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THE POTENTIAL AND OPTIMAL OPERATION OF DISTRIBUTED POWER GENERATION IN ESTONIA

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Estonian electricity generation requires new investments due to limitations for emissions, deterioration of old power plants and growing electricity consumption. This could be the turning point for distributed generation (DG) in Estonia. DG would allow saving energy and reducing emissions due to more efficient fuel usage. Also the supply reliability and energy security would be increased through availability of local power generation. In this paper the definition and potential of DG in Estonia is estimated and the optimal operation criteria are examined. The possible effect of DG development on electricity price and emissions is assessed using LEAP software.

Introduction

The Estonian energy sector is one of the most CO_2-intensive sectors in European countries. As the CO_2 quotas and limits for emissions are becoming more and more tighten, there is a need for production capacities with low emissions. The old oil shale based production units will be closed after the year 2015 as their sulfur dioxide emissions do not comply with the EU directive requirements. This means that significant investments are required for building of new production capacities, which will probably result in higher electricity prices. Also energy saving issue is important aiming that electricity and heat should be produced using technology of higher efficiency and thereby saving primary energy. In quest for new production capacities DG could provide several advantages compared to classical, central power production.

In this paper the definition of DG is analyzed and its main features are brought up. As DG is defined differently depending on specifics of a country, it is necessary to introduce the definition of DG in Estonia. In order to assess the importance of DG in Estonia, the current production capacities are evaluated and divided to central and decentralized producers. When

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analyzing the possible consequences of DG development, it is essential to estimate the potential of DG until the year 2020. Modeling tool LEAP is used to appraise the effect of DG on Estonian electricity and heat generation. Also the influence of DG development on electricity price and CO_2 emissions is analyzed with this software.

It is essential that the possible outcomes of DG depend on different aims of optimal operation. Therefore three different optimal operation criteria are presented and described.

Definition of distributed generation

DG is often used in relation to the term smart grid, which is a modernized electricity network mainly allowing consumers to direct their consumption depending on electricity market price. These networks are also designed integrating local generation, like DG is. The term of DG, which is also called dispersed generation, embedded generation or decentralized generation is defined differently depending on specifics of a country. Some countries define it as production units connected to the distribution network. Others have limits for the production capacities or start from the principle that DG is power production using renewables [1].

Regardless of precise definition, the fundamental principle of DG is to produce electricity close to the point of consumption. The main features of DG are brought up in Table 1.

In the case of DG, the produced energy is supposed to be consumed within the distribution network. However, DG-s can feed back some of their generated electricity to the transmission network, if it exceeds the networks demand [1].

The size of DG units can be very different, which could be in some cases even up to 300 MW. By the production capacities the producers are classified as micro (<5 kW), small (5 kW-5 MW), medium (5 MW-50 MW) and large ones (50 MW-300 MW) [3].

DG comprises all kind of production technologies, and the assortment depends rather on availability of technology in required size. Possible equipments are gas and steam turbines, internal combustion engines, micro turbines, biomass gasification devices, wind turbines, small hydro power plants, photovoltaic panels, fuel cells and storage units. The choice of fuel

Table 1. **Main features of distributed generation [2]**

Purpose	Provide a source of active electric power
Location	Connected to the distribution network or on the customers site of the meter
Delivery area	Energy is mostly consumed within the distribution network
Size	From 1 W up to 300 MW
Technology	Wide variety
Fuels	Renewable as well as fossil

depends on what is locally available, like biomass, biogas, peat, household waste, natural gas wind, water, solar energy, etc. [2].

The advantages of DG are emission reductions and energy savings due to the use of high-efficient production units, such as those of cogeneration of heat and power (CHP), and the use of renewable fuels. DG allows using locally available fuels like biogas, landfill gas and biomass, which improves the independence from imported fuels (energy security). Also the network losses are reduced, power quality and supply reliability are improved. In addition DG could serve as a substitute for investments in transmission and distribution capacity [3].

Distributed generation in Estonia

Fixed electricity prices and investment supports for renewable electricity producers and small CHP plants have provided the essential assurance for investors to renovate the old hydro power plants and to build new wind parks and CHP plants. Also the opening of electricity market has provided producers a possibility to sell their electricity to the market and in addition to receive a subsidy. The short construction time and automated operation are great advantages compared to big power plants as well.

In Estonia DG could be defined as production units generating electricity close to the point of consumption. The connection point of producer is not relevant as long as the size is suitable to cover the local demand. In the case of cogeneration the production should take place at efficient cogeneration regime. All other producers are named as central producers.

In order to assess the importance of DG in Estonia it is necessary to define what kind of existing producers are central and which decentralized producers. Overview of one possible classification is presented in Table 2.

According to the transmission network operator Elering [4], the total installed capacity of all power producers in Estonia is currently about 2400 MW, of which over 2200 MW are central power plants. The generation capacity of DG in 2009 is 213 MW and it consists of small CHP plants, hydro power and wind power (WP) plants. The distributed CHP plants are

Table 2. **Electricity production capacity in Estonia in the year 2009**

	Installed capacity, MW
Oil shale power plants	2 068
Natural gas power plants	156
Total central producers	**2 224**
Distributed CHP plants	78
Hydro power plants	4
Wind power plants	131
Total distributed generation	**213**
Total installed capacity	**2 437**

using wood, peat, natural gas or biogas as a fuel. The electrical capacity of the biggest DG producers is 25 MW, which is the output of CHP plant using wood and peat. Smallest producers are probably small hydro and wind turbines with a capacity below 10 kW.

The potential of distributed generation in Estonia

The capacity of DG in Estonia has doubled during the last year, as in 2009 new CHP-s and wind turbines started operating. The importance of DG is expected to grow also in the nearest future as more plants will be built and some are already under construction. During the research the possible development of DG until the year 2020 was estimated taking into account the potential of cogeneration and availability of local fuels.

Lately interest for building wind parks and CHP plants has grown noticeably. It is expected that soon all the biggest towns and energy intensive industries will have their own CHP plant, which will all be DG sources. Also WP will have an important role in Estonian power generation.

In the next years many industrial consumers could set up their own CHP plant. With opening of electricity market the electricity price for industrial consumers has risen considerably. Also the expenditures on heating and hot water are increased. The required heat is currently often produced using electricity or from fossil fuels like shale oil, which is becoming more and more expensive. Thus by constructing a CHP plant the consumers could benefit from reduced expenditures on electricity as well as heat.

The potential of DG until the year 2020 is estimated to be 900 MW of electricity and 1060 MW of heat, which is specified in Table 3.

Most of DG electricity in 2020 would be produced from wood, natural gas and wind. The growth in the production capacities results from WP and CHP plants running on wood, natural gas, biogas or household waste. The biggest potential of DG is based on building CHP plants instead of boilers. The capacity of these plants could reach 300 MW of electricity and 600 MW of heat.

Table 3. **The available and potential capacity of distributed generation in Estonia**

Production capacity, MW	in 2009		in 2020	
	Electricity	Heat	Electricity	Heat
Wind	117	0	400	0
Wood and peat	68	178	225	685
Natural gas	20	22	196	258
Hydro	5	0	10	0
Biogas	3	3	45	45
Household waste	0	0	24	72
Total	**213**	**203**	**900**	**1060**

WP plants with a capacity of 400 MW are considered to be DG producers as it is assumed that their production is consumed in the same area. By the year 2020 the capacity of WP plants in Estonia will probably be more than that as there have been connection agreements settled for about 750 MW [4]. But only 400 MW of WP is counted DG as at a certain capacity the produced electricity cannot be consumed locally. All offshore WP plants are considered central production.

The availability of 900 MW of DG electricity generation capacities will clearly have an effect on the environmental emissions and on electricity price. The analysis is carried out using the LEAP software, which is a scenario-based energy-environment modeling tool, developed by Stockholm Environment Institute [5]. The model for Estonia's energy system was created in LEAP, and two electricity generation scenarios were designed (central and distributed scenario) based on predicted electricity production capacities until the year 2020.

For creating the Estonian energy system model, statistical data for the years 2000–2008 was inserted in LEAP. The production units for electricity and heat were created and their production was optimized to represent the real situation. Load curve for electricity and heat consumption was designed. A reference model was built, where the production from generating units is at the same level as the actual numbers in 2000–2008. Thereafter the development of energy consumption in 2009–2030 was predicted and for both scenarios changes in the production capacities (closing of plants and building of new ones) were made. The production capacities of DG were inserted based on data presented in Table 3. The software thereafter simulates the generation of these production units based on defined availability factors, type of production (base load, medium load or peak load producer) and other dispatch rules. The desirable outcomes like electricity and heat generation from different production units, CO_2 and SO_2 emissions etc. can be observed in LEAP' graphical as well as numerical results. In this paper some of the findings are presented, detailed information regarding the software, modeling assumptions and possible outcomes can be found in the article [6].

As DG in Estonia comprises electricity generation from renewable energy, therefore the national emission levels will be reduced. The overview of DG electricity generation and saved CO_2 emissions is presented in Fig. 1.

Based on analyzes in LEAP it is evident that the development of DG will reduce notably the CO_2 emissions from electricity and heat sector. As the CHP plants are replacing conventional power production as well as heat production from boilers, less primary energy is used to produce same amount of electricity and heat and less emissions are emitted. Thus DG will have an important role fulfilling the national target of reducing CO_2 emissions from energy sector by 5 million tons. As currently the energy sector emissions are 15.7 million tons [7], the development of DG would reduce the emissions by one third.

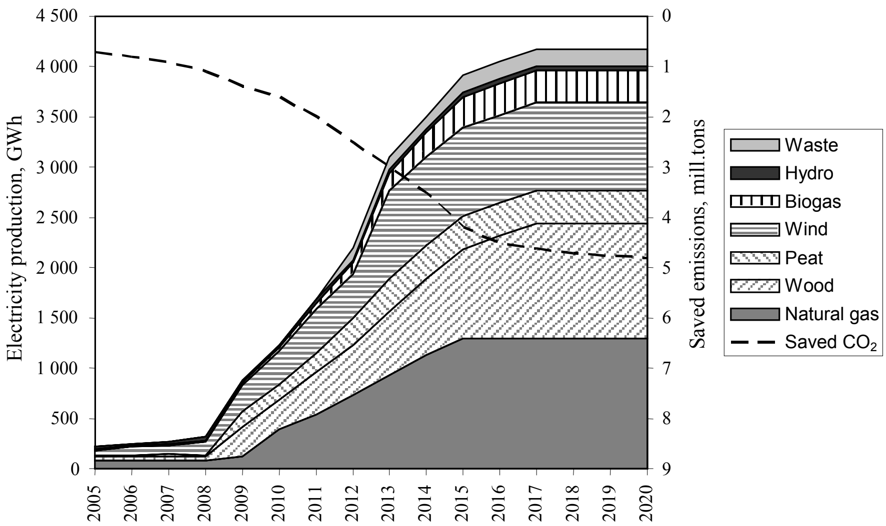

Fig. 1. Electricity generation of DG and saved CO_2 emissions.

In order to evaluate the role of DG in Estonian electricity and heat generation it is essential to examine the DG share in the total production. This can be carried out with LEAP model, as there is no statistical data available about DG in Estonia. In Fig. 2 the share of DG, CHP and renewable energy in gross electricity consumption (consumption + network losses) and the share of DG in gross heat consumption are visible. The figure represents generation only from DG producers. In addition there could be central power plants producing at cogeneration regime or using renewables.

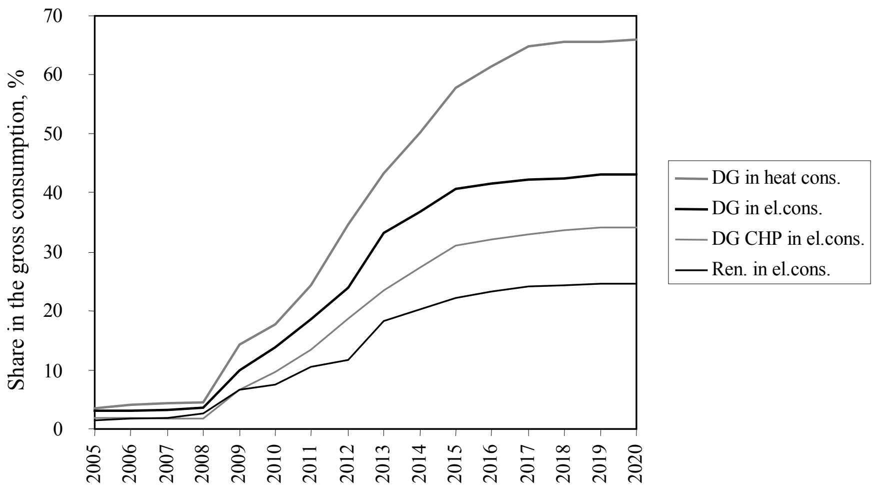

Fig. 2. The importance of distributed generation on the gross consumption.

In the year 2009 DG production was about 10% of the gross electricity and 15% of the heat consumption. In 2020 these shares could be correspondingly 40% and 65%. The goal of Estonian Long-term Electricity Sector Development Plan until 2018 is that 15% of the electricity gross consumption in 2015 be produced from renewable energy sources. Also in 2020 cogeneration should form 20% of the gross electricity consumption [7]. Currently these shares are about 6% and 10%, respectively [8]. The effect of DG is that in 2020 renewable energy sources would form 25% and cogeneration 35% of the gross electricity consumption. This means that DG is one important executor for meeting the goals of electricity sector development. Also it is seen in Fig. 2 that most of the heat will be produced in small distributed CHP plants. Therefore production from boiler houses will be reduced significantly as currently about one third of heat is produced using cogeneration.

Usually the capital costs per kW and also the production price of DG are relatively high compared to central power plants. Therefore Estonian government has introduced subsidies to guarantee the development of renewable electricity production. The subsidy depends on fuel and production technology. Producers generating electricity from renewable energy sources will receive a subsidy 54 €/MWh (84 s/kWh) [9]. In addition the producers get incomes from sale to the electricity market. For the WP plants there is a limit regarding the annual production, each year the subsidy is paid only until the national WP production reaches 600 GWh. Thereafter wind turbine owners get incomes only from electricity sale to the market. CHP plants using waste or peat as fuel receive a subsidy 32 €/MWh (50 s/kWh) [9]. The same subsidy is also paid to small CHP plants with an electrical capacity up to 10 MW using fossil fuels like natural gas.

The subsidy paid to DG is charged from the end-consumers as a fee for renewable energy. Therefore it is clear that the development of DG will affect the electricity price. This fee is calculated by the transmission network operator, and in 2010 it is 8 €/MWh (12.64 s/kWh) [10]. In Fig. 3 the

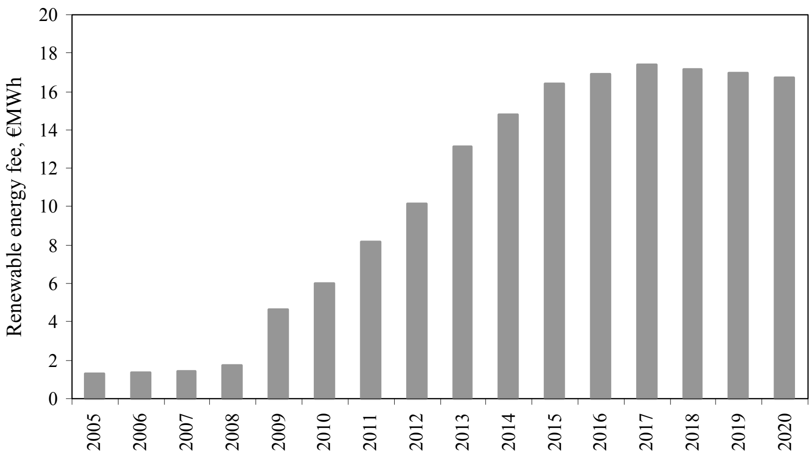

Fig. 3. Renewable energy fee (€/MWh).

renewable energy fee is shown, which is calculated only from DG production. This is only a part of the total fee as also some central producers receive subsidies. Calculations in LEAP showed that availability of 900 MW DG will raise the electricity price in 2020 by 17 €/MWh (26 s/kWh). But as according to Electricity Market Act the subsidies are paid only in the first twelve years of operation, the renewable energy fee will be actually reduced afterwards.

Optimal operation

There are different objectives how the DG plants could be operated. They can be used to cover a part or all of consumer's power demand. DG could be operated as a standby appliance to supply electricity during grid outages or as peak load provider for industrial consumers. In the open electricity market conditions they could be producing only when the market price is high.

It is assumed that DG is connected to a certain part of the energy system, which has a grid connection to the central production network. In this part of distribution network there is a demand for electricity and heat. The objectives of DG in this network are as follows:

- To maximize the profit of electricity and heat producers;
- To maximize the supply reliability and energy security;
- To minimize the environmental emissions.

The first criteria is an economical, a so called classical approach to energy planning. Usually the optimal dispatch problem is determination of power unit loads so that the cogeneration system production cost is minimized [11]. In the deregulated market there is usually a big public power company who owns all production units of a country. In this energy system the production between different power units can be optimized according to lowest production costs.

At the present day the electricity price is formed in open electricity market conditions. The market price is set up as supply and demand equilibrium through matching the offers from many generators to bids from consumers. All producers are now independent market participants and their production cannot be optimized according to lowest costs. Each individual producer is now aiming to maximize its profit.

The goal is to maximize the profit of all producers in the particular part of the energy system:

$$\max E = \sum_{i=1}^{n} E_i \tag{1}$$

It is assumed that all individual producers are maximizing their profits.

DG producers are specific market participants, as in addition to market price, the producer using renewable energy or efficient cogeneration will receive additional incomes from subsidies. Therefore, the aim of DG producers is to maximize the profit of electricity production taking into account the production costs, subsidies and electricity market price.

The electricity production profit of one DG producer i can be represented as follows:

$$E_i = \Sigma P_{gen,t} \cdot (H_t - C_t) \cdot \Delta t + \Sigma P_{gen,\, t} \cdot L_{\, t} \cdot \Delta t, \quad (2)$$

where $P_{gen,t}$ – net capacity at the time t,
H_t – electricity market price at the time t,
C_t – total production costs at the time t,
L_t – subsidies for a specific production type and fuel defined by government,
Δt – time period, where above mentioned variables are constant, usually one hour.

In certain cases, if the DG producer generates only for self-consumption, no electricity is sold to the market and only subsidy is received. Then the production profit can be calculated as follows:

$$E_i = \Sigma P_{gen,\, t} \cdot L_t \cdot \Delta t. \quad (3)$$

In this type of operation optimization it is possible to take into account the technical, supply reliability and environmental conditions as restrictions. For example the generation of wind turbines depends on wind speed. Also the electricity generation of CHP is restricted to heat demand. But if heat storage is available at the CHP plant, then it is also possible to produce electricity when the electricity price is high and not to produce when it is low [12].

Also the conditions when the DG producer is willing to produce are different. The typical central producer is willing to produce electricity whenever the market price is higher than its production cost.

$$C_t < H_t. \quad (4)$$

As the DG producers receive additional subsidy from its electricity generation, the producer is willing to sell electricity also in case the market price is lower than its production cost.

$$C_t - L_t < H_t. \quad (5)$$

For example if the producer generates electricity with wind turbines, he receives a subsidy 54 €/MWh [9]. If the production cost of this wind turbine is for example 53 €/MWh [13], the producer is willing to sell whenever the market pricis higher than 1 €/MWh. If the distributed CHP using wood has a production cost of 74 €/MWh [13] and receives the same subsidy, then the lowest favorable market price is 20 €/MWh. In Estonia electricity has been traded on spot market at NordPool Estonia area since 1 of April 2010. During the first six months of trading, the market price has been changing between 1.94 to 2000 €/MWh, with a daily average changing between 30 to 50 €/MWh [14]. This means that market price will be profitable for DG producers and they are interested producing most of the time.

The second objective of DG optimal operation is maximizing supply reliability, which means maximizing DG in the observed energy system. We can also speak about energy security if there are enough potential fuels in proximity to produce the required amount of energy.

Thus the optimization criterion at the specific area

$$\max P = \sum_{i=1}^{n} P_{gen,i} \tag{6}$$

is subject to the boundary condition:

$$\sum_{i=1}^{n} P_{gen,i} = \sum_{j=1}^{m} P_{D,j} + \Delta P , \tag{7}$$

where $P_{gen,i}$ – electricity generation capacity,
P_D – electricity demand,
ΔP – network losses.

This means that DG should be optimized so that the production should meet the local demand at any given time. Therefore the aim is to locally minimize the shortfall and surplus of electricity.

In the network containing DG, it is possible to calculate the share of DG as follows:

$$k_{DG} = \frac{\sum_{i=1}^{n} P_{gen,max}}{\sum_{j=1}^{m} P_{D,jmax}} , \tag{8}$$

where k_{DG} – share of DG in the observed energy system,
$P_{gen,max}$ – available generation capacity of DG at the moment of maximum electricity demand,
$P_{D,j\,max}$ – maximum electricity demand.

Here the WP generation is not included in the DG, as the generation of wind turbines is unsteady and could not be available on the moment of the maximum demand. If considering also WP, the share of DG is:

$$k_{DG}^{*} = \frac{\sum_{i=1}^{n} P_{gen,max} + \sum_{k=1}^{l} P_{gen,WT}}{\sum_{j=1}^{m} P_{D,jmax}} , \tag{9}$$

where k^{*}_{DG} – share of DG in the observed energy system considering also wind power,
$P_{gen,WT}$ – available generation capacity of wind power.

In the energy system without DG the value of k_{DG} equals 0. In certain cases the factor can also be greater than 1, which means that at this moment the DG production exceeds the consumption and the surplus will be exported. It is also possible to use distributed CHP for balancing the supply and demand in a system with fluctuating WP generation [14]. In that case the aim would be that the value of k_{DG} equals 1. CHP plants would then adjust their production taking into account the local electricity demand, network losses and WP generation. At hours when WP covers the whole electricity demand, the CHP plants avoid producing. Alternatively storage appliances could be used to store the surplus electricity.

The third aim of defining the optimal operation of DG is to minimize environmental emissions. Producers are interested in reducing emissions only if they could thereby save money. Therefore, the aim is to minimize the emission costs, which can be presented as follows:

$$\min B = \sum_{l=1}^{p} B_l \cdot H_l , \tag{10}$$

where B_l – amount of emission,
H_l – price of emission.

This means, that energy should be produced by power units with lower emissions resulting in lower expenditures. These emissions could be CO_2, SO_2, NO_x, water, ashes, etc. Some emissions have a price, for example CO_2, which has a market price. Alternatively, the environmental taxes or charges can be used for emissions without a price. Also it is necessary to take into account that although some modes of operation have emissions, they are nevertheless counted as 0. This is the case of renewable energy, whose CO_2 emissions are not taken into consideration. As the most significant expenditures are made for CO_2 emissions, therefore according to this optimization principle, power units using renewable energy or fuels with low CO_2 emissions should be favored. Already now the expenditures for CO_2 form a considerable part of the production price of fossil power plants. DG has usually low or no CO_2 emissions, therefore their competitiveness will improve in the future, as the CO_2 price is expected to rise.

Conclusions

Distributed generation has currently a small importance in the Estonian electricity production, but opening of the electricity market, favorable feed-in tariffs, investment supports and rising prices of fossil fuels will favor further development of this kind of generation. It does not comprise only small production units generating for consumers own demand, but also wind turbines on land and CHP plants of a size up to 25 MW. In some countries the DG unit capacity could even reach 300 MW. The total electrical capacity of DG in Estonia is currently about 200 MW and their production could form about 10% of electricity consumption. This electricity is mainly produced from wood and wind power. By the year 2020 the capacity of DG in Estonia could reach 900 MW and it could cover 40% of consumption. The availability of DG will be one important means for meeting the targets of the electricity sector development. It will raise noticeably the share of renewable electricity and cogeneration in the electricity and heat production. The 900 MW of DG producers will reduce the CO_2 emissions from electricity sector by one third.

There are different objectives how the DG plants could be operated. In the open electricity market conditions, the DG plants are aiming to maximize their profit as in addition to market price, the producers will receive additional incomes from subsidies. These subsidies are proven to be so favorable that DG producers are interested in maximizing their production and generating most of the time. The subsidy is charged from the end-consumers as a fee for renewable electricity, which would be then doubled. The second optimization aims that the production from DG should meet the local demand at any given time. The objective is to locally minimize the shortfall and surplus of electricity. The third optimization targets minimizing environmental emissions, thus power units using renewable energy or fuels with low emissions should be favored.

The presented optimization conditions could be adapted in LEAP as dispatch rules. Further investigation should include additional simulations of these three particular cases in LEAP. Also sensitivity analysis regarding the effect of different optimal operation criteria on electricity price and emissions could be carried out.

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