Germany's Electricity Industry in 2025: Evaluation of Portfolio Concepts

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Abstract Combining System Dynamics model simulation and data analysis long-term development of electricity industry can be observed and anticipated regarding its reliability and total production cost under different assumed scenarios. In particular, different portfolio concepts to mitigate GHG emissions and to reduce fossil resource consumption are evaluated based on our highly aggregated electricity production and consumption model. Generally speaking, this innovative System Dynamics approach has not been widely used as a tool for optimizing asset structure of an energy portfolio yet. Nevertheless we favor a renewable load management concept which aims at the reshaping of load profile to fit the renewable electricity production output profile. In this context accurate forecasts of both load and production profiles are prerequisite for a well functioning load management. In the case of Germany our preliminary results show that a renewable load management concept may reduce the total production cost by up to 2.7 B€/year or 4.80 €/MWh in 2025 while improving mitigation of GHG emissions from 31.2% to 34.7% (compared to 1990).

1. Introduction

The conventional concept of energy portfolio aims to value and optimally structure different energy sources for providing energy at certain costs and at a certain level of risk. Recent developments in technology have significantly increased opportunities for electricity generation which allow to look at the portfolio concept in a broader sense, though considering technological improvements as portfolio assets. This approach helps to evaluate different portfolio concepts of electricity generation highlighting critical inflows that can reduce production costs and greenhouse gas (GHG) emissions.

This statement is of special importance for Germany, which aims to reduce GHG emissions by 40% in 2020 in comparison to 1990 and additionally phases out the nuclear power generation till the end of 2022. Increasing share of renewables in electricity generation will also increase the demand for storage capacity. During some time periods renewable energy production can be very limited - "unlike markets for storable commodities, electricity markets depend on the real-time balance of supply and demand. Although much of the present-day grid operates effectively without storage technologies, cost-effective ways of storing electrical energy enables the grid to become more efficient and reliable" [Kazempour 2009]. Consequently, stored electricity becomes a part of Germany's energy portfolio and has potential in reducing costs and mitigating GHG emissions, especially CO_2 emissions. Load management which is also refered to as "Smart Grid" steers the grid to fulfill customer demand with minimum production costs while still maximizing supply from renewable energy sources.

The main purpose of this paper is to evaluate different portfolio concepts of electricity generation in Germany considering various technological parameters by comparing their production costs and their CO_2 emissions mitigation potential. It also shows the importance of data analysis and the need of improving prognosis for wind and photovoltaic energy production through the Transmission System Operators (TSOs), but also the energy producers and providers.

The structure of the paper proceeds as follows: the following part discusses recent developments in literature. After that a System Dynamics model of the electricity supply will be explained step by step. In addition some simulation results evaluate different concepts with high potential to influence Germany's electricity portfolio in 2025. Following section deals with data analysis for controlling and anticipation followed by the last section with concluding discussion.

2. Related works

In the last few years the dynamic and mostly unpredictable energy environment required sustainable energy portfolio concepts. Energy portfolio concepts explained in this paper incorporate important cost inter-relationships among alternative energy sources. Especially policy maker in Germany face an uncertain future in the energy environment. On the one hand this future seems to be very technologically and on the other hand will be complex institutionally. System Dynamics models help policy maker establishing renewable energy targets and sustainable energy portfolio concepts that make sense in an economic and policy point of view.

In 1989 [Naill 1989] discussed once more about the limits of the global resources, as it was started in 1972 by the Club of Rome. In details he talks about the US energy policy and furthermore about the extreme energy transition in the US in the last decades. Closely related to the successful FOSSIL2 model he explaines the complex dynamic features of the energy market. Generally speaking Naill showed that the National Energy Policy Plan of 1983 bases upon the FOSSIL2 model. Therefore, the complex energy system can be seen as an ideal issue to apply the System Dynamics methodology.

When talking about energy portfolio, the term energy portfolio can have different meanings. On the one hand energy portfolio can stand for a combination of energy sources used for electricity generation and on the other hand energy portfolio can also mean a combination of either private or state energy investment assets. For this paper only the first explaination of porfolio is relevant. Nevertheless, one of the core advantages of an energy portfolio concept is the following fact. It gives an opportunity to evaluate energy sources and technologies not separately but as a combination or collection of diversified asset. Originally a financial instrument, energy portfolio concept deals with risks and costs of energy supply. In the authors' point of view energy portfolio includes mainly the investment decision problem. This problem has to be further evaluated to manage risk and to maximize the performance of the energy portfolio concept.

There exist few basic approaches that aim to optimize energy portfolio of a certain country. Before speaking about energy portfolio concepts, the one of the main approaches has be explained in details which is based on H. Markowitz’s Modern Portfolio Theory [Markowitz 1952] One of the core issues of Markovitz's modern portfolio theory is the way to calculate cost and risk by diversifying them for achieving an efficient portfolio. Markovitz general idea for defining the optimal portfolio concepts is not only to include the possible profit, he also includes possible risk. Nevertheless the Mean-Variance Portfolio based approach has therefore been criticized for being concentrated on production costs of electricity-generation technologies. Although not production costs but rather expected risks and returns usually serve as a basis for private investment decisions. [Markowitz 1959] Especially in the modern energy economy in Germany this crucial fact can change the amount of energy investment assets and furthermore every portfolio concept. Nevertheless this approach gives an opportunity to evaluate different portfolio concepts of energy sources used for electricity generation in a certain country [see, e.g., Awerbuch 2005]. In many cases risk in energy portfolios is mostly associated with the volatility of fossil fuels prices. Therefore the already mentioned diversification is achieved by adding increased share of renewable energy. Generally speaking, Germany will increase the share of renewable energy sources in the energy portfolio dramatically in the next years. Nevertheless Germany has to invest besides renewable energy sources strongly in all kinds of fossil energy sources to stabilize the energy system while phasing out the nuclear power production. Which means that not only Germany's energy portfolio will be more diversified in the year 2025. Although some energy scenarios conclude that photovoltaic (PV) will remain uncompetitive until 2030, PV can be still regarded as a relevant policy option for Germany's energy portfolio in the year 2025. Especially the rapid PV market growth generates cost reductions in the near future. In addition, PV can help to limit sudden energy price shocks. Furthermore, PV and wind energy reduce risk from fossil-fuel dependence [see, e.g., Albrecht 2007]. Similar to Germany, China has also started to adapt their actual energy portfolio concept and is willing to diversify the energy portfolio for a more efficient energy future [Zhu 2010].

3. A System Dynamics model

This chapter presents a System Dynamics model (Section 3.1) which we are developing continuously to depict and compare different portfolio concepts for a reliable and sustainable electricity supply on a highly aggregated level [see Hu 2011]. The results of our comparative simulations are shown in Section 3.2.

3.1 Stock and Flow diagram

From a aggregated aspect this System Dynamics model considers that the entire electricity supply system consists of the following components: the grid including power generation and consumption, electricity storage subsystem (mostly pump storage), new technology solutions like synthesized natural gas (SNG) and load management. In the following these components are introduced step-by-step into the System Dynamics model.

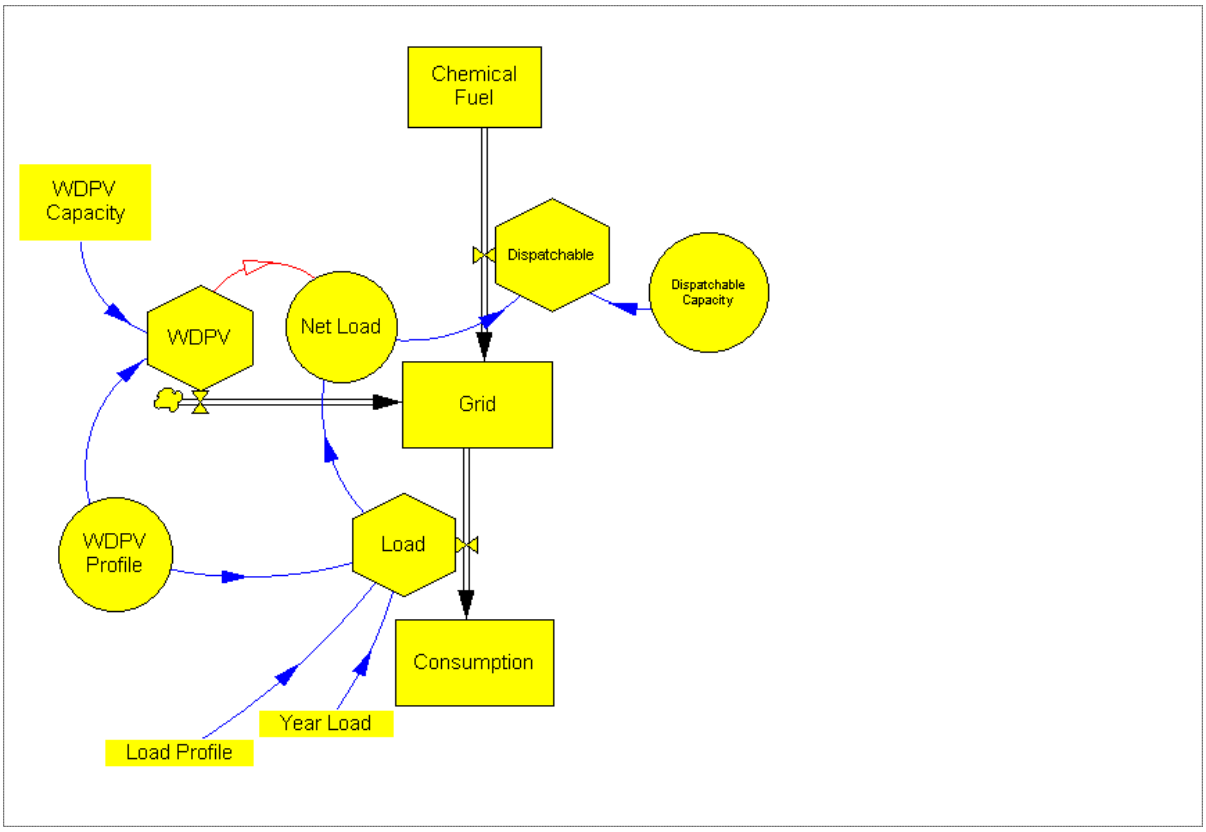


Figure 1: Electricity supply using chemical fuel on the one side, wind and solar power on the other side

Figure 1 depicts the `Dispatchable` power generation mainly using `Chemical Fuel` on the one hand and non-dispatchable power generation using wind and photovoltaic (`WDPV`) energy on the other hand. The installed capacities are given by `Dispatchable Capacity` and `WDPV Capacity` respectively. Both, among others, are essential parameters defining a portfolio concept. `WDPV Profile` specifies the real wind and solar power generation in a hourly resolution. The `Net Load` or residual load is given by the difference of `Load` and `WDPV`.

Generated electricity *flows* into the transmission `Grid` and is then delivered to the customers for `Consumption`. In our model `Grid` is implemented as a stock to record possible excess and shortage of electricity. Since electricity cannot be stored without special facilities `Grid` is reset to zero at the beginning of each time step of the simulation. The time specific consumption, `Load`, is characterized by the `Load Profile` in a hourly resolution and the `Year Load`.

For the sake of clarity dispatchable capacity includes biomass, hydro or geothermal sources so that their positive contribution to emission reduction is neglected. According to the notation we used in this work a blue and opaque arrow (f. i. from `Net Load` to `Dispatchable`) which means a positive influence, whilst a red and transparent arrow (f. i. from `WDPV` to `Net Load`) depicts a negative effect.

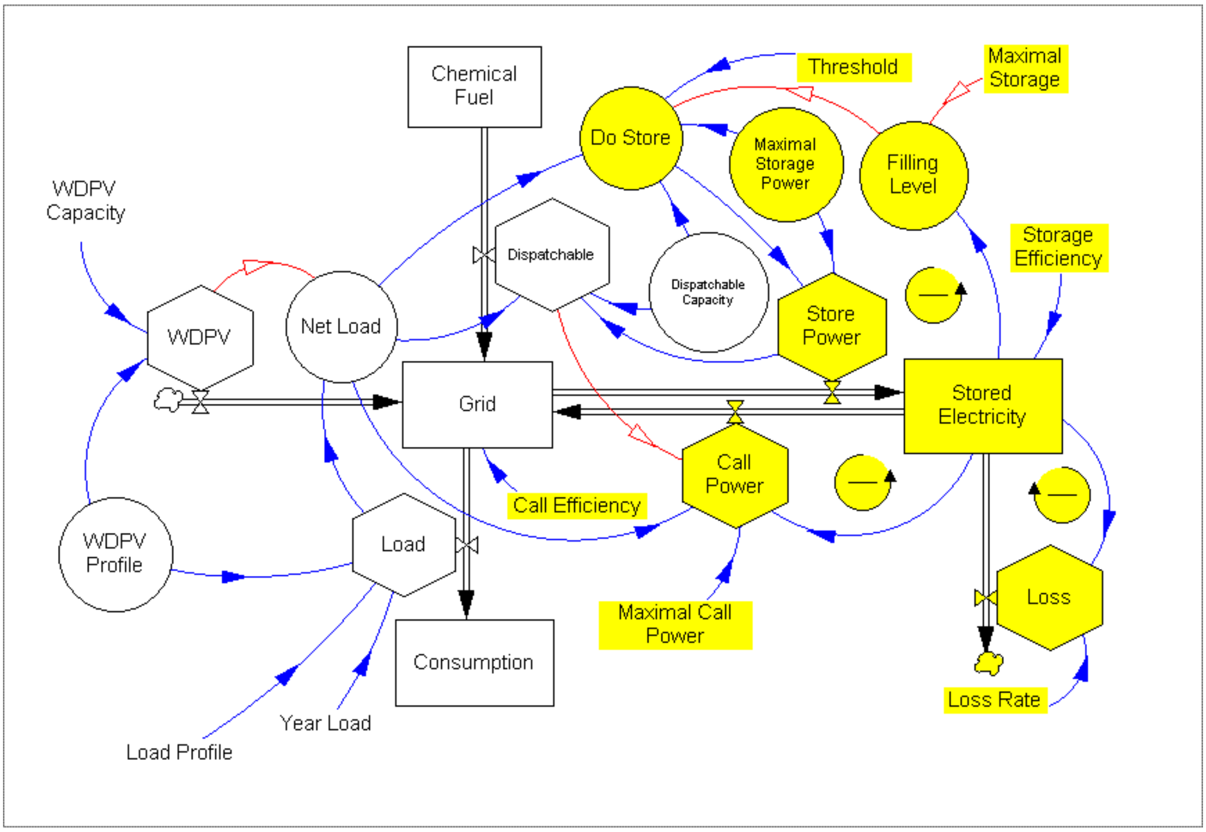


Figure 2: Electricity storage, f. i. pumped-storage power plants

Notice that `Net Load` may be sometimes negative. The higher the `WDPV Capacity`, the more often `Net Load` is negative, and the more it makes sense to have possibility to store electricity f. i. using pumped storage [see, e.g., Chen 2009], as shown in Figure 2. A storage system and its state are characterized by `Maximal Storage`, `Maximal Storage Power` and `Storage Efficiency` as well as `Stored Electricity`. As long as `Net Load` < 0 and `Filling Level` < 1 the storage is activated or `Do Store` > 0. Additionally, the storage is also activated if `Filling Level` < `Threshold`. The stored electricity can be called to provide grid stability when `Net Load` exceeds the maximal `Dispatchable Capacity`. The `Call Power` is limited by `Maximal Call Power`. Additionally, the call function is characterized by `Call Efficiency` and a `Loss` of `Stored Electricity` has to be considered caused by a technology specific `Loss Rate`.

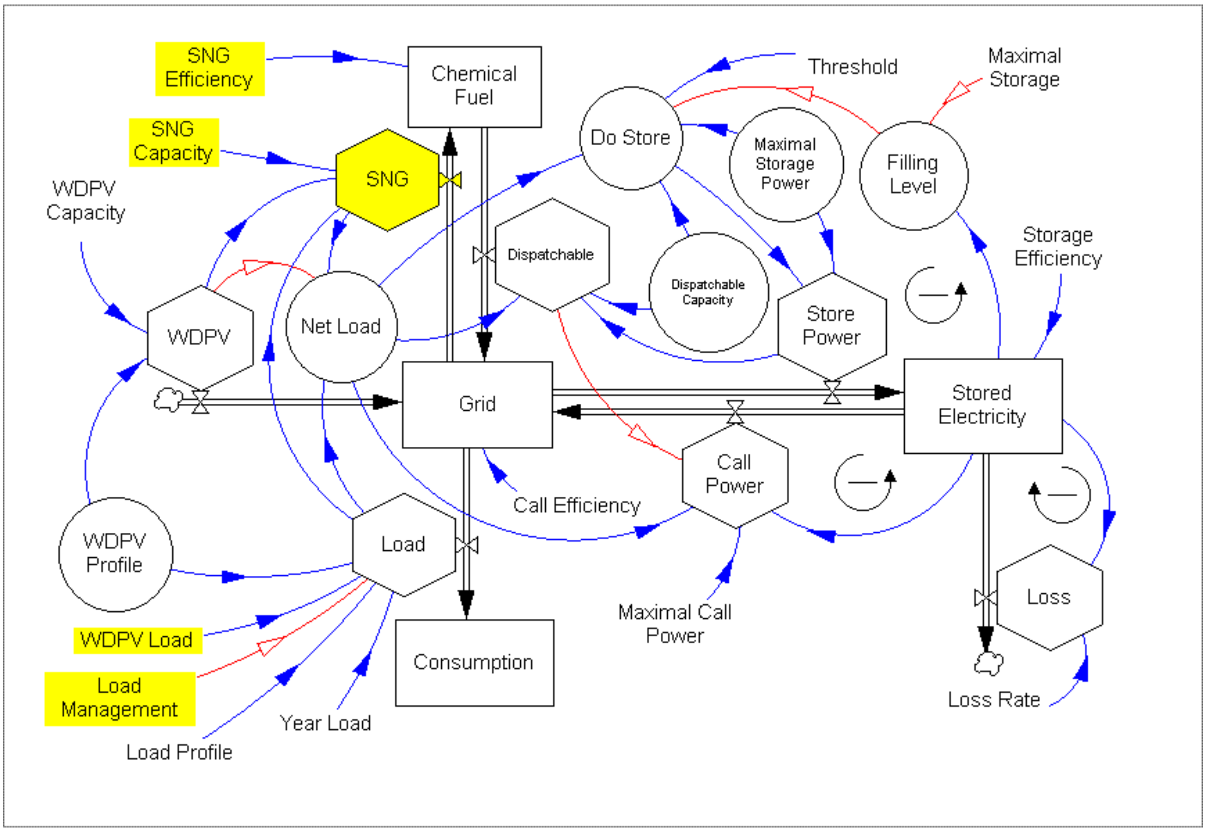


Figure 3: Two alternative concepts: converting excess electricity to chemical fuel and implementing load management

As an alternative to storage, electricity can also be used to produce synthetic natural gas or `SNG` [see, e.g., Sterner 2009], as shown in Figure 3. Depending on `SNG Capacity` and `SNG Efficiency` the net consumption of `Chemical Fuel` for electricity production can be reduced.

To sum up the three steps above the change of the stock variable `Grid` in each time step or `ΔGrid` can be calculated as following:

```
ΔGrid = - Grid + TIME STEP * ( Dispatchable + WDPV -
        - Load + Call Power * Call Efficiency -
        - Store Power - SNG )
```

As explained before (see the third paragraph of this section) the value of `Grid` is reset to 0 using the term -`Grid` at the beginning of each time step of the simulation.

Furthermore, as an extension to our previous work [Hu 2011] a smart grid or a concept occupying load management can be represented using the parameters `Load Management` and `WDPV Load`. The first parameter indicates the penetration or how much percent the load is managed to reshape the load profile. The second parameter specifies if `WDPV Profile` is taken into account instead of `Load Profile`.

Further parameters are used to complete the model (Figure 4). First of all, the initial filling level of the storage is given by `Ini S`. The stability of electricity supply can be tested using `Stress Testing` which reduces `WDPV` and increases `Load` at the same time. The specific costs for fossil fuel and CO$_2$ emission permits are given by `Fuel M` (€/MWh) and `CO2 M` (€/tonCO2). The specific investment costs for storage are given by `Storage M` (B€/GWh), whilst the ones for WDPV, SNG and dispatchable power are given by `WDPV M`, `Dispatchable M` and `SNG M` (B€/GW). Using these parameters the total cost of production can be calculated as the sum of capital and operation costs as well as the costs for fuel and CO_2 emission permits.

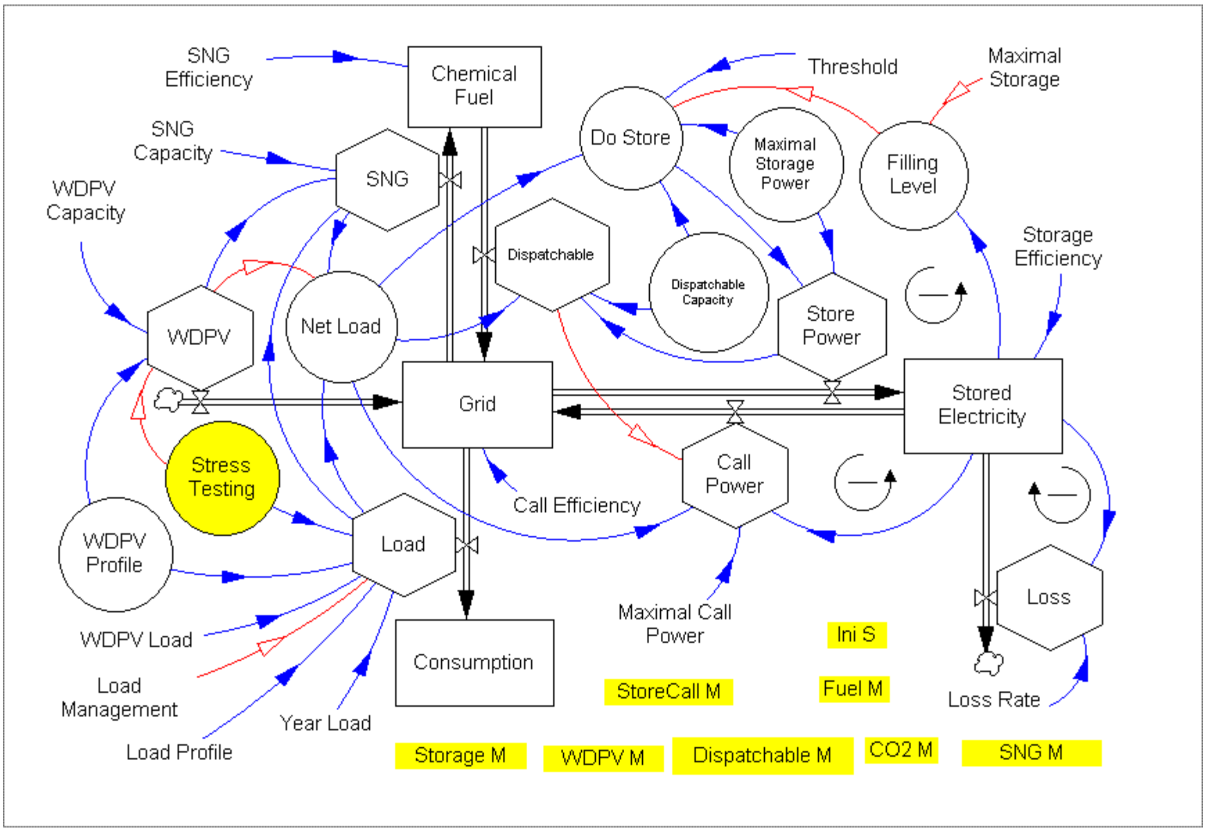
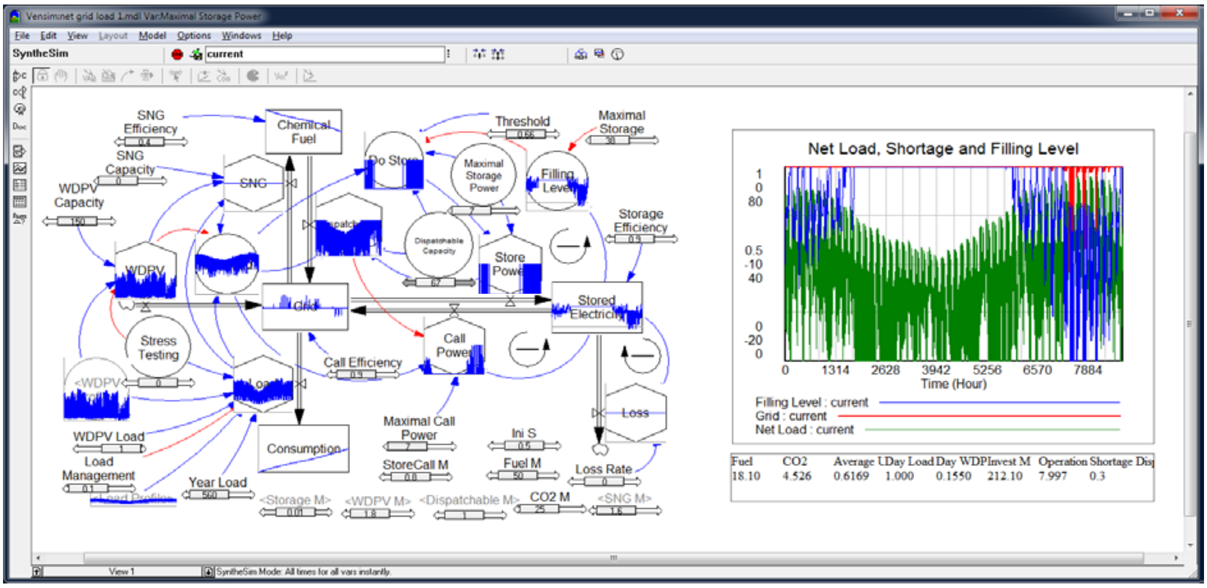


Figure 4: Additional parameters used for numeric simulations

3.2 Simulation results: a concept of renewable load management

In our previous work we compared six portfolio concepts of electricity supply in Germany under three different price scenarios [Hu 2011]. In our System Dynamics simulations the minimal `Dispatchable Capacity` which still provides reliable electricity supply under given `Load Profile` and `WDPV Profile` for an entire year was found interactively for each concept with its characterizing key parameters like `WDPV Capacity`, `SNG Capacity` and so on. A concept is considered as reliable if the cumulative energy shortage which has to be compensated via the European transmission grid is less than 2.6 TWh during the entire year or 0.3 GW in average. Shortages are displayed in red color and in the cumulative amount in the graph on the right side of our interactive user interface (Figure 5). Notice that possible excess electricity occurring at another point of time does not offset the cumulative shortage in the calculation. In this way different concepts to be compared with each other are dimensioned on the same reliability level. The total production cost which includes investment, operating, fuel costs and emission permits was then calculated for each concept.



SNG Efficiency 0.4
SNG Capacity 0
WDPV Capacity 150
Threshold 0.66
Maximal Storage 38
Maximal Storage Power 7
Dispatchable Capacity 67
Storage Efficiency 0.9
Stress Testing 0
Call Efficiency 0.9
WDPV Load 1
Load Management 0.1
Year Load 560
Maximal Call Power 7
StoreCall M 0.8
Ini S 0.5
Fuel M 50
Loss Rate 0
<Storage M> 0.01
<WDPV M> 1.8
<Dispatchable M> 1
CO2 M 25
<SNG M> 1.6

```
Fuel     CO2      Average UDay Load Day WDPInvest M  Operation Shortage Disp
18.10    4.526    0.6169   1.000    0.1550  212.10   7.997     0.3
```

Figure 5: Interactive user interface for simulations using the so-called SyntheSim mode of Vensim PLE [Ventana Systems 2009]

Based on our extended System Dynamics model presented in Section 3.1 we are now able to include two new portfolio concepts occupying "renewable load management" mechanisms ("RLM" and "RLM+" in table 1).

	Portfolio concept for 2025		BAU	Rnw	SRU	SNG	RLM	Rnw+	SNG+	RLM+
Spec. Costs	Load	TWh/a	560	560	560	560	560	560	560	560
1.0 B€/GW	Dispatchable	GW	82	74	60	74	67	72	72	58
1.8 B€/GW	WDPV	GW	36	150	150	150	150	200	200	200
0.8 B€/GW	Cap Storage	GW	7	7	37	7	7	7	7	7
0.8 B€/GW	Cap Call	GW	7	7	37	7	7	7	7	7
0.01 B€/GWh	Max Storage	GWh	38	38	5500	38	38	38	38	38
	Threshold	%	94%	60%	86%	60%	66%	42%	44%	38%
	Load Mgmt.	%	0%	0%	0%	0%	10%	0%	0%	20%
1.6 B€/GW	SNG	GW	0	0	0	10	0	0	20	0

Table 1: Specific costs for investment [Groscurth 2009, Reina 2008, Chen 2009] and key parameters of different portfolio concepts

Renewable load management mechanisms aim to reshape the load profile to fit the forecasted time profile of renewable electricity production without changing the total consumption of electricity in the whole year. In particular major industrial electricity consumers may orientate their consumption by weather prognoses which are relevant for wind and solar power output and receive incentives in the form of price discount or direct payment. For residential customers it has been shown that they do respond to dynamic pricing and thus may contribute to certain load management programs [Wolak 2011].

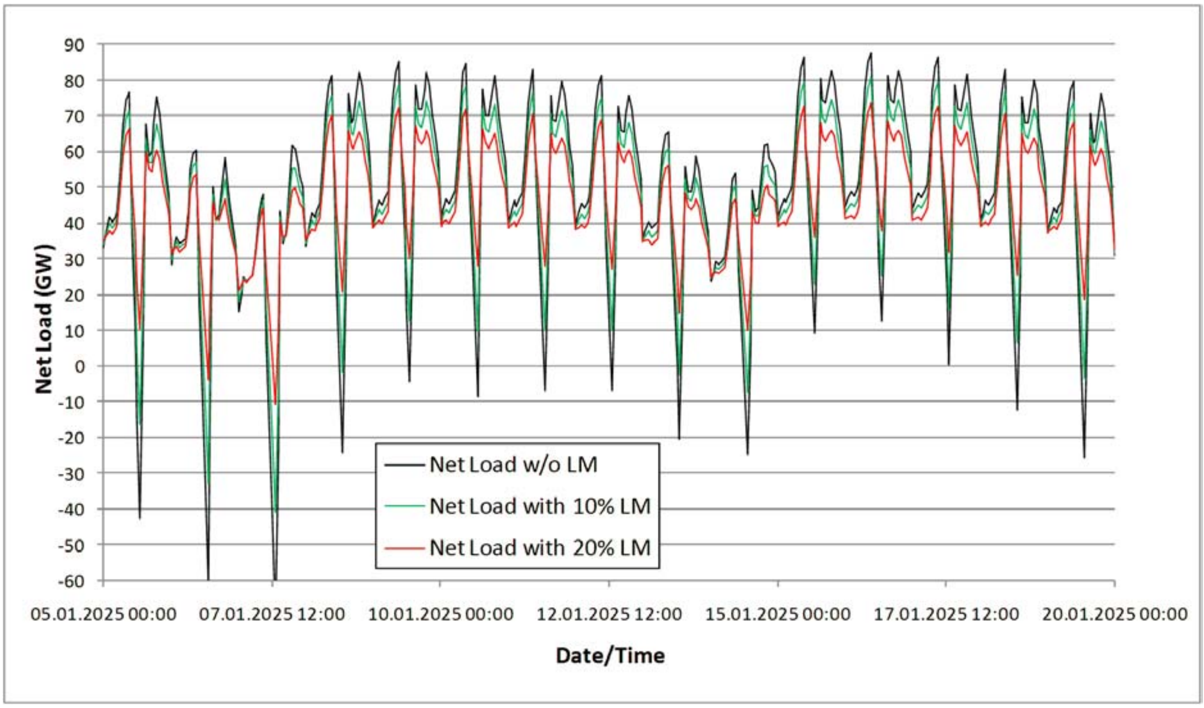


Figure 6: Renewable load management smoothing the net load profile

As shown in Figure 6 a renewable load management, depending on its penetration, may contribute remarkably to smooth the net load profile and thus to reduce the usage of dispatchable electricity production. However, even a penetration of 100% of load management would not be able to facilitate a fully renewable electricity supply alone with an installed WDPV capacity of 150 to 200 GW. According to our simulations a capacity of 33 to 41 GW of dispatchable electricity production is still necessary to provide a reliable power supply. With given dispatchable capacity a load management also contributes to reduce shortages in electricity supply, as depicted in Figure 7, especially when the consumption is high and WDPV production is low due to unfavorable weather conditions. Notice that the filling level of electricity storage comes down to zero many times during such a period.

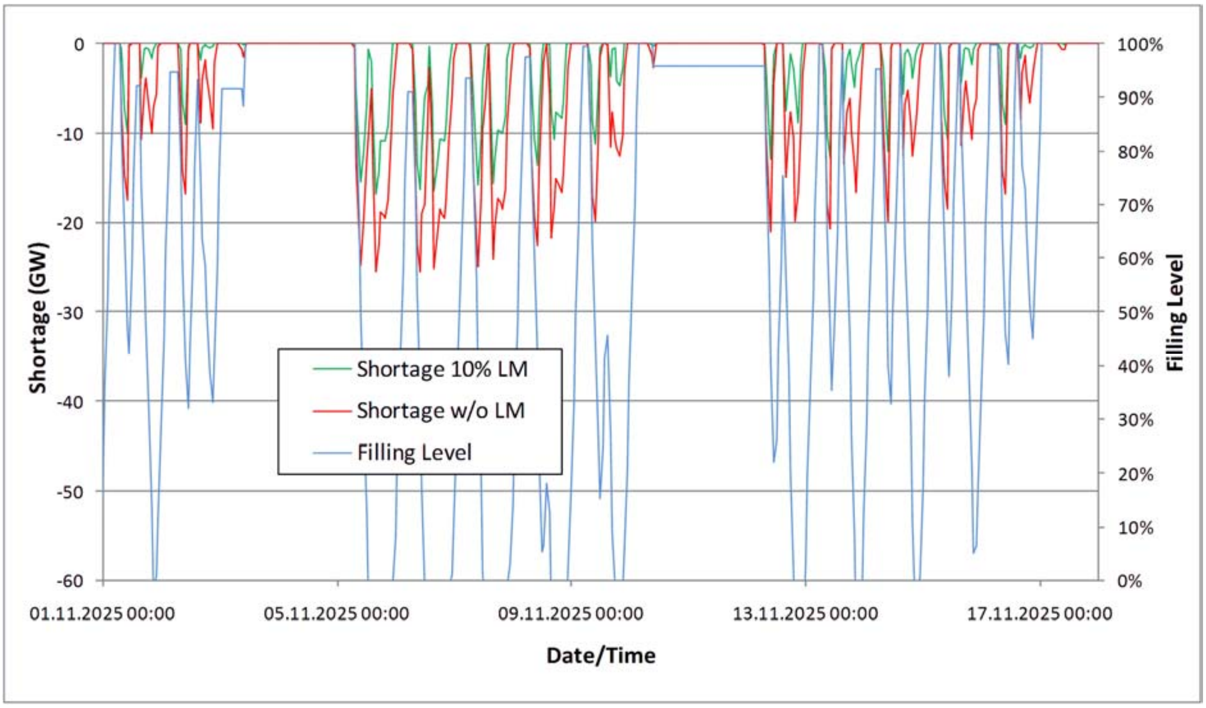


Figure 7: Renewable load management reduces shortages in electricity supply

To calculate the total production cost and the CO_2 mitigation of all eight portfolio concepts four different price scenarios are assumed as following (Table 2):

Price scenario	Fuel (€/MWh_e)	CO2 permits (€/tCO2)	Annual capital cost/interest rate (%)
I	50	25	7.26%/6.00%
II	75	37.5	7.26%/6.00%
III	100	100	10.61%/10.00%
IV	100	100	10.61%/10.00%

Table 2: Price scenarios. The annual capital cost is calculated as the sum of interest and repayment within a period of 30 years.

The results of our calculations are depicted in Figure 8. Our reference portfolio concept "Rnw" ("renewable") facilitating 150 GW wind and solar power can be improved both economically as well as ecologically by a renewable load management penetration of 10% ("RLM"). The total production cost can be reduced by up to 2.7 B€/year or 4.80 €/MWh in 2025 while improving mitigation of GHG emissions from 31.2% to 34.7% (compared to 1990). Under the assumption that 200 GW wind and solar power are installed a renewable load management penetration of 20% on the consumer's side can even improve CO_2 mitigation from 38.4% to 44.7% while saving up to 7.0 B€/year or 12.4 €/MWh.

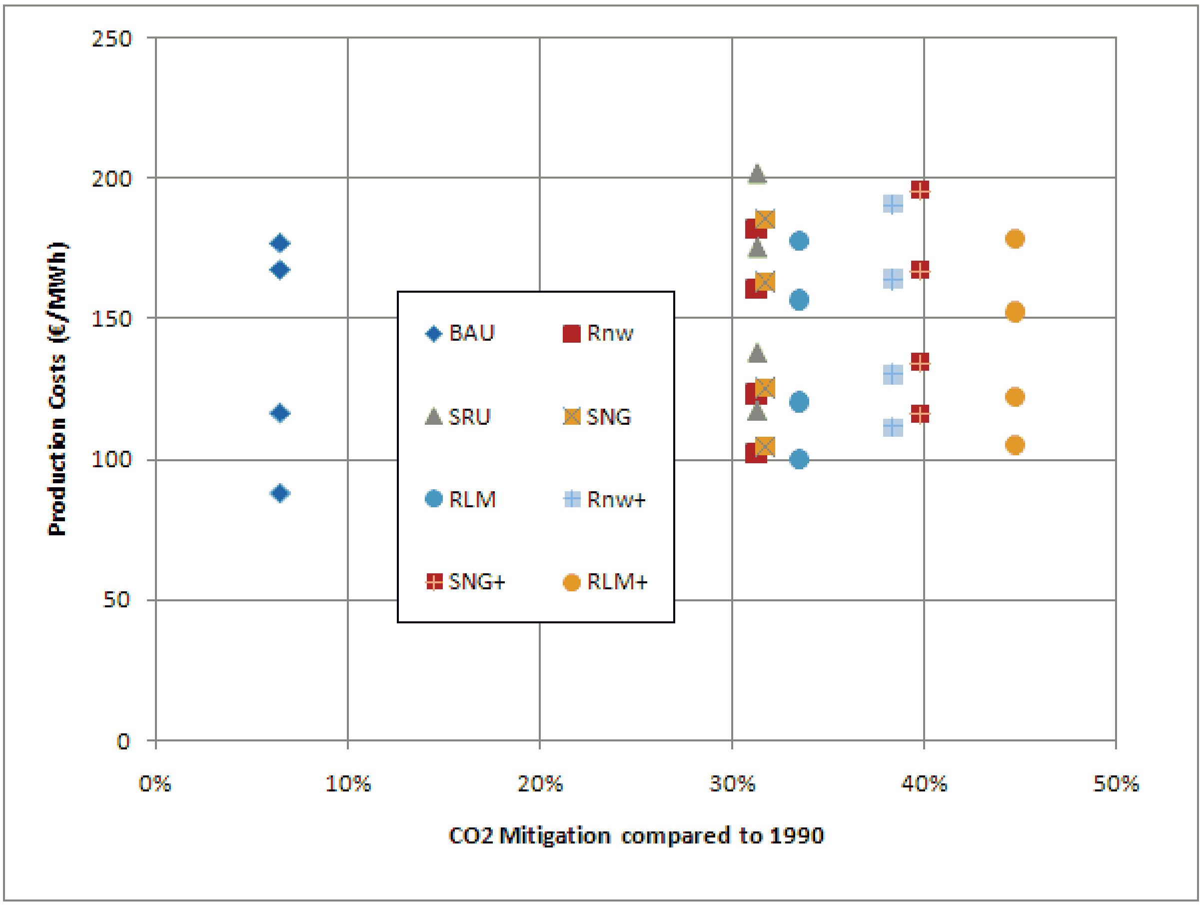


Figure 8: CO_2 mitigation and production costs of eight portfolio concepts under four price scenarios

However, it has to be pointed out that the calculations in this section do not take into account the costs for the implementations of renewable load management on the side of consumers which may include both adoptions in production processes as well as technological investments.

4. Data analysis for forecasting and controlling

The System Dynamics model presented in Section 3.1 is, among others, based on the fact that the sum of electricity delivered into the grid by the power plants (denoted positive) and from the grid to the consumers (denoted negative) must be zero. The grid or the electricity transmission system is operated by Transmission System Operators (TSOs) which are responsible for keeping production and consumption in balance and ensuring network stability. From the operational point of view the TSOs have to master the complexity and uncertainties of electricity consumption in real-time grid operation [entsoe 2012] which is becoming even more challenging due to additional high uncertainties caused by the weather dependent renewable electricity production. For operational planning forecasts are made both for the consumption as well as for the renewable electricity production. These forecasts become more reliable as the moment of delivery approaches. For this reason electricity trading takes place on three markets: future markets for long term obtainment, spot market for the short notice and intraday trading to sell and buy energy quantities on the day of delivery with increased price risk. If an electricity provider ordered too much on the future market (it went long) these quantities can be sold on the spot market and, vice versa, if it ordered too little (it went short), it can make up the shortfall on the spot market. It is obvious that the need for short-term trading increases with declining forecast quality and exposes the trader to a higher price risk.

During the day of delivery TSOs have to ensure the stability of the grid by means of regulation power [Mezger 2007]. The stand-by capacity of regulating power is marketed in auctions, where, besides others, power plant operators with their spare capacities take part [regelleistung 2012]. Actually regulating power is reserved for failure of power plants, transformers or power lines to ensure n-1 criteria, but if the forecast is not accurate regulating power is also used to correct these inaccuracies for which it is not primarily intended.

For example, on February the 7th the whole German energy market was short, which means that most of the balancing groups had too little energy procured. In addition to this situation the temperatures in Western Europe were very low, so that large amounts of power were transferred to France where most households are heated using electrical radiators. To make matters worse, on that day little wind energy was fed into the grid. These reasons led to a high need for control power of more than 3000 MW [fr-online.de 2012]. At the time of writing this paper the costs for the regulating power are not yet published. It is assumed that the prices per MWh are expected to be more than 500 €. On the intraday market in the said hour the price was at 380 €/MWh high and the weighted average at about 270 €/MWh located [epexspot.com 2012]. In late December 2011 there was the exactly opposite situation: the market was obviously long. This led to the situation that the costs for negative control energy (reducing production) per a specific quarter hour raised up to more than 500 €/MWh [amprion.net 2012]. Figure 9 shows the prices per quarter hour in December 2011. The polynomial dashed trend line shows the balanced amount of regulating power of the considered month which was negative in the most time.

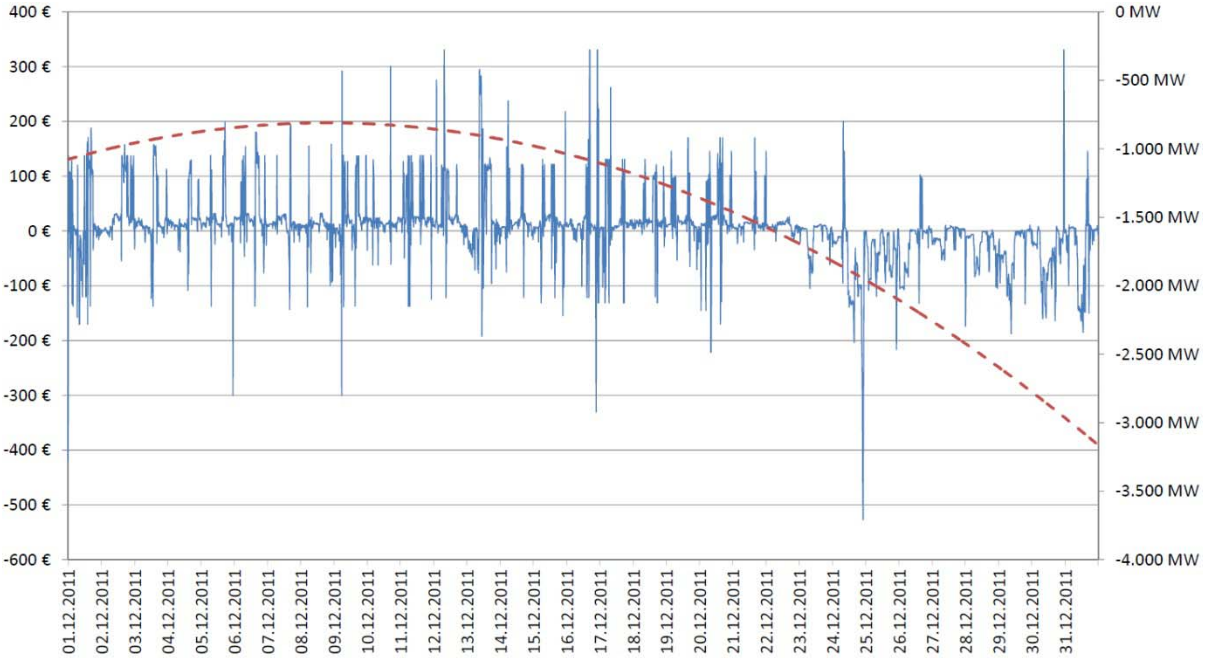


Figure 9: Long positions of the providers' portfolios led to high rates for regulating power [amprion.net 2012]

Both cases, being short or being long, may cause significant additional costs and lead to negative contribution margins [Köhler-Schulte 2007]. It is therefore important to have accurate forecasts both for consumption as well as for wind and solar power production which depends on the weather. Consumption depends on two types of load profiles: standard load profiles (SLPs) for households and for small businesses or profiles of recorded demand measurement (RDMs) for companies with yearly workload of more than 100 MWh or with hourly loads of more than 500 kW. These profiles are used to forecast a consumption behavior for the future. Therefore SLPs will be scaled for 8760 hour values or 35 040 quarter hour values - for each metering point. RDMs with yearly 35 040 values are taken from the younger past. There are several factors taking influence on the forecast: e. g. weather forecast (wind, temperatures, sunshine), holidays, economy in general, and so on. All those input values are calculated with statistical methods to make the consumption forecast as accurate as possible. The German Law of Renewable Energy (EEG) [Deutscher Bundestag 2012] gives renewable energy a higher priority to be fed into the grid than conventional power generation. It is obvious to have a good weather forecast that conventional production does not lead to long or short positions.

Central element of calculation, procurement, forecast, trading, consumption and metering is the load profile. Electricity providers have to handle a large number of metering points, and each load profile consists of a few thousand values. The challenge is to be able to manage on one hand the amount of data that lead to the other one related to the particular customer or metering point to be able to calculate a break-even analysis. So called Energy Data Management Systems (EDMs) should meet the requirements of the providers, but the quality of the used methods for forecasting consumption under the above consideration are essential [Köhler-Schulte 2007].

Especially for an effective renewable load management (see Section 3.2) the prognosis of both Load and WDPV profile is an essential challenge for the TSOs. To have a profile that covers the real consumption over the whole year in 2010, it is necessary to collect data from sources where they were made public. There are several platforms of Germany's TSOs that are publishing information about consumption and also production of wind an photovoltaic. Especially photovoltaic data is hard to get, because the best source for it are the German TSOs, but one of them publishing only since mid 2010. To improve the prognosis for the model in 2025 it is necessary to make analysis to the realistic profiles to get information about dependencies to weekdays, relevant events like holidays, political decisions and so on. To optimize the load management it is not enough to have a valid day-ahead forecast. Energy intensive businesses can't plan production with short lead time. Electricity providers can only offer competitive prices when they use proofed methods and practices that lead to high quality forecast for three or more days ahead. And finally, as shown above, also the day-ahead forecasts are important to reduce risks of additional costs. Analysis of the amount of data can help to improve quality of prognosis.

5. Conclusions

In this paper we employ portfolio concept and System Dynamics approach to evaluate assets in an electrical grid. System Dynamics approach has not been widely used as a tool for optimizing asset structure of an energy portfolio yet. It allows to model the interactions between the assets to get better insights into portfolio management. Technological advancements like electricity storage systems and load management are considered as portfolio assets, consequently portfolio concepts differ due to the different penetration rates of load management, different storage or synthetic natural gas capacity. In a further research some of the explained portfolio concepts will be analysed, focusing in details on the impacts of these concepts. Nevertheless, according to the results produced with the help of System Dynamics model load management produces significant potential savings on production costs at acceptable reliability and helps to achieve the political goal of reducing GHG emissions. Data analysis is especially important for forecasting and controlling and can be employed for balancing the grid. Further research is planned to estimate if the savings on the side of electricity production are sufficient to be used as incentives to motivate consumers to implement the necessary load management.

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