy sources increase in the system. These efforts are performed to answer Research Question 4.

The minimum generation scenario and the cancellation of conventional subsidies scenario are used in the all policies to reach out the German targets in a cost effective manner. Four financial FIT policies are applied to conduct the policy analysis. The model results show that FIT premium has significantly lower cost than fixed-price FIT and it explains the shift from fixed-price FIT to FIT premium in Germany. Moreover, the policy analysis results suggest that investment costs on renewable technologies do not decrease significantly after 2020 and it proves the necessity for the financial FIT policies in the long-term to sustain the energy transformation. Moreover, the model results imply that the FIT percentage of market price policy is the cheapest policy to stimulate renewable energy sources. However, this policy is not applied anymore in Germany. The German government should take this policy into consideration to lower the EEG surcharge. However, this policy might threaten electricity supply security in Germany due to its nature. Therefore, the German institutions should take necessary measures in case they want to apply this policy. As a result of the policy analysis, the German government might apply the mix of the financial FIT policies to balance out the disadvantages of each financial FIT policy and composition of the financial FIT policies would change depending on the priority of the German government in the electricity system. These explanations intend to answer Research Question 5 and Research Question 6.

Practical and theoretical implications of this study are uncovered to give insights in order to reach out the German targets. Firstly, the German government should support research and development activities on the production and installment of physical capital of renewable power plants to decrease the investment costs further. Also, it would add extra value to the German economy due to increasing exports of physical capital of renewable power plants. Secondly, the German government should reduce minimum generation gradually from conventional energy sources. However, they should take necessary precautions to ensure the electricity supply security while the minimum generation is decreasing. They could benefit from electricity imports and electricity storage sources to guarantee supply security according to the Green Paper (2014). Thirdly, the German institutions should support investments on flexible conventional energy plants to overcome the problems resulting from decreasing capacity factors and load hours of conventional energy sources. Fourthly, the German government should manage the perception of the German community on the energy transformation not to damage the process because of huge cost of the energy transformation. It boosts both political risk and the risk perception of the investors. Lastly, the digression rates should not be reduced radically because it would decrease installed capacity of renewable energy sources significantly. However, increasing the financial FIT policies in the long-term to reach out the targets does not work efficiently because the renewable energy sources are getting closer to their capacity limits. Therefore, the German government should adjust the Financial FIT policies carefully to reach out the targets in a cost effective manner.

This study adds the following contributions to the existing knowledge. Firstly, the system is driven by twelve feedback loops and it proves how complex the electricity system is. Analyzing the feedback loops and interactions among the variables would help the decision makers to grasp the system deeply. Secondly, this study shows that the financial FIT policies sustain installed capacity of renewable energy sources in the long-term. Thirdly, residual load, minimum generation and curtailment that have not been modeled in the past SD models are modeled in this study to represent the reality and electricity supply security concerns in Germany. The Green Paper (2014: 16) states that "with a high penetration of renewable energy, minimum generation can hamper the cost-effective and environmentally compatible synchronization of production and consumption at a low residual load". Fourthly, this study demonstrates that reducing minimum generation level from conventional energy sources drives increment on the share of renewable energy sources in the long-term in correspondence with the Green Paper. Fifthly, FIT percentage of market price policy is the cheapest policy to stimulate renewable energy sources.
Masini and Menichetti (2012) emphasize that total renewable energy share in the portfolios of risk-averse investors is lower than the portfolios of risk-neutral and risk-seeking investors. Sixthly, modeling the risk of renewable power plants to invest on sheds light on the importance of this variable in the SD models on the topic correspondingly. Lastly, this study is encompassing many aspects on the topic such as supply security, risk and financial FIT policies to help the decision makers in order to understand the dynamics of the system through a quantitative model.

The SD model used in this study has some limitations. Firstly, installed capacity of electricity storage sources which is crucial to determine the minimum generation is not modeled in this study. Secondly, the financial FIT policies are not modeled endogenously in this study. Thirdly, risk perceptions of the financial FIT policies by the investors are different in the real system but it is assumed same in the model. Fourthly, the Germany Energy Law has often been changing and so it is too dynamic. However, possible changes in the law are not included out in the model. Fifthly, European cross border integration is an important issue on the topic but electricity trade with the neighbor countries are not included out in the model. Lastly, the grid capacity in Germany is not modeled in this study.

Some recommendations could be given to the researchers who want to work on the topic. Firstly, modeling grid capacity in Germany would be useful because the grid capacity is one of the biggest concerns in Germany to sustain the growth of renewable energy sources. However, grid capacity does not constrain feeding in of electricity generation from renewable energy sources in this study. Thus, modeling grid capacity might block to get the targets in the reality and building and improving the grids would bring extra costs for Germany. Also, modeling grid connections with the neighbor countries would be beneficial in the long-term because it causes minor changes in the short-term but it could cause a major impact on the system in the long-term if the grid capacity throughout the Europe extends considerably.

Secondly, modeling the financial FIT policies endogenously would be crucial because it is the biggest driver of investments on renewable energy sources and it also causes huge costs on the German electricity customers. Modeling the financial FIT policies endogenously would help to see the results of possible reactions of the end customers and the German government, which stem from increasing electricity bill costs, on the financial FIT policies. Moreover, the end customers might react to electricity outages in the system and so modeling the financial FIT policies endogenously would help to figure out the results of possible impacts of electricity outages on the financial FIT policies.

Lastly, making a research about the German targets to determine if they are feasible would be crucial for the German government. The energy transformation in Germany reduces the dependence to the foreign countries due to fuel imports and decreases CO_2 emissions (IRENA, 2015). However, it causes huge costs on the electricity customers and it risks the electricity supply security due to the nature of the intermittent sources. Moreover, electricity is one of the most important inputs for production and service sector. Thus, the energy transformation boosts the political risk and threatens the German economy. Also, if the financial FIT policies are reduced significantly by the German government due to the mentioned concerns in the future, installed capacity of renewable energy sources would decrease radically and it would waste the expenditures on the energy transformation. Thus, the German government could make investments on increasing the efficiency of conventional energy sources to reduce C02 emissions and they could revise their targets for the energy transformation to have more smooth transition into renewable energy sources in terms of total cost and supply security.

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7. Annexes

Annex 1. Abbreviation List

Conventionals: Nuclear, Hard Coal, Lignite, and Natural Gas

CO2: Carbon dioxide

EEG: The German Renewable Energy Act, the German Energy Law

Energiewende: Energy transition

Intermittent Sources: Solar Photovoltaic, Onshore Wind, Offshore Wind

FIT: Feed in Tariff

FIT vs Premium: The ratio between electricity generation from Fixed-Price FIT and electricity generation from FIT Premium.

IRR: Internal Rate of Return

NPV: Net Present Value

Other Sources: Nuclear, Hard Coal, Lignite, Natural Gas, Biomass, Hydro

Renewables: Solar Photovoltaic, Onshore Wind, Offshore Wind, Hydro, Biomass

SD: System Dynamics

Solar PV: Solar Photovoltaic

WACC: Weighted Average Cost of Capital

Annex 2. Model Documentation

Accumulated_Cunsomer_Spendings(t) = Accumulated_Cunsomer_Spendings(t - dt) + (cunsomer_spendings) * dt

INIT Accumulated_Cunsomer_Spendings = 0

INFLOWS:

cunsomer_spendings = (local_electricity_demand*hours_per_year*Spot_price)/1000000

Accumulated_Demand(t) = Accumulated_Demand(t - dt) + (Demand_rate) * dt

INIT Accumulated_Demand = 0

INFLOWS:

Demand_rate = local_electricity_demand*DT

Accumulated_investments[All_technology](t) = Accumulated_investments[All_technology](t - dt) + (Flow_5[All_technology]) * dt

INIT Accumulated_investments[All_technology] = 0

INFLOWS:

Flow_5[Solar_PV] = application_for_the_investment[Solar_PV]

Flow_5[Onshore_Wind] = application_for_the_investment[Onshore_Wind]

Flow_5[Offshore_Wind] = application_for_the_investment[Offshore_Wind]

Flow_5[Nuclear] = application_for_the_investment_1[Nuclear]

Flow_5[Hard_Coal] = application_for_the_investment_1[Hard_Coal]

Flow_5[Natural_Gases] = application_for_the_investment_1[Natural_Gases]

Flow_5[Lignite] = application_for_the_investment_1[Lignite]

Flow_5[Biomass] = application_for_the_investment_1[Biomass]

Flow_5[Hydro] = application_for_the_investment_1[Hydro]

Accumulated_Investments_Cost[All_technology](t) = Accumulated_Investments_Cost[All_technology](t - dt) + (Flow_6[All_technology]) * dt

INIT Accumulated_Investments_Cost[All_technology] = 0

INFLOWS:

Flow_6[Solar_PV] = Investment_cost[Solar_PV]*application_for_the_investment[Solar_PV]

Flow_6[Onshore_Wind] = Investment_cost[Onshore_Wind]*application_for_the_investment[Onshore_Wind]

Flow_6[Offshore_Wind] = Investment_cost[Offshore_Wind]*application_for_the_investment[Offshore_Wind]

Flow_6[Nuclear] = Investment_cost[Nuclear]*application_for_the_investment_1[Nuclear]

Flow_6[Hard_Coal] = Investment_cost[Hard_Coal]*application_for_the_investment_1[Hard_Coal]

Flow_6[Natural_Gases] =
Investment_cost[Natural_Gases]*application_for_the_investment_1[Natural_Gases]

Flow_6[Lignite] = Investment_cost[Lignite]*application_for_the_investment_1[Lignite]

Flow_6[Biomass] = Investment_cost[Biomass]*application_for_the_investment_1[Biomass]

Flow_6[Hydro] = Investment_cost[Hydro]*application_for_the_investment_1[Hydro]

Accumulated_Sales(t) = Accumulated_Sales(t - dt) + (Sales_Rate) * dt

INIT Accumulated_Sales = 0

INFLOWS:

Sales_Rate = local_electricity_demand*Spot_price*DT

ACC_cost_FIT_percent(t) = ACC_cost_FIT_percent(t - dt) + (Flow_11) * dt

INIT ACC_cost_FIT_percent = 0

INFLOWS:

Flow_11 = (SUM(expenditures_FIT_percentage)/1000000)/AT_years

ACC_cost_Fixed_FIT(t) = ACC_cost_Fixed_FIT(t - dt) + (Flow_3) * dt

INIT ACC_cost_Fixed_FIT = 0

INFLOWS:

Flow_3 = (SUM(expenditures_Fixed_FIT)/1000000)/AT_years

Acc_cost_of_conventional_subsidies[Conventional](t) =
Acc_cost_of_conventional_subsidies[Conventional](t - dt) + (Flow_10[Conventional]) * dt

INIT Acc_cost_of_conventional_subsidies[Conventional] = 0

INFLOWS:

Flow_10[Nuclear] = IF(TIME>2016)

THEN(Conventional_Subsidies_Scenario[Nuclear]*Total_Supply_Other_Sources[Nuclear])

ELSE(0)

Flow_10[Hard_Coal] = IF(TIME>2016)

then(Conventional_Subsidies_Scenario[Hard_Coal]*Total_Supply_Other_Sources[Hard_Coal])

else(0)

Flow_10[Lignite] = IF(TIME>2016)

then(Conventional_Subsidies_Scenario[Lignite]*Total_Supply_Other_Sources[Lignite])

else(0)

Flow_10[Natural_Gas] = IF(TIME>2016)

then(Conventional_Subsidies_Scenario[Natural_Gas]*Total_Supply_Other_Sources[Natural_Gases])

ELSE(0)

acc_cost_premium_FIT(t) = acc_cost_premium_FIT(t - dt) + (Flow_2) * dt

INIT acc_cost_premium_FIT = 0

INFLOWS:

Flow_2 = (SUM(yearly_FIT_premium_expenditures)/1000000)/AT_years

Average_stantard_deviation(t) = Average_stantard_deviation(t - dt) + (Flow_4) * dt

INIT Average_stantard_deviation = 0

INFLOWS:

Flow_4 = (SQRT(((Spot_price-adaptive_price)/adaptive_price)^2))*(1/44)

Desired_CO2_Emissions(t) = Desired_CO2_Emissions(t - dt) + (Flow_12) * dt

INIT Desired_CO2_Emissions = reference_CO2_emission

INFLOWS:

Flow_12 = (reference_CO2_emission*Desired_CO2_emission_targets-Desired_CO2_Emissions)/AT_SHARE

Perceived__profitability_of_electricity_plan_investment[All_technology](t) = Perceived__profitability_of_electricity_plan_investment[All_technology](t - dt) + (change_in_perceived_profitability[All_technology]) * dt

INIT Perceived__profitability_of_electricity_plan_investment[All_technology] = INIT(Profitability_per_GW)

INFLOWS:

change_in_perceived_profitability[All_technology] = (Profitability_per_GW-Perceived__profitability_of_electricity_plan_investment)/time_to_perceive_profitability

Producing_FIT[Renewables](t) = Producing_FIT[Renewables](t - dt) + (start_FIT[Renewables] - Ending_FIT[Renewables]) * dt

INIT Producing_FIT[Renewables] = 0

INFLOWS:

start_FIT[Solar_PV] = IF(TIME>start_time)

THEN(construction_rate[Solar_PV])

ELSE(0)

start_FIT[Onshore_Wind] = IF(TIME>start_time)

THEN(construction_rate[Onshore_Wind])

ELSE(0)

start_FIT[Offshore_Wind] = IF(TIME>start_time)

THEN(construction_rate[Offshore_Wind])

ELSE(0)

start_FIT[Hydro] = IF(TIME>start_time)

THEN(construction_rate_1[Hydro])

ELSE(0)

start_FIT[Biomass] = IF(TIME>start_time)

THEN(construction_rate_1[Biomass])

ELSE(0)

OUTFLOWS:

Ending_FIT[Renewables] = DELAY(start_FIT,FIT_duration)

Smoothed_CO2_Emission(t) = Smoothed_CO2_Emission(t - dt) + (Flow_13) * dt

INIT Smoothed_CO2_Emission = INT(Total_CO2_emission)

INFLOWS:

Flow_13 = (Total_CO2_emission-Smoothed_CO2_Emission)/AT_SHARE

Accumulated_Production[Solar_PV](t) = Accumulated_Production[Solar_PV](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Solar_PV] = 2500

Accumulated_Production[Onshore_Wind](t) = Accumulated_Production[Onshore_Wind](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Onshore_Wind] = 125000

Accumulated_Production[Offshore_Wind](t) = Accumulated_Production[Offshore_Wind](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Offshore_Wind] = 0.0001

Accumulated_Production[Nuclear](t) = Accumulated_Production[Nuclear](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Nuclear] = 2581000

Accumulated_Production[Hard_Coal](t) = Accumulated_Production[Hard_Coal](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Hard_Coal] = 2300000

Accumulated_Production[Natural_Gases](t) = Accumulated_Production[Natural_Gases](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Natural_Gases] = 771000

Accumulated_Production[Lignite](t) = Accumulated_Production[Lignite](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Lignite] = 2412000

Accumulated_Production[Biomass](t) = Accumulated_Production[Biomass](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Biomass] = 41000

Accumulated_Production[Hydro](t) = Accumulated_Production[Hydro](t - dt) + (Yearly_increase_in_Accumulated_Production[All_technology]) * dt

INIT Accumulated_Production[Hydro] = 304000

INFLOWS:

Yearly_increase_in_Accumulated_Production[All_technology] = total_supply_in_GWH/time_for_accumulated_production

Accumulated_Supply_Deficit(t) = Accumulated_Supply_Deficit(t - dt) + (supply_security_change) * dt

INIT Accumulated_Supply_Deficit = 0

INFLOWS:

supply_security_change = (demand_exegonous*demand_curve_seasonal)-(Total_Supply_GWH*(1-grid_losses))

adaptive_price(t) = adaptive_price(t - dt) + (chng_in_avg_price) * dt

INIT adaptive_price = INIT(Spot_price)

INFLOWS:

chng_in_avg_price = (Spot_price-adaptive_price)/AT_avg_price

Capacity_Under_Construction_for_PV_and_Wind[Solar_PV](t) = Capacity_Under_Construction_for_PV_and_Wind[Solar_PV](t - dt) + (approved_projects[Interminent_technology] - construction_rate[Interminent_technology]) * dt

INIT Capacity_Under_Construction_for_PV_and_Wind[Solar_PV] = 1.88

Capacity_Under_Construction_for_PV_and_Wind[Onshore_Wind](t) = Capacity_Under_Construction_for_PV_and_Wind[Onshore_Wind](t - dt) + (approved_projects[Interminent_technology] - construction_rate[Interminent_technology]) * dt

INIT Capacity_Under_Construction_for_PV_and_Wind[Onshore_Wind] = 2.83

Capacity_Under_Construction_for_PV_and_Wind[Offshore_Wind](t) = Capacity_Under_Construction_for_PV_and_Wind[Offshore_Wind](t - dt) + (approved_projects[Interminent_technology] - construction_rate[Interminent_technology]) * dt

INIT Capacity_Under_Construction_for_PV_and_Wind[Offshore_Wind] = 0

INFLOWS:

approved_projects[Interminent_technology] = Capacity_Under_Review_for_PV_and_wind/approval_time

OUTFLOWS:

construction_rate[Interminent_technology] = Capacity_Under_Construction_for_PV_and_Wind/construction_time

Capacity_Under_Construction_for__other_sources[Nuclear](t) = Capacity_Under_Construction_for__other_sources[Nuclear](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Nuclear] = 0

Capacity_Under_Construction_for__other_sources[Hard_Coal](t) = Capacity_Under_Construction_for__other_sources[Hard_Coal](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Hard_Coal] = 2.97

Capacity_Under_Construction_for__other_sources[Natural_Gases](t) = Capacity_Under_Construction_for__other_sources[Natural_Gases](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Natural_Gases] = 2.49

Capacity_Under_Construction_for__other_sources[Lignite](t) = Capacity_Under_Construction_for__other_sources[Lignite](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Lignite] = 2.23

Capacity_Under_Construction_for__other_sources[Biomass](t) = Capacity_Under_Construction_for__other_sources[Biomass](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Biomass] = 0.69

Capacity_Under_Construction_for__other_sources[Hydro](t) = Capacity_Under_Construction_for__other_sources[Hydro](t - dt) + (approved_projects_1[Other_technology] - construction_rate_1[Other_technology]) * dt

INIT Capacity_Under_Construction_for__other_sources[Hydro] = 0.57

INFLOWS:

approved_projects_1[Other_technology] = Capacity_Under_Review_for_other_sources/approval__time_for_other_sources

OUTFLOWS:

construction_rate_1[Other_technology] = Capacity_Under_Construction_for__other_sources/construction_time_1

Capacity_Under_Review_for_other_sources[Nuclear](t) = Capacity_Under_Review_for_other_sources[Nuclear](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Nuclear] = 0

Capacity_Under_Review_for_other_sources[Hard_Coal](t) = Capacity_Under_Review_for_other_sources[Hard_Coal](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Hard_Coal] = 5.31

Capacity_Under_Review_for_other_sources[Natural_Gases](t) = Capacity_Under_Review_for_other_sources[Natural_Gases](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Natural_Gases] = 5.28

Capacity_Under_Review_for_other_sources[Lignite](t) = Capacity_Under_Review_for_other_sources[Lignite](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Lignite] = 3.92

Capacity_Under_Review_for_other_sources[Biomass](t) = Capacity_Under_Review_for_other_sources[Biomass](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Biomass] = 1.67

Capacity_Under_Review_for_other_sources[Hydro](t) = Capacity_Under_Review_for_other_sources[Hydro](t - dt) + (application_for_the_investment_1[Other_technology] - approved_projects_1[Other_technology]) * dt

INIT Capacity_Under_Review_for_other_sources[Hydro] = 1.04

INFLOWS:

application_for_the_investment_1[Nuclear] = 0

application_for_the_investment_1[Hard_Coal] = investment_to_relative_capacity[Hard_Coal]*Remaning_expansion_potential[Hard_Coal]*effect_of_reserve_margin_on_investments

application_for_the_investment_1[Natural_Gases] = investment_to_relative_capacity[Natural_Gases]*Remaning_expansion_potential[Natural_Gases]*effect_of_reserve_margin_on_investments

application_for_the_investment_1[Lignite] = investment_to_relative_capacity[Lignite]*Remaning_expansion_potential[Lignite]*effect_of_reserve_margin_on_investments

application_for_the_investment_1[Biomass] = investment_to_relative_capacity[Biomass]*Remaning_expansion_potential[Biomass]*effect_of_reserve_margin_on_investments

application_for_the_investment_1[Hydro] = investment_to_relative_capacity[Hydro]*Remaning_expansion_potential[Hydro]*effect_of_reserve_margin_on_investments

OUTFLOWS:

approved_projects_1[Other_technology] = Capacity_Under_Review_for_other_sources/approval__time_for_other_sources

Capacity_Under_Review_for_PV_and_wind[Solar_PV](t) = Capacity_Under_Review_for_PV_and_wind[Solar_PV](t - dt) + (application_for_the_investment[Interminent_technology] - approved_projects[Interminent_technology]) * dt

INIT Capacity_Under_Review_for_PV_and_wind[Solar_PV] = 7.3

Capacity_Under_Review_for_PV_and_wind[Onshore_Wind](t) = Capacity_Under_Review_for_PV_and_wind[Onshore_Wind](t - dt) + (application_for_the_investment[Interminent_technology] - approved_projects[Interminent_technology]) * dt

INIT Capacity_Under_Review_for_PV_and_wind[Onshore_Wind] = 8.07

Capacity_Under_Review_for_PV_and_wind[Offshore_Wind](t) = Capacity_Under_Review_for_PV_and_wind[Offshore_Wind](t - dt) + (application_for_the_investment[Interminent_technology] - approved_projects[Interminent_technology]) * dt

INIT Capacity_Under_Review_for_PV_and_wind[Offshore_Wind] = 0.63

INFLOWS:

application_for_the_investment[Solar_PV] = investment_to_relative_capacity[Solar_PV]*Remaning_expansion_potential[Solar_PV]

application_for_the_investment[Onshore_Wind] = investment_to_relative_capacity[Onshore_Wind]*Remaning_expansion_potential[Onshore_Wind] application_for_the_investment[Offshore_Wind] = IF(TIME<2009)

then(0)

else(investment_to_relative_capacity[Offshore_Wind]*Remaning_expansion_potential[Offshore_Wind])

OUTFLOWS:

approved_projects[Interminent_technology] = Capacity_Under_Review_for_PV_and_wind/approval_time

Installed_capacity_for_other_sources[Nuclear](t) = Installed_capacity_for_other_sources[Nuclear](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Nuclear] = 20.34

Installed_capacity_for_other_sources[Hard_Coal](t) = Installed_capacity_for_other_sources[Hard_Coal](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Hard_Coal] = 27.64

Installed_capacity_for_other_sources[Natural_Gases](t) = Installed_capacity_for_other_sources[Natural_Gases](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Natural_Gases] = 20.6

Installed_capacity_for_other_sources[Lignite](t) = Installed_capacity_for_other_sources[Lignite](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Lignite] = 20.68

Installed_capacity_for_other_sources[Biomass](t) = Installed_capacity_for_other_sources[Biomass](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Biomass] = 3.53

Installed_capacity_for_other_sources[Hydro](t) = Installed_capacity_for_other_sources[Hydro](t - dt) + (construction_rate_1[Other_technology] - depreciation_rate_1[Other_technology] - decommissiong_rate_1[Other_technology]) * dt

INIT Installed_capacity_for_other_sources[Hydro] = 5.21

INFLOWS:

construction_rate_1[Other_technology] = Capacity_Under_Construction_for__other_sources/construction_time_1

OUTFLOWS:

depreciation_rate_1[Nuclear] = 0

depreciation_rate_1[Hard_Coal] = Installed_capacity_for_other_sources[Hard_Coal]/plant_life_time[Hard_Coal]

depreciation_rate_1[Natural_Gases] = Installed_capacity_for_other_sources[Natural_Gases]/plant_life_time[Natural_Gases] depreciation_rate_1[Lignite] = Installed_capacity_for_other_sources[Lignite]/plant_life_time[Lignite]

depreciation_rate_1[Biomass] = Installed_capacity_for_other_sources[Biomass]/plant_life_time[Biomass]

depreciation_rate_1[Hydro] = Installed_capacity_for_other_sources[Hydro]/plant_life_time[Hydro]

decommissiong_rate_1[Nuclear] = nuclear_shut_down

decommissiong_rate_1[Hard_Coal] = 0

decommissiong_rate_1[Natural_Gases] = 0

decommissiong_rate_1[Lignite] = 0

decommissiong_rate_1[Biomass] = 0

decommissiong_rate_1[Hydro] = 0

Installed_capacity_for_PV_and_Wind[Solar_PV](t) = Installed_capacity_for_PV_and_Wind[Solar_PV](t - dt) + (construction_rate[Interminent_technology] - depreciation_rate[Interminent_technology]) * dt

INIT Installed_capacity_for_PV_and_Wind[Solar_PV] = 2.06

Installed_capacity_for_PV_and_Wind[Onshore_Wind](t) = Installed_capacity_for_PV_and_Wind[Onshore_Wind](t - dt) + (construction_rate[Interminent_technology] - depreciation_rate[Interminent_technology]) * dt

INIT Installed_capacity_for_PV_and_Wind[Onshore_Wind] = 18.38

Installed_capacity_for_PV_and_Wind[Offshore_Wind](t) = Installed_capacity_for_PV_and_Wind[Offshore_Wind](t - dt) + (construction_rate[Interminent_technology] - depreciation_rate[Interminent_technology]) * dt

INIT Installed_capacity_for_PV_and_Wind[Offshore_Wind] = 0

INFLOWS:

construction_rate[Interminent_technology] = Capacity_Under_Construction_for_PV_and_Wind/construction_time

OUTFLOWS:

depreciation_rate[Solar_PV] = Installed_capacity_for_PV_and_Wind[Solar_PV]/plant_life_time[Solar_PV]

depreciation_rate[Onshore_Wind] = Installed_capacity_for_PV_and_Wind[Onshore_Wind]/plant_life_time[Onshore_Wind]

depreciation_rate[Offshore_Wind] = Installed_capacity_for_PV_and_Wind[Offshore_Wind]/plant_life_time[Offshore_Wind]

Remaning_expansion_potential[All_technology](t) = Remaning_expansion_potential[All_technology](t - dt) + (replenish_of_potential[All_technology] - use_of_potential[All_technology]) * dt

INIT Remaning_expansion_potential[All_technology] = INIT(Total_Potential)-INIT(Installed_capacity_all_sources)

INFLOWS:

replenish_of_potential[Solar_PV] = depreciation_rate[Solar_PV]

replenish_of_potential[Onshore_Wind] = depreciation_rate[Onshore_Wind] replenish_of_potential[Offshore_Wind] = depreciation_rate[Offshore_Wind]

replenish_of_potential[Nuclear] = depreciation_rate_1[Nuclear]

replenish_of_potential[Hard_Coal] = depreciation_rate_1[Hard_Coal]

replenish_of_potential[Natural_Gases] = depreciation_rate_1[Natural_Gases]

replenish_of_potential[Lignite] = depreciation_rate_1[Lignite]

replenish_of_potential[Biomass] = depreciation_rate_1[Biomass]

replenish_of_potential[Hydro] = depreciation_rate_1[Hydro]

OUTFLOWS:

use_of_potential[Solar_PV] = application_for_the_investment[Solar_PV]

use_of_potential[Onshore_Wind] = application_for_the_investment[Onshore_Wind]

use_of_potential[Offshore_Wind] = application_for_the_investment[Offshore_Wind]

use_of_potential[Nuclear] = application_for_the_investment_1[Nuclear]

use_of_potential[Hard_Coal] = application_for_the_investment_1[Hard_Coal]

use_of_potential[Natural_Gases] = application_for_the_investment_1[Natural_Gases]

use_of_potential[Lignite] = application_for_the_investment_1[Lignite]

use_of_potential[Biomass] = application_for_the_investment_1[Biomass]

use_of_potential[Hydro] = application_for_the_investment_1[Hydro]

Smoothed_Share_renewables(t) = Smoothed_Share_renewables(t - dt) + (Flow_1) * dt

INIT Smoothed_Share_renewables = 0.1

INFLOWS:

Flow_1 = (renewable_share-Smoothed_Share_renewables)/AT_SHARE

Spot_price(t) = Spot_price(t - dt) + (change_in_price) * dt

INIT Spot_price = 59820

INFLOWS:

change_in_price = (Indicated_price-Spot_price)/price_AT

Accumulated_Investment_Renewables = Accumulated_investments[Solar_PV]+Accumulated_investments[Onshore_Wind]+Accumulated_investments[Offshore_Wind]+Accumulated_investments[Biomass]+Accumulated_investments[Hydro]

Accumulated_Total_Investments = SUM(Accumulated_investments)

Acc_Investment_Conventionals = Accumulated_Total_Investments-Accumulated_Investment_Renewables

Acc_Invest_Cost_Conventionals = Acc_Total_Invest_Cost-Acc_Invest_Cost_Renewables

Acc_Invest_Cost_Renewables = Accumulated_Investments_Cost[Solar_PV]+Accumulated_Investments_Cost[Onshore_Wind]+Accum ulated_Investments_Cost[Offshore_Wind]+Accumulated_Investments_Cost[Biomass]+Accumulated_Investments_Cost[Hydro]

Acc_Total_Invest_Cost = sum(Accumulated_Investments_Cost)

Annual_Operational_Fixed_Cost[Solar_PV] = 25000000

Annual_Operational_Fixed_Cost[Onshore_Wind] = 35000000

Annual_Operational_Fixed_Cost[Offshore_Wind] = IF(TIME<2009)

THEN(0)

ELSE(80000000)

Annual_Operational_Fixed_Cost[Nuclear] = 66000000

Annual_Operational_Fixed_Cost[Hard_Coal] = 32000000

Annual_Operational_Fixed_Cost[Natural_Gases] = 20000000

Annual_Operational_Fixed_Cost[Lignite] = 30000000

Annual_Operational_Fixed_Cost[Biomass] = 100000000

Annual_Operational_Fixed_Cost[Hydro] = 40000000

approval_time[Solar_PV] = 0.5

approval_time[Onshore_Wind] = 0.5

approval_time[Offshore_Wind] = 1.75

approval__time_for_other_sources[Nuclear] = 12

approval__time_for_other_sources[Hard_Coal] = 4

approval__time_for_other_sources[Natural_Gases] = 2

approval__time_for_other_sources[Lignite] = 4

approval__time_for_other_sources[Biomass] = 1

approval__time_for_other_sources[Hydro] = 2

AT_avg_price = 3

AT_SHARE = 1

AT_years = 1

Available_capacity_for_PV_and_Wind[Solar_PV] = monthly__technical_capacity_factor_for_PV_and_Wind[Solar_PV]*Installed_capacity_for_PV_and_Wind[Solar_PV]

Available_capacity_for_PV_and_Wind[Onshore_Wind] = monthly__technical_capacity_factor_for_PV_and_Wind[Onshore_Wind]*Installed_capacity_for_PV_and_Wind[Onshore_Wind]

Available_capacity_for_PV_and_Wind[Offshore_Wind] = monthly__technical_capacity_factor_for_PV_and_Wind[Offshore_Wind]*Installed_capacity_for_PV_and_Wind[Offshore_Wind] available_capacity_from_other_sources[Nuclear] = Installed_capacity_for_other_sources[Nuclear]*capacity_factor[Nuclear]

available_capacity_from_other_sources[Hard_Coal] = Installed_capacity_for_other_sources[Hard_Coal]*capacity_factor[Hard_Coal]

available_capacity_from_other_sources[Natural_Gases] = Installed_capacity_for_other_sources[Natural_Gases]*capacity_factor[Natural_Gases]

available_capacity_from_other_sources[Lignite] = Installed_capacity_for_other_sources[Lignite]*capacity_factor[Lignite]

available_capacity_from_other_sources[Biomass] = Installed_capacity_for_other_sources[Biomass]*capacity_factor[Biomass]

available_capacity_from_other_sources[Hydro] = Installed_capacity_for_other_sources[Hydro]*capacity_factor[Hydro]

available_capacity_with_grid_losses_from_other_sources[Other_technology] = available_capacity_from_other_sources*(1-grid_losses)

average_weighted_price = accumulated_sales/(accumulated_demand+0.000000000000001)

b[All_technology] = (LN(Converter_1)/LN(2))*-1

b2[All_technology] = (LN(Converter_2)/LN(2))*-1

capacity_factor[Solar_PV] = monthly__technical_capacity_factor_for_PV_and_Wind[Solar_PV]

capacity_factor[Onshore_Wind] = monthly__technical_capacity_factor_for_PV_and_Wind[Onshore_Wind]

capacity_factor[Offshore_Wind] = monthly__technical_capacity_factor_for_PV_and_Wind[Offshore_Wind]

capacity_factor[Nuclear] = reference_capacity_factor[Nuclear]

capacity_factor[Hard_Coal] = reference_capacity_factor[Hard_Coal]+elasticity_of_progress_ratio[Hard_Coal]*capacity_utilization_progress_ratio[Hard_Coal]

capacity_factor[Natural_Gases] = reference_capacity_factor[Natural_Gases]+capacity_utilization_progress_ratio[Natural_Gases]*elasticity_of_progress_ratio[Natural_Gases]

capacity_factor[Lignite] = reference_capacity_factor[Lignite]+elasticity_of_progress_ratio[Lignite]*capacity_utilization_progress_ratio[Lignite]

capacity_factor[Biomass] = min(1,reference_capacity_factor[Biomass]+elasticity_of_progress_ratio[Biomass]*capacity_utilization_progress_ratio[Biomass])

capacity_factor[Hydro] = reference_capacity_factor[Hydro]+elasticity_of_progress_ratio[Hydro]*capacity_utilization_progress_ratio[Hydro]

capacity_utilization_model[Nuclear] = received_price[Nuclear]/variable_cost[Nuclear]

capacity_utilization_model[Hard_Coal] = received_price[Hard_Coal]/variable_cost[Hard_Coal]

capacity_utilization_model[Natural_Gases] = received_price[Natural_Gases]/variable_cost[Natural_Gases] capacity_utilization_model[Lignite] = received_price[Lignite]/variable_cost[Lignite]

capacity_utilization_model[Biomass] = received_price[Biomass]/variable_cost[Biomass]

capacity_utilization_model[Hydro] = received_price[Hydro]/variable_cost[Hydro]

capacity_utilization_progress_ratio[Other_technology] = capacity_utilization_model/initial_capacity_utilization_model-1

CO2_allowance_price = GRAPH(TIME)

(2006, 5.30), (2013, 5.30), (2021, 20.0), (2028, 30.0), (2035, 36.0), (2043, 40.0), (2050, 47.5)

CO2_emission[Solar_PV] = 0

CO2_emission[Onshore_Wind] = 0

CO2_emission[Offshore_Wind] = 0

CO2_emission[Nuclear] = 0

CO2_emission[Hard_Coal] = 340

CO2_emission[Natural_Gases] = 200

CO2_emission[Lignite] = 360

CO2_emission[Biomass] = 0

CO2_emission[Hydro] = 0

CO2_emission_per_technology[Nuclear] = 0

CO2_emission_per_technology[Hard_Coal] = CO2_emission[Hard_Coal]*Total_Supply_Other_Sources[Hard_Coal]

CO2_emission_per_technology[Natural_Gases] = CO2_emission[Natural_Gases]*Total_Supply_Other_Sources[Natural_Gases]

CO2_emission_per_technology[Lignite] = CO2_emission[Lignite]*Total_Supply_Other_Sources[Lignite]

CO2_emission_per_technology[Biomass] = 0

CO2_emission_per_technology[Hydro] = 0

construction_time[Solar_PV] = 2

construction_time[Onshore_Wind] = 2

construction_time[Offshore_Wind] = 3.5

construction_time_1[Nuclear] = 6

construction_time_1[Hard_Coal] = 4

construction_time_1[Natural_Gases] = 2

construction_time_1[Lignite] = 4

construction_time_1[Biomass] = 3

construction_time_1[Hydro] = 3

Conventional_Subsidies[Nuclear] = GRAPH(TIME)

(2006, 22000), (2007, 22000), (2008, 22000), (2009, 22000), (2010, 22000), (2011, 22000), (2012, 20000), (2013, 20000), (2014, 20000), (2015, 6000), (2016, 6000), (2017, 6000), (2018, 6000), (2019, 6000), (2020, 6000), (2021, 6000), (2022, 6000), (2023, 6000), (2024, 6000), (2025, 6000), (2026, 6000), (2027, 6000), (2028, 6000), (2029, 6000), (2030, 6000), (2031, 6000), (2032, 6000), (2033, 6000), (2034, 6000), (2035, 6000), (2036, 6000), (2037, 6000), (2038, 6000), (2039, 6000), (2040, 6000), (2041, 6000), (2042, 6000), (2043, 6000), (2044, 6000), (2045, 6000), (2046, 6000), (2047, 6000), (2048, 6000), (2049, 6000), (2050, 6000)

Conventional_Subsidies[Hard_Coal] = GRAPH(TIME)

(2006, 31000), (2007, 31000), (2008, 31000), (2009, 31000), (2010, 31000), (2011, 31000), (2012, 19000), (2013, 19000), (2014, 19000), (2015, 24000), (2016, 24000), (2017, 24000), (2018, 24000), (2019, 24000), (2020, 24000), (2021, 24000), (2022, 24000), (2023, 24000), (2024, 24000), (2025, 24000), (2026, 24000), (2027, 24000), (2028, 24000), (2029, 24000), (2030, 24000), (2031, 24000), (2032, 24000), (2033, 24000), (2034, 24000), (2035, 24000), (2036, 24000), (2037, 24000), (2038, 24000), (2039, 24000), (2040, 24000), (2041, 24000), (2042, 24000), (2043, 24000), (2044, 24000), (2045, 24000), (2046, 24000), (2047, 24000), (2048, 24000), (2049, 24000), (2050, 24000)

Conventional_Subsidies[Lignite] = GRAPH(TIME)

(2006, 10000), (2007, 10000), (2008, 10000), (2009, 10000), (2010, 10000), (2011, 10000), (2012, 10000), (2013, 10000), (2014, 10000), (2015, 10000), (2016, 10000), (2017, 10000), (2018, 10000), (2019, 10000), (2020, 10000), (2021, 10000), (2022, 10000), (2023, 10000), (2024, 10000), (2025, 10000), (2026, 10000), (2027, 10000), (2028, 10000), (2029, 10000), (2030, 10000), (2031, 10000), (2032, 10000), (2033, 10000), (2034, 10000), (2035, 10000), (2036, 10000), (2037, 10000), (2038, 10000), (2039, 10000), (2040, 10000), (2041, 10000), (2042, 10000), (2043, 10000), (2044, 10000), (2045, 10000), (2046, 10000), (2047, 10000), (2048, 10000), (2049, 10000), (2050, 10000)

Conventional_Subsidies[Natural_Gas] = GRAPH(TIME)

(2006, 55000), (2007, 55000), (2008, 55000), (2009, 55000), (2010, 55000), (2011, 55000), (2012, 55000), (2013, 55000), (2014, 55000), (2015, 55000), (2016, 55000), (2017, 55000), (2018, 55000), (2019, 55000), (2020, 55000), (2021, 55000), (2022, 55000), (2023, 55000), (2024, 55000), (2025, 55000), (2026, 55000), (2027, 55000), (2028, 55000), (2029, 55000), (2030, 55000), (2031, 55000), (2032, 55000), (2033, 55000), (2034, 55000), (2035, 55000), (2036, 55000), (2037, 55000), (2038, 55000), (2039, 55000), (2040, 55000), (2041, 55000), (2042, 55000), (2043, 55000), (2044, 55000), (2045, 55000), (2046, 55000), (2047, 55000), (2048, 55000), (2049, 55000), (2050, 55000)

Conventional_Subsidies_Scenario[Conventional] = IF(TIME>2016)

THEN(0*Switch_Conventional_Subsidies+(1-Switch_Conventional_Subsidies)*Conventional_Subsidies)

ELSE(Conventional_Subsidies)

Conventional_Supply_Ratio_Feeding_in = min(1,total_electrity_supply_in_merit_order_from_other_sources/Total_Available_Supply_from_conventionals)

Converter_1[All_technology] = 1-learning_rate_2006_2016

Converter_2[All_technology] = 1-learning_rate_2016_2050

curtailment = IF(residual_load>minimum_generation_scenario_test)

THEN(0)

ELSE(minimum_generation_scenario_test-residual_load)

Degression_Rate_of_FIT_past_policy[Solar_PV] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.000484), (2017, 0.000714), (2018, 0.00101), (2019, 0.0012), (2020, 0.00159), (2021, 0.00173), (2022, 0.002), (2023, 0.00221), (2024, 0.00253), (2025, 0.0027), (2026, 0.00306), (2027, 0.00336), (2028, 0.00362), (2029, 0.00373), (2030, 0.00396), (2031, 0.0041), (2032, 0.0044), (2033, 0.00459), (2034, 0.00477), (2035, 0.005), (2036, 0.005), (2037, 0.005), (2038, 0.005), (2039, 0.005), (2040, 0.005), (2041, 0.005), (2042, 0.005), (2043, 0.005), (2044, 0.005), (2045, 0.005), (2046, 0.005), (2047, 0.005), (2048, 0.005), (2049, 0.005), (2050, 0.005)

Degression_Rate_of_FIT_past_policy[Onshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00221), (2016, 0.00297), (2017, 0.00353), (2018, 0.00394), (2019, 0.00477), (2020, 0.00525), (2021, 0.00601), (2022, 0.00671), (2023, 0.00747), (2024, 0.00836), (2025, 0.00919), (2026, 0.00982), (2027, 0.0102), (2028, 0.0106), (2029, 0.0116), (2030, 0.0125), (2031, 0.0133), (2032, 0.014), (2033, 0.0149), (2034, 0.015), (2035, 0.015), (2036, 0.015), (2037, 0.015), (2038, 0.015), (2039, 0.015), (2040, 0.015), (2041, 0.015), (2042, 0.015), (2043, 0.015), (2044, 0.015), (2045, 0.015), (2046, 0.015), (2047, 0.015), (2048, 0.015), (2049, 0.015), (2050, 0.015)

Degression_Rate_of_FIT_past_policy[Offshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.000484), (2017, 0.000714), (2018, 0.00101), (2019, 0.0012), (2020, 0.00159), (2021, 0.00173), (2022, 0.002), (2023, 0.00221), (2024, 0.00253), (2025, 0.0027), (2026, 0.00306), (2027, 0.00336), (2028, 0.00362), (2029, 0.00373), (2030, 0.00396), (2031, 0.0041), (2032, 0.0044), (2033, 0.00459), (2034, 0.00477), (2035, 0.005), (2036, 0.005), (2037, 0.005), (2038, 0.005), (2039, 0.005), (2040, 0.005), (2041, 0.005), (2042, 0.005), (2043, 0.005), (2044, 0.005), (2045, 0.005), (2046, 0.005), (2047, 0.005), (2048, 0.005), (2049, 0.005), (2050, 0.005)

Degression_Rate_of_FIT_past_policy[Hydro] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.000484), (2017, 0.000714), (2018, 0.00101), (2019, 0.0012), (2020, 0.00159), (2021, 0.00173), (2022, 0.002), (2023, 0.00221), (2024, 0.00253), (2025, 0.0027), (2026, 0.00306), (2027, 0.00336), (2028, 0.00362), (2029, 0.00373), (2030, 0.00396), (2031, 0.0041), (2032, 0.0044), (2033, 0.00459), (2034, 0.00477), (2035, 0.005), (2036, 0.005), (2037, 0.005), (2038, 0.005), (2039, 0.005), (2040, 0.005), (2041, 0.005), (2042, 0.005), (2043, 0.005), (2044, 0.005), (2045, 0.005), (2046, 0.005), (2047, 0.005), (2048, 0.005), (2049, 0.005), (2050, 0.005)

Degression_Rate_of_FIT_past_policy[Biomass] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.000484), (2017, 0.000714), (2018, 0.00101), (2019, 0.0012), (2020, 0.00159), (2021, 0.00173), (2022, 0.002), (2023, 0.00221), (2024, 0.00253), (2025, 0.0027), (2026, 0.00306), (2027, 0.00336), (2028, 0.00362), (2029, 0.00373), (2030, 0.00396), (2031, 0.0041), (2032, 0.0044), (2033, 0.00459), (2034, 0.00477), (2035, 0.005), (2036, 0.005), (2037, 0.005), (2038, 0.005), (2039, 0.005), (2040, 0.005), (2041, 0.005), (2042, 0.005), (2043, 0.005), (2044, 0.005), (2045, 0.005), (2046, 0.005), (2047, 0.005), (2048, 0.005), (2049, 0.005), (2050, 0.005)

Degression_Rate_of_New_Policy[Renewables] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

Degression_Rate_of_Policy[Renewables] = IF(TIME>2016)

THEN(Degression_Rate_of_New_Policy*switch_degresssion_rate_of_policy+(1-switch_degresssion_rate_of_policy)*(Degression_Rate_of_FIT_past_policy))

ELSE(Degression_Rate_of_FIT_past_policy)

demand_curve_seasonal = GRAPH(TIME)

(2006, 1.14), (2006, 1.05), (2006, 1.10), (2006, 0.96), (2006, 0.935), (2006, 0.927), (2007, 0.971), (2007, 0.937), (2007, 0.921), (2007, 0.987), (2007, 1.04), (2007, 1.03), (2007, 1.14), (2007, 1.05), (2007, 1.10), (2007, 0.96), (2007, 0.935), (2007, 0.927), (2008, 0.971), (2008, 0.937), (2008, 0.921), (2008, 0.987), (2008, 1.04), (2008, 1.03), (2008, 1.14), (2008, 1.05), (2008, 1.10), (2008, 0.96), (2008, 0.935), (2008, 0.927), (2009, 0.971), (2009, 0.937), (2009, 0.921), (2009, 0.987), (2009, 1.04), (2009, 1.03), (2009, 1.14), (2009, 1.05), (2009, 1.10), (2009, 0.96), (2009, 0.935), (2009, 0.927), (2010, 0.971), (2010, 0.937), (2010, 0.921), (2010, 0.987), (2010, 1.04), (2010, 1.03), (2010, 1.14), (2010, 1.05), (2010, 1.10), (2010, 0.96), (2010, 0.935), (2010, 0.927), (2011, 0.971), (2011, 0.937), (2011, 0.921), (2011, 0.987), (2011, 1.04), (2011, 1.03), (2011, 1.14), (2011, 1.05), (2011, 1.10), (2011, 0.96), (2011, 0.935), (2011, 0.927), (2012, 0.971), (2012, 0.937), (2012, 0.921), (2012, 0.987), (2012, 1.04), (2012, 1.03), (2012, 1.14), (2012, 1.05), (2012, 1.10), (2012, 0.96), (2012, 0.935), (2012, 0.927), (2013, 0.971), (2013, 0.937), (2013, 0.921), (2013, 0.987), (2013, 1.04), (2013, 1.03), (2013, 1.14), (2013, 1.05), (2013, 1.10), (2013, 0.96), (2013, 0.935), (2013, 0.927), (2014, 0.971), (2014, 0.937), (2014, 0.921), (2014, 0.987), (2014, 1.04), (2014, 1.03), (2014, 1.14), (2014, 1.05), (2014, 1.10), (2014, 0.96), (2014, 0.935), (2014, 0.927), (2015, 0.971), (2015, 0.937), (2015, 0.921), (2015, 0.987), (2015, 1.04), (2015, 1.03), (2015, 1.14), (2015, 1.05), (2015, 1.10), (2015, 0.96), (2015, 0.935), (2015, 0.927), (2016, 0.971), (2016, 0.937), (2016, 0.921), (2016, 0.987), (2016, 1.04), (2016, 1.03), (2016, 1.14), (2016, 1.05), (2016, 1.10), (2016, 0.96), (2016, 0.935), (2016, 0.927), (2017, 0.971), (2017, 0.937), (2017, 0.921), (2017, 0.987), (2017, 1.04), (2017, 1.03), (2017, 1.14), (2017, 1.05), (2017, 1.10), (2017, 0.96), (2017, 0.935), (2017, 0.927), (2018, 0.971), (2018, 0.937), (2018, 0.921), (2018, 0.987), (2018, 1.04), (2018, 1.03), (2018, 1.14), (2018, 1.05), (2018, 1.10), (2018, 0.96), (2018, 0.935), (2018, 0.927), (2019, 0.971), (2019, 0.937), (2019, 0.921), (2019, 0.987), (2019, 1.04), (2019, 1.03), (2019, 1.14), (2019, 1.05), (2019, 1.10), (2019, 0.96), (2019, 0.935), (2019, 0.927), (2020, 0.971), (2020, 0.937), (2020, 0.921), (2020, 0.987), (2020, 1.04), (2020, 1.03), (2020, 1.14), (2020, 1.05), (2020, 1.10), (2020, 0.96), (2020, 0.935), (2020, 0.927), (2021, 0.971), (2021, 0.937), (2021, 0.921), (2021, 0.987), (2021, 1.04), (2021, 1.03), (2021, 1.14), (2021, 1.05), (2021, 1.10), (2021, 0.96), (2021, 0.935), (2021, 0.927), (2022, 0.971), (2022, 0.937), (2022, 0.921), (2022, 0.987), (2022, 1.04), (2022, 1.03), (2022, 1.14), (2022, 1.05), (2022, 1.10), (2022, 0.96), (2022, 0.935), (2022, 0.927), (2023, 0.971), (2023, 0.937), (2023, 0.921), (2023, 0.987), (2023, 1.04), (2023, 1.03), (2023, 1.14), (2023, 1.05), (2023, 1.10), (2023, 0.96), (2023, 0.935), (2023, 0.927), (2024, 0.971), (2024, 0.937), (2024, 0.921), (2024, 0.987), (2024, 1.04), (2024, 1.03), (2024, 1.14), (2024, 1.05), (2024, 1.10), (2024, 0.96), (2024, 0.935), (2024, 0.927), (2025, 0.971), (2025, 0.937), (2025, 0.921), (2025, 0.987), (2025, 1.04), (2025, 1.03), (2025, 1.14), (2025, 1.05), (2025, 1.10), (2025, 0.96), (2025, 0.935), (2025, 0.927), (2026, 0.971), (2026, 0.937), (2026, 0.921), (2026, 0.987), (2026, 1.04), (2026, 1.03), (2026, 1.14), (2026, 1.05), (2026, 1.10), (2026, 0.96), (2026, 0.935), (2026, 0.927), (2027, 0.971), (2027, 0.937), (2027, 0.921), (2027, 0.987), (2027, 1.04), (2027, 1.03), (2027, 1.14), (2027, 1.05), (2027, 1.10), (2027, 0.96), (2027, 0.935), (2027, 0.927), (2028, 0.971), (2028, 0.937), (2028, 0.921), (2028, 0.987), (2028, 1.04), (2028, 1.03), (2028, 1.14), (2028, 1.05), (2028, 1.10), (2028, 0.96), (2028, 0.935), (2028, 0.927), (2029, 0.971), (2029, 0.937), (2029, 0.921), (2029, 0.987), (2029, 1.04), (2029, 1.03), (2029, 1.14), (2029, 1.05), (2029, 1.10), (2029, 0.96), (2029, 0.935), (2029, 0.927), (2030, 0.971), (2030, 0.937), (2030, 0.921), (2030, 0.987), (2030, 1.04), (2030, 1.03), (2030, 1.14), (2030, 1.05), (2030, 1.10), (2030, 0.96), (2030, 0.935), (2030, 0.927), (2031, 0.971), (2031, 0.937), (2031, 0.921), (2031, 0.987), (2031, 1.04), (2031, 1.03), (2031, 1.14), (2031, 1.05), (2031, 1.10), (2031, 0.96), (2031, 0.935), (2031, 0.927), (2032, 0.971), (2032, 0.937), (2032, 0.921), (2032, 0.987), (2032, 1.04), (2032, 1.03), (2032, 1.14), (2032, 1.05), (2032, 1.10), (2032, 0.96), (2032, 0.935), (2032, 0.927), (2033, 0.971), (2033, 0.937), (2033, 0.921), (2033, 0.987), (2033, 1.04), (2033, 1.03), (2033, 1.14), (2033, 1.05), (2033, 1.10), (2033, 0.96), (2033, 0.935), (2033, 0.927), (2034, 0.971), (2034, 0.937), (2034, 0.921), (2034, 0.987), (2034, 1.04), (2034, 1.03), (2034, 1.14), (2034, 1.05), (2034, 1.10), (2034, 0.96), (2034, 0.935), (2034, 0.927), (2035, 0.971), (2035, 0.937), (2035, 0.921), (2035, 0.987), (2035, 1.04), (2035, 1.03), (2035, 1.14), (2035, 1.05), (2035, 1.10), (2035, 0.96), (2035, 0.935), (2035, 0.927), (2036, 0.971), (2036, 0.937), (2036, 0.921), (2036, 0.987), (2036, 1.04), (2036, 1.03), (2036, 1.14), (2036, 1.05), (2036, 1.10), (2036, 0.96), (2036, 0.935), (2036, 0.927), (2037, 0.971), (2037, 0.937), (2037, 0.921), (2037, 0.987), (2037, 1.04), (2037, 1.03), (2037, 1.14), (2037, 1.05), (2037, 1.10), (2037, 0.96), (2037, 0.935), (2037, 0.927), (2038, 0.971), (2038, 0.937), (2038, 0.921), (2038, 0.987), (2038, 1.04), (2038, 1.03), (2038, 1.14), (2038, 1.05), (2038, 1.10), (2038, 0.96), (2038, 0.935), (2038, 0.927), (2039, 0.971), (2039, 0.937), (2039, 0.921), (2039, 0.987), (2039, 1.04), (2039, 1.03), (2039, 1.14), (2039, 1.05), (2039, 1.10), (2039, 0.96), (2039, 0.935), (2039, 0.927), (2040, 0.971), (2040, 0.937), (2040, 0.921), (2040, 0.987), (2040, 1.04), (2040, 1.03), (2040, 1.14), (2040, 1.05), (2040, 1.10), (2040, 0.96), (2040, 0.935), (2040, 0.927), (2041, 0.971), (2041, 0.937), (2041, 0.921), (2041, 0.987), (2041, 1.04), (2041, 1.03), (2041, 1.14), (2041, 1.05), (2041, 1.10), (2041, 0.96), (2041, 0.935), (2041, 0.927), (2042, 0.971), (2042, 0.937), (2042, 0.921), (2042, 0.987), (2042, 1.04), (2042, 1.03), (2042, 1.14), (2042, 1.05), (2042, 1.10), (2042, 0.96), (2042, 0.935), (2042, 0.927), (2043, 0.971), (2043, 0.937), (2043, 0.921), (2043, 0.987), (2043, 1.04), (2043, 1.03), (2043, 1.14), (2043, 1.05), (2043, 1.10), (2043, 0.96), (2043, 0.935), (2043, 0.927), (2044, 0.971), (2044, 0.937), (2044, 0.921), (2044, 0.987), (2044, 1.04), (2044, 1.03), (2044, 1.14), (2044, 1.05), (2044, 1.10), (2044, 0.96), (2044, 0.935), (2044, 0.927), (2045, 0.971), (2045, 0.937), (2045, 0.921), (2045, 0.987), (2045, 1.04), (2045, 1.03), (2045, 1.14), (2045, 1.05), (2045, 1.10), (2045, 0.96), (2045, 0.935), (2045, 0.927), (2046, 0.971), (2046, 0.937), (2046, 0.921), (2046, 0.987), (2046, 1.04), (2046, 1.03), (2046, 1.14), (2046, 1.05), (2046, 1.10), (2046, 0.96), (2046, 0.935), (2046, 0.927), (2047, 0.971), (2047, 0.937), (2047, 0.921), (2047, 0.987), (2047, 1.04), (2047, 1.03), (2047, 1.14), (2047, 1.05), (2047, 1.10), (2047, 0.96), (2047, 0.935), (2047, 0.927), (2048, 0.971), (2048, 0.937), (2048, 0.921), (2048, 0.987), (2048, 1.04), (2048, 1.03), (2048, 1.14), (2048, 1.05), (2048, 1.10), (2048, 0.96), (2048, 0.935), (2048, 0.927), (2049, 0.971), (2049, 0.937), (2049, 0.921), (2049, 0.987), (2049, 1.04), (2049, 1.03), (2049, 1.14), (2049, 1.05), (2049, 1.10), (2049, 0.96), (2049, 0.935), (2049, 0.927), (2050, 0.971), (2050, 0.937), (2050, 0.921), (2050, 0.987), (2050, 1.04), (2050, 1.03), (2050, 1.14)

demand_exegonous = GRAPH(TIME)

(2006, 614100), (2007, 619800), (2008, 621500), (2009, 618200), (2010, 581300), (2011, 615400), (2012, 606800), (2013, 607100), (2014, 604900), (2015, 592200), (2016, 597000), (2017, 589273), (2018, 581645), (2019, 574116), (2020, 566685), (2021, 563252), (2022, 559840), (2023, 556448), (2024, 553077), (2025, 549726), (2026, 546396), (2027, 543085), (2028, 539795), (2029, 536525), (2030, 533274), (2031, 530044), (2032, 526832), (2033, 523641), (2034, 520468), (2035, 517315), (2036, 514181), (2037, 511066), (2038, 507970), (2039, 504892), (2040, 501833), (2041, 498793), (2042, 495771), (2043, 492768), (2044, 489782), (2045, 486815), (2046, 483866), (2047, 480934), (2048, 478021), (2049, 475125), (2050, 472246)

Desired_CO2_emission_targets = GRAPH(TIME)

(2006, 1.00), (2007, 0.992), (2008, 0.984), (2009, 0.976), (2010, 0.968), (2011, 0.961), (2012, 0.953), (2013, 0.945), (2014, 0.938), (2015, 0.928), (2016, 0.919), (2017, 0.91), (2018, 0.901), (2019, 0.892), (2020, 0.883), (2021, 0.874), (2022, 0.869), (2023, 0.864), (2024, 0.858), (2025, 0.853), (2026, 0.848), (2027, 0.843), (2028, 0.838), (2029, 0.833), (2030, 0.828), (2031, 0.823), (2032, 0.818), (2033, 0.813), (2034, 0.808), (2035, 0.803), (2036, 0.799), (2037, 0.794), (2038, 0.789), (2039, 0.784), (2040, 0.78), (2041, 0.775), (2042, 0.77), (2043, 0.766), (2044, 0.761), (2045, 0.757), (2046, 0.752), (2047, 0.747), (2048, 0.743), (2049, 0.739), (2050, 0.734)

effect_of_daily_price_fluctuations_conventionals[Nuclear] = 1.015

effect_of_daily_price_fluctuations_conventionals[Hard_Coal] = 1.17

effect_of_daily_price_fluctuations_conventionals[Lignite] = 1.05

effect_of_daily_price_fluctuations_conventionals[Natural_Gas] = 1.14

effect_of_daily_price_fluctuations_renewables[Solar_PV] = 0.98

effect_of_daily_price_fluctuations_renewables[Onshore_Wind] = 0.86

effect_of_daily_price_fluctuations_renewables[Offshore_Wind] = 0.86

effect_of_daily_price_fluctuations_renewables[Hydro] = 1.02

effect_of_daily_price_fluctuations_renewables[Biomass] = 1.02

effect_of_reserve_margin_on_investments = GRAPH(Reserve_Margin)

(1.00, 1.50), (1.10, 1.43), (1.20, 1.36), (1.30, 1.28), (1.40, 1.16), (1.50, 1.00), (1.60, 0.96), (1.70, 0.92), (1.80, 0.9) effect_of_supply_ratio = GRAPH(Conventional_Supply_Ratio_Feeding_in)

(0.00, 0.00), (0.1, 0.263), (0.2, 0.456), (0.3, 0.582), (0.4, 0.656), (0.5, 0.73), (0.6, 0.793), (0.7, 0.856), (0.8, 0.902), (0.9, 0.951), (1.00, 1.00)

elasticity_of_progress_ratio[Nuclear] = 0.15

elasticity_of_progress_ratio[Hard_Coal] = 0.3

elasticity_of_progress_ratio[Natural_Gases] = 0.5

elasticity_of_progress_ratio[Lignite] = 0.15

elasticity_of_progress_ratio[Biomass] = 0.6

elasticity_of_progress_ratio[Hydro] = 0.5

expenditures_FIT_percentage[Renewables] = production_FIT*FIT_percentage_of_retail_price_Euro*Switch_FIT__Retail_Percentage

expenditures_Fixed_FIT[Renewables] = IF(TIME>2016)

then(production_FIT*FIT_Data*(FIT_Premium_Ratio_Policy/(1+FIT_Premium_Ratio_Policy))*(1-Switch_FIT__Retail_Percentage)+(Switch_FIT__Retail_Percentage*0))

ELSE(production_FIT*FIT_Data*(FIT_Premium_Ratio_Policy/(1+FIT_Premium_Ratio_Policy)))

FIT_Data[Renewables] = IF(TIME<2016)

THEN(FIT_data_historic)

ELSE(FIT_data_historic*(1-Degression_Rate_of_Policy))

FIT_data_historic[Solar_PV] = GRAPH(TIME)

(2006, 529730), (2007, 529730), (2008, 519519), (2009, 501924), (2010, 479759), (2011, 435627), (2012, 387332), (2013, 365356), (2014, 339971), (2015, 274835), (2016, 328148), (2017, 328148), (2018, 328148), (2019, 328148), (2020, 328148), (2021, 328148), (2022, 328148), (2023, 328148), (2024, 328148), (2025, 328148), (2026, 328148), (2027, 328148), (2028, 328148), (2029, 328148), (2030, 328148), (2031, 328148), (2032, 328148), (2033, 328148), (2034, 328148), (2035, 328148), (2036, 328148), (2037, 328148), (2038, 328148), (2039, 328148), (2040, 328148), (2041, 328148), (2042, 328148), (2043, 328148), (2044, 328148), (2045, 328148), (2046, 328148), (2047, 328148), (2048, 328148), (2049, 328148), (2050, 328148)

FIT_data_historic[Onshore_Wind] = GRAPH(TIME)

(2006, 88997), (2007, 88997), (2008, 88334), (2009, 87768), (2010, 87904), (2011, 88118), (2012, 86211), (2013, 84680), (2014, 78425), (2015, 85683), (2016, 85388), (2017, 85388), (2018, 85388), (2019, 85388), (2020, 85388), (2021, 85388), (2022, 85388), (2023, 85388), (2024, 85388), (2025, 85388), (2026, 85388), (2027, 85388), (2028, 85388), (2029, 85388), (2030, 85388), (2031, 85388), (2032, 85388), (2033, 85388), (2034, 85388), (2035, 85388), (2036, 85388), (2037, 85388), (2038, 85388), (2039, 85388), (2040, 85388), (2041, 85388), (2042, 85388), (2043, 85388), (2044, 85388), (2045, 85388), (2046, 85388), (2047, 85388), (2048, 85388), (2049, 85388), (2050, 85388)

FIT_data_historic[Offshore_Wind] = GRAPH(TIME)

(2006, 149867), (2007, 149867), (2008, 149867), (2009, 149867), (2010, 149867), (2011, 150289), (2012, 150000), (2013, 153086), (2014, 0.00), (2015, 184000), (2016, 153636), (2017, 153636), (2018, 153636), (2019, 153636), (2020, 153636), (2021, 153636), (2022, 153636), (2023, 153636), (2024, 153636), (2025, 153636), (2026, 153636), (2027, 153636), (2028, 153636), (2029, 153636), (2030, 153636), (2031, 153636), (2032, 153636), (2033, 153636), (2034, 153636), (2035, 153636), (2036, 153636), (2037, 153636), (2038, 153636), (2039, 153636), (2040, 153636), (2041, 153636), (2042, 153636), (2043, 153636), (2044, 153636), (2045, 153636), (2046, 153636), (2047, 153636), (2048, 153636), (2049, 153636), (2050, 153636)

FIT_data_historic[Hydro] = GRAPH(TIME)

(2006, 74445), (2007, 74445), (2008, 75316), (2009, 76051), (2010, 78405), (2011, 69415), (2012, 47629), (2013, 81818), (2014, 80319), (2015, 87927), (2016, 102337), (2017, 102337), (2018, 102337), (2019, 102337), (2020, 102337), (2021, 102337), (2022, 102337), (2023, 102337), (2024, 102337), (2025, 102337), (2026, 102337), (2027, 102337), (2028, 102337), (2029, 102337), (2030, 102337), (2031, 102337), (2032, 102337), (2033, 102337), (2034, 102337), (2035, 102337), (2036, 102337), (2037, 102337), (2038, 102337), (2039, 102337), (2040, 102337), (2041, 102337), (2042, 102337), (2043, 102337), (2044, 102337), (2045, 102337), (2046, 102337), (2047, 102337), (2048, 102337), (2049, 102337), (2050, 102337)

FIT_data_historic[Biomass] = GRAPH(TIME)

(2006, 111825), (2007, 111825), (2008, 126203), (2009, 135071), (2010, 153680), (2011, 158940), (2012, 161503), (2013, 188597), (2014, 194171), (2015, 199703), (2016, 242656), (2017, 242656), (2018, 242656), (2019, 242656), (2020, 242656), (2021, 242656), (2022, 242656), (2023, 242656), (2024, 242656), (2025, 242656), (2026, 242656), (2027, 242656), (2028, 242656), (2029, 242656), (2030, 242656), (2031, 242656), (2032, 242656), (2033, 242656), (2034, 242656), (2035, 242656), (2036, 242656), (2037, 242656), (2038, 242656), (2039, 242656), (2040, 242656), (2041, 242656), (2042, 242656), (2043, 242656), (2044, 242656), (2045, 242656), (2046, 242656), (2047, 242656), (2048, 242656), (2049, 242656), (2050, 242656)

FIT_duration = 20

FIT_percentage_of_retail_price[Solar_PV] = 2.5

FIT_percentage_of_retail_price[Onshore_Wind] = 1.4

FIT_percentage_of_retail_price[Offshore_Wind] = 2.3

FIT_percentage_of_retail_price[Hydro] = 0.7

FIT_percentage_of_retail_price[Biomass] = 2.3

FIT_percentage_of_retail_price_Euro[Renewables] = FIT_percentage_of_retail_price*Spot_price

FIT_premium[Renewables] = IF(TIME<2016)

THEN(FIT_Premium_HISTORIC)

ELSE((1-Degression_Rate_of_Policy)*FIT_Premium_HISTORIC)

FIT_Premium_HISTORIC[Solar_PV] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 246094), (2014, 215319), (2015, 197832), (2016, 178256), (2017, 178256), (2018, 178256), (2019, 178256), (2020, 178256), (2021, 178256), (2022, 178256), (2023, 178256), (2024, 178256), (2025, 178256), (2026, 178256), (2027, 178256), (2028, 178256), (2029, 178256), (2030, 178256), (2031, 178256), (2032, 178256), (2033, 178256), (2034, 178256), (2035, 178256), (2036, 178256), (2037, 178256), (2038, 178256), (2039, 178256), (2040, 178256), (2041, 178256), (2042, 178256), (2043, 178256), (2044, 178256), (2045, 178256), (2046, 178256), (2047, 178256), (2048, 178256), (2049, 178256), (2050, 178256)

FIT_Premium_HISTORIC[Onshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 67434), (2014, 67752), (2015, 70591), (2016, 69886), (2017, 69886), (2018, 69886), (2019, 69886), (2020, 69886), (2021, 69886), (2022, 69886), (2023, 69886), (2024, 69886), (2025, 69886), (2026, 69886), (2027, 69886), (2028, 69886), (2029, 69886), (2030, 69886), (2031, 69886), (2032, 69886), (2033, 69886), (2034, 69886), (2035, 69886), (2036, 69886), (2037, 69886), (2038, 69886), (2039, 69886), (2040, 69886), (2041, 69886), (2042, 69886), (2043, 69886), (2044, 69886), (2045, 69886), (2046, 69886), (2047, 69886), (2048, 69886), (2049, 69886), (2050, 69886)

FIT_Premium_HISTORIC[Offshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 128125), (2014, 134956), (2015, 142308), (2016, 154668), (2017, 154668), (2018, 154668), (2019, 154668), (2020, 154668), (2021, 154668), (2022, 154668), (2023, 154668), (2024, 154668), (2025, 154668), (2026, 154668), (2027, 154668), (2028, 154668), (2029, 154668), (2030, 154668), (2031, 154668), (2032, 154668), (2033, 154668), (2034, 154668), (2035, 154668), (2036, 154668), (2037, 154668), (2038, 154668), (2039, 154668), (2040, 154668), (2041, 154668), (2042, 154668), (2043, 154668), (2044, 154668), (2045, 154668), (2046, 154668), (2047, 154668), (2048, 154668), (2049, 154668), (2050, 154668)

FIT_Premium_HISTORIC[Hydro] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 28518), (2014, 33144), (2015, 45962), (2016, 52143), (2017, 52143), (2018, 52143), (2019, 52143), (2020, 52143), (2021, 52143), (2022, 52143), (2023, 52143), (2024, 52143), (2025, 52143), (2026, 52143), (2027, 52143), (2028, 52143), (2029, 52143), (2030, 52143), (2031, 52143), (2032, 52143), (2033, 52143), (2034, 52143), (2035, 52143), (2036, 52143), (2037, 52143), (2038, 52143), (2039, 52143), (2040, 52143), (2041, 52143), (2042, 52143), (2043, 52143), (2044, 52143), (2045, 52143), (2046, 52143), (2047, 52143), (2048, 52143), (2049, 52143), (2050, 52143)

FIT_Premium_HISTORIC[Biomass] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 87310), (2014, 115342), (2015, 142264), (2016, 146711), (2017, 146711), (2018, 146711), (2019, 146711), (2020, 146711), (2021, 146711), (2022, 146711), (2023, 146711), (2024, 146711), (2025, 146711), (2026, 146711), (2027, 146711), (2028, 146711), (2029, 146711), (2030, 146711), (2031, 146711), (2032, 146711), (2033, 146711), (2034, 146711), (2035, 146711), (2036, 146711), (2037, 146711), (2038, 146711), (2039, 146711), (2040, 146711), (2041, 146711), (2042, 146711), (2043, 146711), (2044, 146711), (2045, 146711), (2046, 146711), (2047, 146711), (2048, 146711), (2049, 146711), (2050, 146711)

FIT_Premium_Ratio_Policy[Renewables] = IF(TIME>2016)

THEN((Fixed_vs_Premium_Policy*FIT_Switch_Change+(1-FIT_Switch_Change)*FIT_vs_Premium_Ratio_Past))

else(FIT_vs_Premium_Ratio_Past)

FIT_Switch_Change = 0

FIT_Switch__between_Fixed_and_Premium_Policy = 1

FIT_vs_Premium_Ratio_Past[Solar_PV] = GRAPH(TIME)

(2006, 1e+006), (2007, 1e+006), (2008, 1e+006), (2009, 1e+006), (2010, 1e+006), (2011, 1e+006), (2012, 1e+006), (2013, 23.8), (2014, 7.17), (2015, 6.12), (2016, 4.40), (2017, 4.40), (2018, 4.40), (2019, 4.40), (2020, 4.40), (2021, 4.40), (2022, 4.40), (2023, 4.40), (2024, 4.40), (2025, 4.40), (2026, 4.40), (2027, 4.40), (2028, 4.40), (2029, 4.40), (2030, 4.40), (2031, 4.40), (2032, 4.40), (2033, 4.40), (2034, 4.40), (2035, 4.40), (2036, 4.40), (2037, 4.40), (2038, 4.40), (2039, 4.40), (2040, 4.40), (2041, 4.40), (2042, 4.40), (2043, 4.40), (2044, 4.40), (2045, 4.40), (2046, 4.40), (2047, 4.40), (2048, 4.40), (2049, 4.40), (2050, 4.40)

FIT_vs_Premium_Ratio_Past[Onshore_Wind] = GRAPH(TIME)

(2006, 1e+006), (2007, 1e+006), (2008, 1e+006), (2009, 1e+006), (2010, 1e+006), (2011, 1e+006), (2012, 1e+006), (2013, 0.451), (2014, 0.209), (2015, 0.153), (2016, 0.109), (2017, 0.109), (2018, 0.109), (2019, 0.109), (2020, 0.109), (2021, 0.109), (2022, 0.109), (2023, 0.109), (2024, 0.109), (2025, 0.109), (2026, 0.109), (2027, 0.109), (2028, 0.109), (2029, 0.109), (2030, 0.109), (2031, 0.109), (2032, 0.109), (2033, 0.109), (2034, 0.109), (2035, 0.109), (2036, 0.109), (2037, 0.109), (2038, 0.109), (2039, 0.109), (2040, 0.109), (2041, 0.109), (2042, 0.109), (2043, 0.109), (2044, 0.109), (2045, 0.109), (2046, 0.109), (2047, 0.109), (2048, 0.109), (2049, 0.109), (2050, 0.109)

FIT_vs_Premium_Ratio_Past[Offshore_Wind] = GRAPH(TIME)

(2006, 1e+006), (2007, 1e+006), (2008, 1e+006), (2009, 1e+006), (2010, 1e+006), (2011, 1e+006), (2012, 1e+006), (2013, 0.127), (2014, 0.00), (2015, 0.115), (2016, 0.0027), (2017, 0.0027), (2018, 0.0027), (2019, 0.0027), (2020, 0.0027), (2021, 0.0027), (2022, 0.0027), (2023, 0.0027), (2024, 0.0027), (2025, 0.0027), (2026, 0.0027), (2027, 0.0027), (2028, 0.0027), (2029, 0.0027), (2030, 0.0027), (2031, 0.0027), (2032, 0.0027), (2033, 0.0027), (2034, 0.0027), (2035, 0.0027), (2036, 0.0027), (2037, 0.0027), (2038, 0.0027), (2039, 0.0027), (2040, 0.0027), (2041, 0.0027), (2042, 0.0027), (2043, 0.0027), (2044, 0.0027), (2045, 0.0027), (2046, 0.0027), (2047, 0.0027), (2048, 0.0027), (2049, 0.0027), (2050, 0.0027)

FIT_vs_Premium_Ratio_Past[Hydro] = GRAPH(TIME)

(2006, 1e+006), (2007, 1e+006), (2008, 1e+006), (2009, 1e+006), (2010, 1e+006), (2011, 1e+006), (2012, 1e+006), (2013, 1.76), (2014, 1.54), (2015, 1.05), (2016, 0.868), (2017, 0.868), (2018, 0.868), (2019, 0.868), (2020, 0.868), (2021, 0.868), (2022, 0.868), (2023, 0.868), (2024, 0.868), (2025, 0.868), (2026, 0.868), (2027, 0.868), (2028, 0.868), (2029, 0.868), (2030, 0.868), (2031, 0.868), (2032, 0.868), (2033, 0.868), (2034, 0.868), (2035, 0.868), (2036, 0.868), (2037, 0.868), (2038, 0.868), (2039, 0.868), (2040, 0.868), (2041, 0.868), (2042, 0.868), (2043, 0.868), (2044, 0.868), (2045, 0.868), (2046, 0.868), (2047, 0.868), (2048, 0.868), (2049, 0.868), (2050, 0.868)

FIT_vs_Premium_Ratio_Past[Biomass] = GRAPH(TIME)

(2006, 1e+006), (2007, 1e+006), (2008, 1e+006), (2009, 1e+006), (2010, 1e+006), (2011, 1e+006), (2012, 1e+006), (2013, 13.9), (2014, 8.65), (2015, 4.94), (2016, 4.21), (2017, 4.21), (2018, 4.21), (2019, 4.21), (2020, 4.21), (2021, 4.21), (2022, 4.21), (2023, 4.21), (2024, 4.21), (2025, 4.21), (2026, 4.21), (2027, 4.21), (2028, 4.21), (2029, 4.21), (2030, 4.21), (2031, 4.21), (2032, 4.21), (2033, 4.21), (2034, 4.21), (2035, 4.21), (2036, 4.21), (2037, 4.21), (2038, 4.21), (2039, 4.21), (2040, 4.21), (2041, 4.21), (2042, 4.21), (2043, 4.21), (2044, 4.21), (2045, 4.21), (2046, 4.21), (2047, 4.21), (2048, 4.21), (2049, 4.21), (2050, 4.21)

Fixed_vs_Premium_Policy = Only__Fixed_FIT_policy*FIT_Switch__between_Fixed_and_Premium_Policy+(1-FIT_Switch__between_Fixed_and_Premium_Policy)*Only_Premium_Policy

fuel_cost[Solar_PV] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

fuel_cost[Onshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

fuel_cost[Offshore_Wind] = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

fuel_cost[Nuclear] = GRAPH(TIME)

(2006, 7030), (2028, 7030), (2050, 7030)

fuel_cost[Hard_Coal] = GRAPH(TIME)

(2006, 11400), (2013, 11400), (2021, 10800), (2028, 14000), (2035, 17000), (2043, 19000), (2050, 20000)

fuel_cost[Natural_Gases] = GRAPH(TIME)

(2006, 28000), (2013, 28387), (2021, 30000), (2028, 32000), (2035, 35000), (2043, 40000), (2050, 47000)

fuel_cost[Lignite] = GRAPH(TIME)

(2006, 1600), (2028, 1600), (2050, 1600)

fuel_cost[Biomass] = GRAPH(TIME)

(2006, 30000), (2013, 30000), (2021, 32500), (2028, 32500), (2035, 36000), (2043, 40000), (2050, 40000)

fuel_cost[Hydro] = GRAPH(TIME)

(2006, 0.00), (2013, 0.00), (2021, 0.00), (2028, 0.00), (2035, 0.00), (2043, 0.00), (2050, 0.00)

Future_Capacity[Solar_PV] = Future_Capacity_PV_and_Wind[Solar_PV]

Future_Capacity[Onshore_Wind] = Future_Capacity_PV_and_Wind[Onshore_Wind]

Future_Capacity[Offshore_Wind] = Future_Capacity_PV_and_Wind[Offshore_Wind]

Future_Capacity[Nuclear] = Future_Other_Sources_Capacity[Nuclear]

Future_Capacity[Hard_Coal] = Future_Other_Sources_Capacity[Hard_Coal]

Future_Capacity[Natural_Gases] = Future_Other_Sources_Capacity[Natural_Gases]

Future_Capacity[Lignite] = Future_Other_Sources_Capacity[Lignite]

Future_Capacity[Biomass] = Future_Other_Sources_Capacity[Biomass]

Future_Capacity[Hydro] = Future_Other_Sources_Capacity[Hydro]

Future_Capacity_PV_and_Wind[Interminent_technology] = Capacity_Under_Construction_for_PV_and_Wind+Installed_capacity_for_PV_and_Wind+Capacity_Under_Review_for_PV_and_wind

Future_Demand = LOOKUP(demand_exegonous,time+10)*LOOKUP(demand_curve_seasonal,time+10)/hours_per_year

Future_Other_Sources_Capacity[Other_technology] = Capacity_Under_Construction_for__other_sources+Installed_capacity_for_other_sources+Capacity_Under_Review_for_other_sources

Future_Supply = SUM(Future_Supply_by_technology)

Future_Supply_by_technology[All_technology] = Future_Capacity*capacity_factor gap_accumulated_production[All_technology] = (304000-Accumulated_Production)/304000

grid_losses = 0.04

hours_per_year = 8760

hydro_water_tax = 14000

Indicated_price = (MAX_Variable_Cost*effect_of_supply_ratio)+(1-effect_of_supply_ratio)*variable_cost[Biomass]

initial_capacity_utilization_model[Other_technology] = INIT(capacity_utilization_model)

Installed_capacity_all_sources[Solar_PV] = Installed_capacity_for_PV_and_Wind[Solar_PV]

Installed_capacity_all_sources[Onshore_Wind] = Installed_capacity_for_PV_and_Wind[Onshore_Wind]

Installed_capacity_all_sources[Offshore_Wind] = Installed_capacity_for_PV_and_Wind[Offshore_Wind]+0.2

Installed_capacity_all_sources[Nuclear] = MAX(10,Installed_capacity_for_other_sources[Nuclear])

Installed_capacity_all_sources[Hard_Coal] = Installed_capacity_for_other_sources[Hard_Coal]

Installed_capacity_all_sources[Natural_Gases] = Installed_capacity_for_other_sources[Natural_Gases]

Installed_capacity_all_sources[Lignite] = Installed_capacity_for_other_sources[Lignite]

Installed_capacity_all_sources[Biomass] = Installed_capacity_for_other_sources[Biomass]

Installed_capacity_all_sources[Hydro] = Installed_capacity_for_other_sources[Hydro]

Installed_Capacity_Biomass = GRAPH(TIME)

(2006, 3.53), (2007, 4.28), (2008, 4.72), (2009, 5.27), (2010, 6.00), (2011, 6.61), (2012, 7.26), (2013, 7.61), (2014, 8.38), (2015, 8.86), (2016, 8.97)

Installed_Capacity_Conventionals = Installed_Capacity_Conventionals_without_Natural_Gases+Installed_Capacity_Natural_Gases

Installed_Capacity_Conventionals_without_Natural_Gases = Installed_Capacity_Hard_Coal+Installed_Capacity_Lignite+Installed_Capacity_Nuclear

Installed_Capacity_Hard_Coal = GRAPH(TIME)

(2006, 27.6), (2007, 27.0), (2008, 27.5), (2009, 27.8), (2010, 27.3), (2011, 28.4), (2012, 25.7), (2013, 25.2), (2014, 26.0), (2015, 26.2), (2016, 28.6)

Installed_Capacity_Historic_All_Sources = Installed_Capacity_Renewables+Installed_Capacity_Conventionals

Installed_Capacity_Hydro = GRAPH(TIME)

(2006, 5.21), (2007, 5.19), (2008, 5.14), (2009, 5.16), (2010, 5.34), (2011, 5.41), (2012, 5.63), (2013, 5.61), (2014, 5.59), (2015, 5.58), (2016, 5.59)

Installed_Capacity_Lignite = GRAPH(TIME)

(2006, 20.7), (2007, 20.5), (2008, 21.1), (2009, 21.1), (2010, 21.1), (2011, 21.3), (2012, 19.9), (2013, 21.3), (2014, 21.2), (2015, 21.3), (2016, 21.1)

Installed_Capacity_Natural_Gases = GRAPH(TIME)

(2006, 20.6), (2007, 21.2), (2008, 21.3), (2009, 22.8), (2010, 23.1), (2011, 23.8), (2012, 27.3), (2013, 27.4), (2014, 28.4), (2015, 28.9), (2016, 28.4)

Installed_Capacity_Nuclear = GRAPH(TIME)

(2006, 20.3), (2007, 20.1), (2008, 20.2), (2009, 20.5), (2010, 20.4), (2011, 20.4), (2012, 12.1), (2013, 12.1), (2014, 12.1), (2015, 12.1), (2016, 10.8)

Installed_Capacity_Offhore = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.03), (2011, 0.08), (2012, 0.19), (2013, 0.27), (2014, 0.62), (2015, 0.99), (2016, 3.43)

Installed_Capacity_Onshore = GRAPH(TIME)

(2006, 18.4), (2007, 20.6), (2008, 22.2), (2009, 23.8), (2010, 25.6), (2011, 27.0), (2012, 28.6), (2013, 30.6), (2014, 33.3), (2015, 37.6), (2016, 41.2)

Installed_Capacity_Renewables = Installed_Capacity_Hydro+Installed_Capacity_Onshore+Installed_Capacity_Solar+Installed_Capacity_Biomass+Installed_Capacity_Offhore

Installed_Capacity_Solar = GRAPH(TIME)

(2006, 2.06), (2007, 2.90), (2008, 4.17), (2009, 6.12), (2010, 10.6), (2011, 17.9), (2012, 25.4), (2013, 33.0), (2014, 36.3), (2015, 37.9), (2016, 39.3)

interest_rate = 0.05

Internal_rate_of_return[All_technology] = yearly_NPV/Investment_cost

Investment_cost[All_technology] = IF(learning_curve<1)

then((Investment_cost_2006*learning_curve)/1000000)

ELSE(Investment_cost_2006/1000000)

Investment_cost_2006[All_technology] = investment_cost_2010/Investment_cost_2006_Converter

Investment_cost_2006_Converter[Solar_PV] = 0.50

Investment_cost_2006_Converter[Onshore_Wind] = 0.97

Investment_cost_2006_Converter[Offshore_Wind] = 1

Investment_cost_2006_Converter[Nuclear] = 0.999

Investment_cost_2006_Converter[Hard_Coal] = 0.999

Investment_cost_2006_Converter[Natural_Gases] = 0.978

Investment_cost_2006_Converter[Lignite] = 0.999

Investment_cost_2006_Converter[Biomass] = 0.91

Investment_cost_2006_Converter[Hydro] = 0.99

investment_cost_2010[Solar_PV] = 1560000000

investment_cost_2010[Onshore_Wind] = 1300000000

investment_cost_2010[Offshore_Wind] = 3000000000

investment_cost_2010[Nuclear] = 6000000000 investment_cost_2010[Hard_Coal] = 1525000000

investment_cost_2010[Natural_Gases] = 750000000

investment_cost_2010[Lignite] = 1887000000

investment_cost_2010[Biomass] = 2500000000

investment_cost_2010[Hydro] = 2000000000

Investment_Ratio[All_technology] = Internal_rate_of_return/WACC

investment_risk_ratio[All_technology] = Investment_Ratio/risk_ratio

investment_to_relative_capacity[All_technology] = GRAPH(investment_risk_ratio)

(1.00, 0.0301), (1.50, 0.0602), (2.00, 0.0903), (2.50, 0.13), (3.00, 0.191), (3.50, 0.278), (4.00, 0.381), (4.50, 0.442), (5.00, 0.474), (5.50, 0.499), (6.00, 0.509)

learning_curve[All_technology] = IF(TIME>2016)

THEN(learning_curve_2016_2050_ref*HISTORY(learning_curve_2006_2016_ref,2016))/(HISTORY(learning_curve_2016_2050_ref,2016))

else(learning_curve_2006_2016_ref)

learning_curve_2006_2016_ref[All_technology] = (Installed_capacity_all_sources/INIT(Installed_capacity_all_sources))^-b

learning_curve_2016_2050_ref[All_technology] = ((Installed_capacity_all_sources)/(INIT(Installed_capacity_all_sources)))^-b2

learning_rate[Solar_PV] = GRAPH(TIME)

(2006, 0.2), (2007, 0.2), (2008, 0.2), (2009, 0.2), (2010, 0.2), (2011, 0.2), (2012, 0.2), (2013, 0.2), (2014, 0.2), (2015, 0.2), (2016, 0.2), (2017, 0.1), (2018, 0.1), (2019, 0.1), (2020, 0.1), (2021, 0.1), (2022, 0.1), (2023, 0.1), (2024, 0.1), (2025, 0.1), (2026, 0.1), (2027, 0.1), (2028, 0.1), (2029, 0.1), (2030, 0.1), (2031, 0.1), (2032, 0.1), (2033, 0.1), (2034, 0.1), (2035, 0.1), (2036, 0.1), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Onshore_Wind] = GRAPH(TIME)

(2006, 0.05), (2007, 0.05), (2008, 0.05), (2009, 0.05), (2010, 0.05), (2011, 0.05), (2012, 0.05), (2013, 0.05), (2014, 0.05), (2015, 0.05), (2016, 0.05), (2017, 0.01), (2018, 0.01), (2019, 0.01), (2020, 0.01), (2021, 0.01), (2022, 0.01), (2023, 0.01), (2024, 0.01), (2025, 0.01), (2026, 0.01), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Offshore_Wind] = GRAPH(TIME)

(2006, 0.2), (2007, 0.2), (2008, 0.2), (2009, 0.2), (2010, 0.2), (2011, 0.2), (2012, 0.2), (2013, 0.2), (2014, 0.2), (2015, 0.2), (2016, 0.2), (2017, 0.2), (2018, 0.2), (2019, 0.2), (2020, 0.2), (2021, 0.2), (2022, 0.2), (2023, 0.2), (2024, 0.2), (2025, 0.2), (2026, 0.2), (2027, 0.1), (2028, 0.1), (2029, 0.1), (2030, 0.1), (2031, 0.1), (2032, 0.1), (2033, 0.1), (2034, 0.1), (2035, 0.1), (2036, 0.1), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Nuclear] = GRAPH(TIME)

(2006, 0.01), (2007, 0.01), (2008, 0.01), (2009, 0.01), (2010, 0.01), (2011, 0.01), (2012, 0.01), (2013, 0.01), (2014, 0.01), (2015, 0.01), (2016, 0.01), (2017, 0.01), (2018, 0.01), (2019, 0.01), (2020, 0.01), (2021, 0.01), (2022, 0.01), (2023, 0.01), (2024, 0.01), (2025, 0.01), (2026, 0.01), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Hard_Coal] = GRAPH(TIME)

(2006, 0.01), (2007, 0.01), (2008, 0.01), (2009, 0.01), (2010, 0.01), (2011, 0.01), (2012, 0.01), (2013, 0.01), (2014, 0.01), (2015, 0.01), (2016, 0.01), (2017, 0.01), (2018, 0.01), (2019, 0.01), (2020, 0.01), (2021, 0.01), (2022, 0.01), (2023, 0.01), (2024, 0.01), (2025, 0.01), (2026, 0.01), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Natural_Gases] = GRAPH(TIME)

(2006, 0.1), (2007, 0.1), (2008, 0.1), (2009, 0.1), (2010, 0.1), (2011, 0.1), (2012, 0.1), (2013, 0.1), (2014, 0.1), (2015, 0.1), (2016, 0.1), (2017, 0.1), (2018, 0.1), (2019, 0.1), (2020, 0.1), (2021, 0.1), (2022, 0.1), (2023, 0.1), (2024, 0.1), (2025, 0.1), (2026, 0.1), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Lignite] = GRAPH(TIME)

(2006, 0.01), (2007, 0.01), (2008, 0.01), (2009, 0.01), (2010, 0.01), (2011, 0.01), (2012, 0.01), (2013, 0.01), (2014, 0.01), (2015, 0.01), (2016, 0.01), (2017, 0.01), (2018, 0.01), (2019, 0.01), (2020, 0.01), (2021, 0.01), (2022, 0.01), (2023, 0.01), (2024, 0.01), (2025, 0.01), (2026, 0.01), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Biomass] = GRAPH(TIME)

(2006, 0.1), (2007, 0.1), (2008, 0.1), (2009, 0.1), (2010, 0.1), (2011, 0.1), (2012, 0.1), (2013, 0.1), (2014, 0.1), (2015, 0.1), (2016, 0.1), (2017, 0.1), (2018, 0.1), (2019, 0.1), (2020, 0.1), (2021, 0.1), (2022, 0.1), (2023, 0.1), (2024, 0.1), (2025, 0.1), (2026, 0.1), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate[Hydro] = GRAPH(TIME)

(2006, 0.05), (2007, 0.05), (2008, 0.05), (2009, 0.05), (2010, 0.05), (2011, 0.05), (2012, 0.05), (2013, 0.05), (2014, 0.05), (2015, 0.05), (2016, 0.05), (2017, 0.01), (2018, 0.01), (2019, 0.01), (2020, 0.01), (2021, 0.01), (2022, 0.01), (2023, 0.01), (2024, 0.01), (2025, 0.01), (2026, 0.01), (2027, 0.01), (2028, 0.01), (2029, 0.01), (2030, 0.01), (2031, 0.01), (2032, 0.01), (2033, 0.01), (2034, 0.01), (2035, 0.01), (2036, 0.01), (2037, 0.01), (2038, 0.01), (2039, 0.01), (2040, 0.01), (2041, 0.01), (2042, 0.01), (2043, 0.01), (2044, 0.01), (2045, 0.01), (2046, 0.01), (2047, 0.01), (2048, 0.01), (2049, 0.01), (2050, 0.01)

learning_rate_2006_2016[Solar_PV] = 0.2

learning_rate_2006_2016[Onshore_Wind] = 0.05

learning_rate_2006_2016[Offshore_Wind] = 0.20

learning_rate_2006_2016[Nuclear] = 0.01

learning_rate_2006_2016[Hard_Coal] = 0.01

learning_rate_2006_2016[Natural_Gases] = 0.1

learning_rate_2006_2016[Lignite] = 0.01

learning_rate_2006_2016[Biomass] = 0.1

learning_rate_2006_2016[Hydro] = 0.05

learning_rate_2016_2050[Solar_PV] = 0.0372

learning_rate_2016_2050[Onshore_Wind] = 0.01

learning_rate_2016_2050[Offshore_Wind] = 0.0495

learning_rate_2016_2050[Nuclear] = 0.01

learning_rate_2016_2050[Hard_Coal] = 0.01

learning_rate_2016_2050[Natural_Gases] = 0.0206

learning_rate_2016_2050[Lignite] = 0.01

learning_rate_2016_2050[Biomass] = 0.0206

learning_rate_2016_2050[Hydro] = 0.01

load_hours[Solar_PV] = hours_per_year*capacity_factor[Solar_PV]*ratio_of_RES_feeding_in

load_hours[Onshore_Wind] =
hours_per_year*capacity_factor[Onshore_Wind]*ratio_of_RES_feeding_in

load_hours[Offshore_Wind] =
capacity_factor[Offshore_Wind]*hours_per_year*ratio_of_RES_feeding_in

load_hours[Nuclear] = hours_per_year*capacity_factor[Nuclear]

load_hours[Hard_Coal] =
hours_per_year*capacity_factor[Hard_Coal]*Conventional_Supply_Ratio_Feeding_in

load_hours[Natural_Gases] =
hours_per_year*capacity_factor[Natural_Gases]*Conventional_Supply_Ratio_Feeding_in

load_hours[Lignite] =
hours_per_year*capacity_factor[Lignite]*Conventional_Supply_Ratio_Feeding_in

load_hours[Biomass] = hours_per_year*capacity_factor[Biomass]

load_hours[Hydro] = hours_per_year*capacity_factor[Hydro]

local_electricity_demand = (demand_curve_seasonal*demand_exegonous)/hours_per_year

MAX_Variable_Cost = MAX(variable_cost[*])

merit_order_guarenteed_supply = total_supply_from_renewables

minimum_generation = 20

minimum_generation_scenario = GRAPH(TIME)

(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 19.5), (2018, 19.0), (2019, 18.5), (2020, 18.0), (2021, 17.5), (2022, 17.0), (2023, 16.5), (2024, 16.0), (2025, 15.5), (2026, 15.0), (2027, 14.5), (2028, 14.0), (2029, 13.5), (2030, 13.0), (2031, 12.5), (2032, 12.0), (2033, 11.5), (2034, 11.0), (2035, 10.5), (2036, 10.0), (2037, 9.50), (2038, 9.00), (2039, 8.50), (2040, 8.00), (2041, 7.50), (2042, 7.00), (2043, 6.50), (2044, 6.00), (2045, 5.50), (2046, 5.00), (2047, 5.00), (2048, 5.00), (2049, 5.00), (2050, 5.00)

minimum_generation_scenario_test = minimum_generation*(1-
Switch_Minimum_Generation)+minimum_generation_scenario*Switch_Minimum_Generation

monthly__technical_capacity_factor_for_PV_and_Wind[Solar_PV] = GRAPH(TIME)

(2006, 0.0325), (2006, 0.0213), (2006, 0.0527), (2006, 0.109), (2006, 0.169), (2006, 0.168), (2007, 0.173), (2007, 0.187), (2007, 0.175), (2007, 0.123), (2007, 0.074), (2007, 0.0354), (2007, 0.0325), (2007, 0.0213), (2007, 0.0527), (2007, 0.109), (2007, 0.169), (2007, 0.168), (2008, 0.173), (2008, 0.187), (2008, 0.175), (2008, 0.123), (2008, 0.074), (2008, 0.0354), (2008, 0.0325), (2008, 0.0213), (2008, 0.0527), (2008, 0.109), (2008, 0.169), (2008, 0.168), (2009, 0.173), (2009, 0.187), (2009, 0.175), (2009, 0.123), (2009, 0.074), (2009, 0.0354), (2009, 0.0325), (2009, 0.0213), (2009, 0.0527), (2009, 0.109), (2009, 0.169), (2009, 0.168), (2010, 0.173), (2010, 0.187), (2010, 0.175), (2010, 0.123), (2010, 0.074), (2010, 0.0354), (2010, 0.0325), (2010, 0.0213), (2010, 0.0527), (2010, 0.109), (2010, 0.169), (2010, 0.168), (2011, 0.173), (2011, 0.187), (2011, 0.175), (2011, 0.123), (2011, 0.074), (2011, 0.0354), (2011, 0.0325), (2011, 0.0213), (2011, 0.0527), (2011, 0.109), (2011, 0.169), (2011, 0.168), (2012, 0.173), (2012, 0.187), (2012, 0.175), (2012, 0.123), (2012, 0.074), (2012, 0.0354), (2012, 0.0325), (2012, 0.0213), (2012, 0.0527), (2012, 0.109), (2012, 0.169), (2012, 0.168), (2013, 0.173), (2013, 0.187), (2013, 0.175), (2013, 0.123), (2013, 0.074), (2013, 0.0354), (2013, 0.0325), (2013, 0.0213), (2013, 0.0527), (2013, 0.109), (2013, 0.169), (2013, 0.168), (2014, 0.173), (2014, 0.187), (2014, 0.175), (2014, 0.123), (2014, 0.074), (2014, 0.0354), (2014, 0.0325), (2014, 0.0213), (2014, 0.0527), (2014, 0.109), (2014, 0.169), (2014, 0.168), (2015, 0.173), (2015, 0.187), (2015, 0.175), (2015, 0.123), (2015, 0.074), (2015, 0.0354), (2015, 0.0325), (2015, 0.0213), (2015, 0.0527), (2015, 0.109), (2015, 0.169), (2015, 0.168), (2016, 0.173), (2016, 0.187), (2016, 0.175), (2016, 0.123), (2016, 0.074), (2016, 0.0354), (2016, 0.0325), (2016, 0.0213), (2016, 0.0527), (2016, 0.109), (2016, 0.169), (2016, 0.168), (2017, 0.173), (2017, 0.187), (2017, 0.175), (2017, 0.123), (2017, 0.074), (2017, 0.0354), (2017, 0.0325), (2017, 0.0213), (2017, 0.0527), (2017, 0.109), (2017, 0.169), (2017, 0.168), (2018, 0.173), (2018, 0.187), (2018, 0.175), (2018, 0.123), (2018, 0.074), (2018, 0.0354), (2018, 0.0325), (2018, 0.0213), (2018, 0.0527), (2018, 0.109), (2018, 0.169), (2018, 0.168), (2019, 0.173), (2019, 0.187), (2019, 0.175), (2019, 0.123), (2019, 0.074), (2019, 0.0354), (2019, 0.0325), (2019, 0.0213), (2019, 0.0527), (2019, 0.109), (2019, 0.169), (2019, 0.168), (2020, 0.173), (2020, 0.187), (2020, 0.175), (2020, 0.123), (2020, 0.074), (2020, 0.0354), (2020, 0.0325), (2020, 0.0213), (2020, 0.0527), (2020, 0.109), (2020, 0.169), (2020, 0.168), (2021, 0.173), (2021, 0.187), (2021, 0.175), (2021, 0.123), (2021, 0.074), (2021, 0.0354), (2021, 0.0325), (2021, 0.0213), (2021, 0.0527), (2021, 0.109), (2021, 0.169), (2021, 0.168), (2022, 0.173), (2022, 0.187), (2022, 0.175), (2022, 0.123), (2022, 0.074), (2022, 0.0354), (2022, 0.0325), (2022, 0.0213), (2022, 0.0527), (2022, 0.109), (2022, 0.169), (2022, 0.168), (2023, 0.173), (2023, 0.187), (2023, 0.175), (2023, 0.123), (2023, 0.074), (2023, 0.0354), (2023, 0.0325), (2023, 0.0213), (2023, 0.0527), (2023, 0.109), (2023, 0.169), (2023, 0.168), (2024, 0.173), (2024, 0.187), (2024, 0.175), (2024, 0.123), (2024, 0.074), (2024, 0.0354), (2024, 0.0325), (2024, 0.0213), (2024, 0.0527), (2024, 0.109), (2024, 0.169), (2024, 0.168), (2025, 0.173), (2025, 0.187), (2025, 0.175), (2025, 0.123), (2025, 0.074), (2025, 0.0354), (2025, 0.0325), (2025, 0.0213), (2025, 0.0527), (2025, 0.109), (2025, 0.169), (2025, 0.168), (2026, 0.173), (2026, 0.187), (2026, 0.175), (2026, 0.123), (2026, 0.074), (2026, 0.0354), (2026, 0.0325), (2026, 0.0213), (2026, 0.0527), (2026, 0.109), (2026, 0.169), (2026, 0.168), (2027, 0.173), (2027, 0.187), (2027, 0.175), (2027, 0.123), (2027, 0.074), (2027, 0.0354), (2027, 0.0325), (2027, 0.0213), (2027, 0.0527), (2027, 0.109), (2027, 0.169), (2027, 0.168), (2028, 0.173), (2028, 0.187), (2028, 0.175), (2028, 0.123), (2028, 0.074), (2028, 0.0354), (2028, 0.0325), (2028, 0.0213), (2028, 0.0527), (2028, 0.109), (2028, 0.169), (2028, 0.168), (2029, 0.173), (2029, 0.187), (2029, 0.175), (2029, 0.123), (2029, 0.074), (2029, 0.0354), (2029, 0.0325), (2029, 0.0213), (2029, 0.0527), (2029, 0.109), (2029, 0.169), (2029, 0.168), (2030, 0.173), (2030, 0.187), (2030, 0.175), (2030, 0.123), (2030, 0.074), (2030, 0.0354), (2030, 0.0325), (2030, 0.0213), (2030, 0.0527), (2030, 0.109), (2030, 0.169), (2030, 0.168), (2031, 0.173), (2031, 0.187), (2031, 0.175), (2031, 0.123), (2031, 0.074), (2031, 0.0354), (2031, 0.0325), (2031, 0.0213), (2031, 0.0527), (2031, 0.109), (2031, 0.169), (2031, 0.168), (2032, 0.173), (2032, 0.187), (2032, 0.175), (2032, 0.123), (2032, 0.074), (2032, 0.0354), (2032, 0.0325), (2032, 0.0213), (2032, 0.0527), (2032, 0.109), (2032, 0.169), (2032, 0.168), (2033, 0.173), (2033, 0.187), (2033, 0.175), (2033, 0.123), (2033, 0.074), (2033, 0.0354), (2033, 0.0325), (2033, 0.0213), (2033, 0.0527), (2033, 0.109), (2033, 0.169), (2033, 0.168), (2034, 0.173), (2034, 0.187), (2034, 0.175), (2034, 0.123), (2034, 0.074), (2034, 0.0354), (2034, 0.0325), (2034, 0.0213), (2034, 0.0527), (2034, 0.109), (2034, 0.169), (2034, 0.168), (2035, 0.173), (2035, 0.187), (2035, 0.175), (2035, 0.123), (2035, 0.074), (2035, 0.0354), (2035, 0.0325), (2035, 0.0213), (2035, 0.0527), (2035, 0.109), (2035, 0.169), (2035, 0.168), (2036, 0.173), (2036, 0.187), (2036, 0.175), (2036, 0.123), (2036, 0.074), (2036, 0.0354), (2036, 0.0325), (2036, 0.0213), (2036, 0.0527), (2036, 0.109), (2036, 0.169), (2036, 0.168), (2037, 0.173), (2037, 0.187), (2037, 0.175), (2037, 0.123), (2037, 0.074), (2037, 0.0354), (2037, 0.0325), (2037, 0.0213), (2037, 0.0527), (2037, 0.109), (2037, 0.169), (2037, 0.168), (2038, 0.173), (2038, 0.187), (2038, 0.175), (2038, 0.123), (2038, 0.074), (2038, 0.0354), (2038, 0.0325), (2038, 0.0213), (2038, 0.0527), (2038, 0.109), (2038, 0.169), (2038, 0.168), (2039, 0.173), (2039, 0.187), (2039, 0.175), (2039, 0.123), (2039, 0.074), (2039, 0.0354), (2039, 0.0325), (2039, 0.0213), (2039, 0.0527), (2039, 0.109), (2039, 0.169), (2039, 0.168), (2040, 0.173), (2040, 0.187), (2040, 0.175), (2040, 0.123), (2040, 0.074), (2040, 0.0354), (2040, 0.0325), (2040, 0.0213), (2040, 0.0527), (2040, 0.109), (2040, 0.169), (2040, 0.168), (2041, 0.173), (2041, 0.187), (2041, 0.175), (2041, 0.123), (2041, 0.074), (2041, 0.0354), (2041, 0.0325), (2041, 0.0213), (2041, 0.0527), (2041, 0.109), (2041, 0.169), (2041, 0.168), (2042, 0.173), (2042, 0.187), (2042, 0.175), (2042, 0.123), (2042, 0.074), (2042, 0.0354), (2042, 0.0325), (2042, 0.0213), (2042, 0.0527), (2042, 0.109), (2042, 0.169), (2042, 0.168), (2043, 0.173), (2043, 0.187), (2043, 0.175), (2043, 0.123), (2043, 0.074), (2043, 0.0354), (2043, 0.0325), (2043, 0.0213), (2043, 0.0527), (2043, 0.109), (2043, 0.169), (2043, 0.168), (2044, 0.173), (2044, 0.187), (2044, 0.175), (2044, 0.123), (2044, 0.074), (2044, 0.0354), (2044, 0.0325), (2044, 0.0213), (2044, 0.0527), (2044, 0.109), (2044, 0.169), (2044, 0.168), (2045, 0.173), (2045, 0.187), (2045, 0.175), (2045, 0.123), (2045, 0.074), (2045, 0.0354), (2045, 0.0325), (2045, 0.0213), (2045, 0.0527), (2045, 0.109), (2045, 0.169), (2045, 0.168), (2046, 0.173), (2046, 0.187), (2046, 0.175), (2046, 0.123), (2046, 0.074), (2046, 0.0354), (2046, 0.0325), (2046, 0.0213), (2046, 0.0527), (2046, 0.109), (2046, 0.169), (2046, 0.168), (2047, 0.173), (2047, 0.187), (2047, 0.175), (2047, 0.123), (2047, 0.074), (2047, 0.0354), (2047, 0.0325), (2047, 0.0213), (2047, 0.0527), (2047, 0.109), (2047, 0.169), (2047, 0.168), (2048, 0.173), (2048, 0.187), (2048, 0.175), (2048, 0.123), (2048, 0.074), (2048, 0.0354), (2048, 0.0325), (2048, 0.0213), (2048, 0.0527), (2048, 0.109), (2048, 0.169), (2048, 0.168), (2049, 0.173), (2049, 0.187), (2049, 0.175), (2049, 0.123), (2049, 0.074), (2049, 0.0354), (2049, 0.0325), (2049, 0.0213), (2049, 0.0527), (2049, 0.109), (2049, 0.169), (2049, 0.168), (2050, 0.173), (2050, 0.187), (2050, 0.175), (2050, 0.123), (2050, 0.074), (2050, 0.0354), (2050, 0.0325)

monthly__technical_capacity_factor_for_PV_and_Wind[Onshore_Wind] = GRAPH(TIME)

(2006, 0.344), (2006, 0.321), (2006, 0.175), (2006, 0.241), (2006, 0.171), (2006, 0.165), (2007, 0.126), (2007, 0.179), (2007, 0.11), (2007, 0.16), (2007, 0.104), (2007, 0.315), (2007, 0.344), (2007, 0.321), (2007, 0.175), (2007, 0.241), (2007, 0.171), (2007, 0.165), (2008, 0.126), (2008, 0.179), (2008, 0.11), (2008, 0.16), (2008, 0.104), (2008, 0.315), (2008, 0.344), (2008, 0.321), (2008, 0.175), (2008, 0.241), (2008, 0.171), (2008, 0.165), (2009, 0.126), (2009, 0.179), (2009, 0.11), (2009, 0.16), (2009, 0.104), (2009, 0.315), (2009, 0.344), (2009, 0.321), (2009, 0.175), (2009, 0.241), (2009, 0.171), (2009, 0.165), (2010, 0.126), (2010, 0.179), (2010, 0.11), (2010, 0.16), (2010, 0.104), (2010, 0.315), (2010, 0.344), (2010, 0.321), (2010, 0.175), (2010, 0.241), (2010, 0.171), (2010, 0.165), (2011, 0.126), (2011, 0.179), (2011, 0.11), (2011, 0.16), (2011, 0.104), (2011, 0.315), (2011, 0.344), (2011, 0.321), (2011, 0.175), (2011, 0.241), (2011, 0.171), (2011, 0.165), (2012, 0.126), (2012, 0.179), (2012, 0.11), (2012, 0.16), (2012, 0.104), (2012, 0.315), (2012, 0.344), (2012, 0.321), (2012, 0.175), (2012, 0.241), (2012, 0.171), (2012, 0.165), (2013, 0.126), (2013, 0.179), (2013, 0.11), (2013, 0.16), (2013, 0.104), (2013, 0.315), (2013, 0.344), (2013, 0.321), (2013, 0.175), (2013, 0.241), (2013, 0.171), (2013, 0.165), (2014, 0.126), (2014, 0.179), (2014, 0.11), (2014, 0.16), (2014, 0.104), (2014, 0.315), (2014, 0.344), (2014, 0.321), (2014, 0.175), (2014, 0.241), (2014, 0.171), (2014, 0.165), (2015, 0.126), (2015, 0.179), (2015, 0.11), (2015, 0.16), (2015, 0.104), (2015, 0.315), (2015, 0.344), (2015, 0.321), (2015, 0.175), (2015, 0.241), (2015, 0.171), (2015, 0.165), (2016, 0.126), (2016, 0.179), (2016, 0.11), (2016, 0.16), (2016, 0.104), (2016, 0.315), (2016, 0.344), (2016, 0.321), (2016, 0.175), (2016, 0.241), (2016, 0.171), (2016, 0.165), (2017, 0.126), (2017, 0.179), (2017, 0.11), (2017, 0.16), (2017, 0.104), (2017, 0.315), (2017, 0.344), (2017, 0.321), (2017, 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monthly__technical_capacity_factor_for_PV_and_Wind[Offshore_Wind] = GRAPH(TIME)

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(2047, 0.484), (2048, 0.289), (2048, 0.373), (2048, 0.305), (2048, 0.405), (2048, 0.468), (2048, 0.683),
(2048, 0.783), (2048, 0.731), (2048, 0.536), (2048, 0.152), (2048, 0.468), (2048, 0.484), (2049, 0.289),
(2049, 0.373), (2049, 0.305), (2049, 0.405), (2049, 0.468), (2049, 0.683), (2049, 0.783), (2049, 0.731),
(2049, 0.536), (2049, 0.152), (2049, 0.468), (2049, 0.484), (2050, 0.289), (2050, 0.373), (2050, 0.305),
(2050, 0.405), (2050, 0.468), (2050, 0.683), (2050, 0.783)

NPV_perceived_profitability[All_technology] = (Perceived__profitability_of_electricity_plan_investment*(((1+interest_rate)^time_horizon)-1)/(((1+interest_rate)^time_horizon)*interest_rate))

nuclear_shut_down = GRAPH(TIME)

(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 8.40), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 1.35), (2017, 0.00), (2018, 1.34), (2019, 0.00), (2020, 1.47), (2021, 0.00), (2022, 4.25), (2023, 4.59), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

Only_Premium_Policy = 1e-07

Only__Fixed_FIT_policy = 10000000

plant_life_time[Solar_PV] = 25

plant_life_time[Onshore_Wind] = 20

plant_life_time[Offshore_Wind] = 20

plant_life_time[Nuclear] = 50

plant_life_time[Hard_Coal] = 40

plant_life_time[Natural_Gases] = 30

plant_life_time[Lignite] = 40

plant_life_time[Biomass] = 20

plant_life_time[Hydro] = 80

policy_cost = acc_cost_premium_FIT+ACC_cost_Fixed_FIT+ACC_cost_FIT_percent

price_AT = 0.08333

production_FIT[Solar_PV] = Producing_FIT[Solar_PV]*load_hours[Solar_PV]

production_FIT[Onshore_Wind] = Producing_FIT[Onshore_Wind]*load_hours[Onshore_Wind]

production_FIT[Offshore_Wind] = Producing_FIT[Offshore_Wind]*load_hours[Offshore_Wind]

production_FIT[Hydro] = Producing_FIT[Hydro]*load_hours[Hydro]

production_FIT[Biomass] = Producing_FIT[Biomass]*load_hours[Biomass]

Profitability_per_GW[All_technology] = ((received_price*load_hours)-(variable_cost*load_hours)-(Annual_Operational_Fixed_Cost))/1000000

ratio_of_RES_feeding_in = (Total_Supply_from_PV_and_Wind_before_feeding_grid-curtailment)/Total_Supply_from_PV_and_Wind_before_feeding_grid

received_price[Solar_PV] = received_price_renewables[Solar_PV]

received_price[Onshore_Wind] = received_price_renewables[Onshore_Wind]

received_price[Offshore_Wind] = received_price_renewables[Offshore_Wind]

received_price[Nuclear] = received_price_conventional[Nuclear]

received_price[Hard_Coal] = received_price_conventional[Hard_Coal] received_price[Natural_Gases] = received_price_conventional[Natural_Gas]

received_price[Lignite] = received_price_conventional[Lignite]

received_price[Biomass] = received_price_renewables[Biomass]

received_price[Hydro] = received_price_renewables[Hydro]

received_price_conventional[Conventional] = Spot_price*effect_of_daily_price_fluctuations_conventionals+Conventional_Subsidies_Scenario

received_price_renewables[Renewables] = IF(TIME>2016)

THEN((Switch_FIT__Retail_Percentage*receiver_price_FIT__Retail_percentage+(1-Switch_FIT__Retail_Percentage)*((FIT_Data*FIT_Premium_Ratio_Policy)+(Spot_price*effect_of_daily_price_fluctuations_renewables+FIT_premium))/(1+FIT_Premium_Ratio_Policy)))

ELSE(((FIT_Data*FIT_Premium_Ratio_Policy)+(Spot_price*effect_of_daily_price_fluctuations_renewables+FIT_premium))/(1+FIT_Premium_Ratio_Policy))

receiver_price_FIT__Retail_percentage[Renewables] = (Spot_price*effect_of_daily_price_fluctuations_renewables)+FIT_percentage_of_retail_price_Euro

reference_capacity_factor[Nuclear] = 0.91

reference_capacity_factor[Hard_Coal] = 0.57

reference_capacity_factor[Natural_Gases] = 0.4

reference_capacity_factor[Lignite] = 0.86

reference_capacity_factor[Biomass] = 0.47

reference_capacity_factor[Hydro] = 0.43

reference_CO2_emission = INT(Total_CO2_emission)

renewable_share = (Supply_from_PV_and_Wind[Solar_PV]+Supply_from_PV_and_Wind[Onshore_Wind]+Supply_from_PV_and_Wind[Offshore_Wind]+Total_Supply_Other_Sources[Biomass]+Total_Supply_Other_Sources[Hydro])/Total_Supply_GWH

Reserve_Margin = Future_Supply/Future_Demand

residual_load = local_electricity_demand-Total_Supply_from_PV_and_Wind_before_feeding_grid

risk_ratio[All_technology] = MAX(1,EXP(gap_accumulated_production))

Simulation_Installed_Capacity_Conventionals = Installed_capacity_for_other_sources[Nuclear]+Installed_capacity_for_other_sources[Hard_Coal]+Installed_capacity_for_other_sources[Natural_Gases]+Installed_capacity_for_other_sources[Lignite]

Simulation_Installed_Capacity_Renewables = SUM(Installed_capacity_for_PV_and_Wind)+Installed_capacity_for_other_sources[Hydro]+Installed_capacity_for_other_sources[Biomass]

Simulation_Installed_Capacity_Sum_of_All_Sources = SUM(Installed_capacity_all_sources)

Simulation_Installed_Capacity_without_Natural_Gases = Installed_capacity_for_other_sources[Nuclear]+Installed_capacity_for_other_sources[Hard_Coal]+Installed_capacity_for_other_sources[Lignite]

start_time = 2016

Supply_from_PV_and_Wind[Solar_PV] = hours_per_year*ratio_of_RES_feeding_in*Available_capacity_for_PV_and_Wind[Solar_PV]

Supply_from_PV_and_Wind[Onshore_Wind] = hours_per_year*ratio_of_RES_feeding_in*Available_capacity_for_PV_and_Wind[Onshore_Wind]

Supply_from_PV_and_Wind[Offshore_Wind] = hours_per_year*ratio_of_RES_feeding_in*Available_capacity_for_PV_and_Wind[Offshore_Wind]

Supply_Security_Ratio = (Total_Supply_GWH*(1-grid_losses))/(demand_curve_seasonal*demand_exegonous)

Switch_Conventional_Subsidies = 0

switch_degresssion_rate_of_policy = 0

Switch_FIT__Retail_Percentage = 0

Switch_Minimum_Generation = 0

tax_rate = 20500

time_for_accumulated_production = 1

time_horizon = 20

time_to_perceive_profitability[All_technology] = GRAPH(Accumulated_Production)

(0.00, 1.01), (23810, 1.02), (47619, 1.04), (71429, 1.06), (95238, 1.08), (119048, 1.10), (142857, 1.11), (166667, 1.14), (190476, 1.17), (214286, 1.21), (238095, 1.28), (261905, 1.34), (285714, 1.41), (309524, 1.46), (333333, 1.55), (357143, 1.60), (380952, 1.70), (404762, 1.78), (428571, 1.90), (452381, 1.98), (476190, 2.09), (500000, 2.20), (523810, 2.27), (547619, 2.33), (571429, 2.44), (595238, 2.52), (619048, 2.59), (642857, 2.65), (666667, 2.72), (690476, 2.77), (714286, 2.82), (738095, 2.84), (761905, 2.89), (785714, 2.91), (809524, 2.92), (833333, 2.94), (857143, 2.95), (880952, 2.96), (904762, 2.97), (928571, 2.98), (952381, 2.99), (976190, 2.99), (1e+006, 3.00)

Total_available_supply_by_technology[Solar_PV] = Available_capacity_for_PV_and_Wind[Solar_PV]

Total_available_supply_by_technology[Onshore_Wind] = Available_capacity_for_PV_and_Wind[Onshore_Wind]

Total_available_supply_by_technology[Offshore_Wind] = Available_capacity_for_PV_and_Wind[Offshore_Wind]

Total_available_supply_by_technology[Nuclear] = available_capacity_from_other_sources[Nuclear]

Total_available_supply_by_technology[Hard_Coal] = available_capacity_from_other_sources[Hard_Coal]

Total_available_supply_by_technology[Natural_Gases] = available_capacity_from_other_sources[Natural_Gases]

Total_available_supply_by_technology[Lignite] = available_capacity_from_other_sources[Lignite]

Total_available_supply_by_technology[Biomass] = available_capacity_from_other_sources[Biomass]

Total_available_supply_by_technology[Hydro] = available_capacity_from_other_sources[Hydro]

Total_Available_Supply_from_conventionals = available_capacity_with_grid_losses_from_other_sources[Nuclear]+available_capacity_with_grid_losses_from_other_sources[Hard_Coal]+available_capacity_with_grid_losses_from_other_sources[Natural_Gases]+available_capacity_with_grid_losses_from_other_sources[Lignite] total_available_supply_wind_and_PV = SUM(total_supply_from_PV_and_Wind)

Total_CO2_emission = (CO2_emission_per_technology[Hard_Coal]+CO2_emission_per_technology[Natural_Gases]+CO2_emission_per_technology[Lignite])/1000000

total_consomer_cost = policy_cost+Total_Conventional_Cost_of_Conv_Subsidies+Accumulated_Cunsomer_Spendings

Total_Conventional_Cost_of_Conv_Subsidies = sum(Acc_cost_of_conventional_subsidies)/1000000

total_electrity_supply_in_merit_order_from_other_sources = MAX(minimum_generation_scenario_test,local_electricity_demand-merit_order_guarenteed_supply)

Total_Potential[Solar_PV] = 67.2

Total_Potential[Onshore_Wind] = 83.3

Total_Potential[Offshore_Wind] = 32

Total_Potential[Nuclear] = 20.43

Total_Potential[Hard_Coal] = 30.1

Total_Potential[Natural_Gases] = 37.25

Total_Potential[Lignite] = 26.4

Total_Potential[Biomass] = 14.3

Total_Potential[Hydro] = 5.2

Total_Supply = total_supply_from_renewables+total_electrity_supply_in_merit_order_from_other_sources

total_supply_from_PV_and_Wind[Interminent_technology] = ratio_of_RES_feeding_in*(1-grid_losses)*Available_capacity_for_PV_and_Wind

Total_Supply_from_PV_and_Wind_before_feeding_grid = SUM(Available_capacity_for_PV_and_Wind)

total_supply_from_renewables = total_available_supply_wind_and_PV+available_capacity_with_grid_losses_from_other_sources[Biomass]+available_capacity_with_grid_losses_from_other_sources[Hydro]

Total_Supply_GWH = SUM(Total_Supply_Other_Sources)+SUM(Supply_from_PV_and_Wind)

total_supply_in_GWH[Solar_PV] = Supply_from_PV_and_Wind[Solar_PV]

total_supply_in_GWH[Onshore_Wind] = Supply_from_PV_and_Wind[Onshore_Wind]

total_supply_in_GWH[Offshore_Wind] = Supply_from_PV_and_Wind[Offshore_Wind]

total_supply_in_GWH[Nuclear] = Total_Supply_Other_Sources[Nuclear]

total_supply_in_GWH[Hard_Coal] = Total_Supply_Other_Sources[Hard_Coal]

total_supply_in_GWH[Natural_Gases] = Total_Supply_Other_Sources[Natural_Gases]

total_supply_in_GWH[Lignite] = Total_Supply_Other_Sources[Lignite]

total_supply_in_GWH[Biomass] = Total_Supply_Other_Sources[Biomass]

total_supply_in_GWH[Hydro] = Total_Supply_Other_Sources[Hydro]

Total_Supply_Other_Sources[Nuclear] =
hours_per_year*available_capacity_from_other_sources[Nuclear]

Total_Supply_Other_Sources[Hard_Coal] =
hours_per_year*available_capacity_from_other_sources[Hard_Coal]*Conventional_Supply_Ratio_Feeding_in

Total_Supply_Other_Sources[Natural_Gases] =
hours_per_year*available_capacity_from_other_sources[Natural_Gases]*Conventional_Supply_Ratio_Feeding_in

Total_Supply_Other_Sources[Lignite] =
hours_per_year*available_capacity_from_other_sources[Lignite]*Conventional_Supply_Ratio_Feeding_in

Total_Supply_Other_Sources[Biomass] =
hours_per_year*available_capacity_from_other_sources[Biomass]

Total_Supply_Other_Sources[Hydro] =
hours_per_year*available_capacity_from_other_sources[Hydro]

variable_cost[Solar_PV] = 0

variable_cost[Onshore_Wind] = 0

variable_cost[Offshore_Wind] = 0

variable_cost[Nuclear] = fuel_cost[Nuclear]+variable_OM_COST[Nuclear]+tax_rate

variable_cost[Hard_Coal] =
fuel_cost[Hard_Coal]+CO2_emission[Hard_Coal]*CO2_allowance_price+variable_OM_COST[Hard_Coal]+tax_rate

variable_cost[Natural_Gases] =
CO2_emission[Natural_Gases]*CO2_allowance_price+fuel_cost[Natural_Gases]+variable_OM_COST[Natural_Gases]+tax_rate

variable_cost[Lignite] =
fuel_cost[Lignite]+CO2_emission[Lignite]*CO2_allowance_price+variable_OM_COST[Lignite]+tax_rate

variable_cost[Biomass] = fuel_cost[Biomass]+CO2_emission[Biomass]*CO2_allowance_price

variable_cost[Hydro] = hydro_water_tax

variable_OM_COST[Solar_PV] = 0

variable_OM_COST[Onshore_Wind] = 0

variable_OM_COST[Offshore_Wind] = 0

variable_OM_COST[Nuclear] = 5000

variable_OM_COST[Hard_Coal] = 6000

variable_OM_COST[Natural_Gases] = 4000

variable_OM_COST[Lignite] = 7000

variable_OM_COST[Biomass] = 0

variable_OM_COST[Hydro] = 0

WACC[Solar_PV] = 0.028

WACC[Onshore_Wind] = 0.038

WACC[Offshore_Wind] = 0.077

WACC[Nuclear] = 0.09

WACC[Hard_Coal] = 0.069

WACC[Natural_Gases] = 0.069

WACC[Lignite] = 0.069

WACC[Biomass] = 0.041

WACC[Hydro] = 0.057

yearly_FIT_premium_expenditures[Renewables] = IF(TIME>2016)

THEN(production_FIT*FIT_premium*(1/(1+FIT_Premium_Ratio_Policy))*(1-Switch_FIT__Retail_Percentage)+(Switch_FIT__Retail_Percentage*0))

ELSE(production_FIT*FIT_premium*(1/(1+FIT_Premium_Ratio_Policy)))

yearly_NPV[All_technology] = NPV_perceived_profitability/time_horizon