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Energy modeling for an efficient system development in Indonesian Province Nusa Tenggara Timur (NTT)

F. Klug [a,*], H. Wicaksono [a], R. Budiarto [b]

[a] Institute for Information Management in Engineering, Karlsruhe Institute of Technology, Zirkel 2, 76131 Karlsruhe, Germany
[b] Department of Engineering Physics, Universitas Gadjah Mada, Jl Grafika 2, Yogyakarta 55281, Indonesia

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A B S T R A C T

The Indonesian province Nusa Tenggara Timur (NTT) has a great potential of renewable energy, especially geothermal resources. However, electricity demand nowadays is mainly served by diesel generators. For inducing a change in the power generation portfolio the Indonesian government has formulated the goal to generate 25% of the electricity with renewable energy carriers from 2025 on. There are numerous possible ways for reaching this goal. In the course of this study a computational energy model was implemented to evaluate future system configurations. The evaluation was based on six different analysis scenarios. Particular scenario components were defined with different available options, e.g. high or low potential of renewables and the scenarios were determined by the combination of the chosen component options. The model area was divided into 10 model regions with specific properties and the temporal horizon of the model mostly covered a time period until 2032. The results showed a favored fast expansion of geothermal and hydro generation technologies in NTT. For regions without these resources electricity generation by coal fired plants was preferred over oil fired plants. However, it is recommended to keep certain capacities of oil fired plants for peak demand. Additionally, carbon dioxide tracking was included and a comparison of the emissions among the scenarios showed a significant impact of decreasing investment prices for renewable technologies and the 25% policy.

Introduction

The access to electrical energy is a basic attribute of a modern living environment for human beings. In the Indonesian province Nusa Tenggara Timur (NTT) the electrification rate is currently less than 50% (PT PLN, 2011). It is intended to ensure more people and regions access to the electricity grid and increase this ratio extensively. The consumption of electrical energy per capita is expected to increase significantly: the annual electrical energy demand in NTT is estimated to raise by more than 200% until 2020 compared to 2013 (PT PLN, 2012). As Indonesia is situated in a volcanic area and geothermal energy is relatively easy to reach, NTT has a high potential of geothermal energy. According to (Federal Ministry of Economics and Technology, Germany, 2008) Indonesia is the country with the biggest geothermal potential in the world. Motivated by this potential, the Indonesian government plans to abandon the dependence on fossil fuels and has formulated a goal to supply 25% of the electricity until 2025 with renewable energy (Kementerian Energi dan Sumber Daya Mineral, 2015). Big efforts are being made to find the best way to reach this goal. There are numerous possible configurations of the future electrical supply system. Evaluating and optimizing these configurations are challenging tasks. Computational models are a helpful tool for supporting this optimization process. Therefore, a computational energy model was developed for evaluating efficient future system configurations and expansion plans.

In this paper the current energy system configuration and the future possible configuration are described first in the introduction. Subsequently the related work is presented. The concept of the NTT model is explained by introducing the applied energy model type. The scenario definitions which were used as basis of the analysis as well as the regional and temporal layout of the model are the major part of the model presentation. Additionally, the underlying model data are described. Finally the results are shown and analyzed and the conclusions are given.

For the NTT energy model the following four system components were identified as major model parts:

- Energy sources
- Generation of electrical energy
- Transmission of electrical energy
- Consumption of electrical energy

As major renewable energy sources for NTT wind, geothermal energy, solar radiation and hydro energy were detected. In addition, coal and

* Corresponding author at: Königsberger Str. 1a, 66849 Landstuhl, Germany. Tel.: +49 157 84269248.
E-mail address: fridolin.klug@web.de (F. Klug).

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oil were included as fossil energy carriers. The generation technologies for the production of electrical energy in NTT are determined from the available energy sources.

Until now, electricity in NTT was mainly generated by oil-based fuels, namely diesel (PT PLN, 2011). The use of diesel as generation technology originates from the flexible installation opportunities of diesel generators. They can be installed locally and in relatively small unit sizes. For the substitution of these generators several technologies are available and foreseen. Geothermal power stations represent the most important renewable generation technologies and are planned to take a central role for the future supply in NTT. Aside from this, the potential of run-of-river plants is not exploited by far and seems to be an economically valuable alternative. Wind and solar power complete the renewable portfolio and are intended to be introduced in NTT to fulfill the renewable goals. Hydro, wind and solar energy sources were also evaluated as applicable in NTT in (van der Veen, 2011). In regions without sufficient potential of any renewable energy, coal fired plants are foreseen to serve the demand and some of these are already under construction.

Table 1
Scenario components with available options.

Supply components	
Potential of renewable energies	High/medium/low
Learning effects in new technologies	Yes/no
Demand components	
Development electricity demand	High/medium/low
Policy components	
Renewable goal	Yes/no
CDM	Yes/no
Techno-economic component	
Fuel prices	High/medium/constant
Investment costs renewables	High/medium/low
Additional components	
Time horizon	2020/2032/2040
Calibration	2012/2020

State of the art and related work

Various different modeling approaches are used for energy models and their structure is dependent on the distinctive purpose of the particular model. Commonly, energy model approaches are divided into top-down and bottom-up models (Herbst et al., 2012). Top-down models describe the system in a holistic manner, set it in relation to other economy sectors and observe the interconnections between these sectors. In contrast, bottom-up approaches describe single technical units in detail. The connection of these units forms the energy system itself. These bottom-up models can be further divided into simulation and optimization models. With optimization models the adaption of the system on future boundary conditions is optimized. The optimization is done by calculating the extremum of a given objective function. In general this objective function describes the overall system costs. While optimization models chose the ideal development option, simulation models predict the effects of a given development option on the system (Möst and Fichtner, 2008).

One type of simulation models are agent based models, which are composed of small individual units, the agents. The agents are defined by technical, economic or environmental attributes. Agents follow their own defined rules, which do not necessarily contribute the main goal of the system. When modeling an energy system, all the participants, such as production units, electricity traders or consumers might be represented by agents. The interaction of all the different agents defines the behavior of the complete system. In Loulou and Labriet (2008) applications of multi-agent models for energy systems are observed. Due to the large variety of properties and their individual behavior, agent based models are able to represent complex systems. A disadvantage of agent based models might be that the approach can be extensive, as the agent behavior has to be described on a microeconomic level.

A model categorized as an optimization model is the TIMES (Kremers, 2013) model. It is implemented as a linear programming model, so the objective function is formulated with linear interdependencies, but a mixed integer programming module is integrated as well. The objective function in TIMES describes the total discounted costs of the system. Accordingly, the optimal solution is defined by its minimum. The model uses the so called perfect foresight approach, which means it optimizes the energy system over the entire modeled time span. TIMES has a flexible temporal structure. The modeled time span is divided into periods for which the model equilibria are generated and model output is delivered. Additionally, model years can be fractioned into time-slices, whose structure consists of up to three stages. These stages might be used to integrate seasonal, weekly (week-day/weekend) or daily (day/night) differentiations of technology or fuel parameters. The model is multi-regional and the number of regions is not limited, but consequently, the complexity of the linear programming increases with a higher number of regions. Regions may differ in the technologies used, the demand structure, available fuels or the natural energy resource potentials. The different regions are linked with each other and energy, materials or certificates can be traded among them.

Another optimization model is presented in Winkelmüller (2006). It has a high regional resolution for analyzing energy systems of urban extent. In Fleury et al. (2008) an optimization model of higher regional extent was developed. Special regard was taken on the emissions of exhaust gases. The BALMOREL optimization model (Ravn, 2001) was implemented for energy systems of multi-national extent, with particular consideration of the combined heat and power and the inter-regional interactions. It uses a myopic model approach, which means that decisions are based on time limited information. The model is optimized stepwise so it is contrary to the perfect foresight approach.

Methods and NTT model concept

Since a technology-oriented approach was favored for NTT, bottom-up optimization based models were chosen, since the NTT model should calculate cost efficient system configurations. For the implementation of the NTT model the TIMES energy model was selected due to its multi-regional, time variable character and its flexible application and adaption possibilities. The objective function of TIMES is defined as follows: *EQ_OBJ = Capital costs + Fixed costs + Variable costs + Commodity delivery costs + Import costs + Taxes + Surveillance costs − Revenues from exports − Subsidies − Recuperation of embedded material − Salvage value*

Scenarios

The evaluation of future system configurations with the NTT model is based on scenario definitions. These scenarios represent different future boundary conditions, such as economic or technological developments. In Schönfelder et al. (2011) the evaluation and development of scenarios with energy models are described. The specified scenario components with their available options for the NTT model are shown in Table 1. Eight analysis scenarios were applied and each of them is defined by the combination of the chosen component options. In Table 2 the scenarios along with their individually selected components are listed. For the supply and techno-economic components as well as for the fuel prices time dependent data structures were defined. The three options for the electricity demand for example were defined to increase by different gradients (see 'Model data'). The learning effect for new technologies is implemented by exogenously decreasing investment

Table 2
Each of the six analysis scenarios is defined as combination of the available component options.

	Reference scenario	BAU scenario	Renewable scenario	CDM scenario	Learning scenario	Renewables full
Potential renewables	Medium	Medium	Medium	Medium	Medium	Medium
Learning effects	No	No	No	No	Yes	Yes
Electricity demand	Medium	Medium	Medium	Medium	Medium	Medium
CDM	No	No	No	Yes	No	Yes
Renewable goal	No	No	Yes	No	No	Yes
Fuel price	Medium	Medium	Medium	Medium	Medium	Medium
Investment costs ren.	Medium	Medium	Medium	Medium	Medium	Medium
Time horizon	2032	2020	2032	2032	2032	2032
Calibration	2012	2020	2012	2012	2012	2012

prices for the respective technologies. Contrary to the time-dependent data structures, the Clean Development Mechanism[1] (CDM) was assumed to be a constant gratification paid for the reduction of CO_2 emissions. The reduction was referred to the emissions calculated with the business as usual (BAU) scenario, which calculates the behavior of the electricity system based on the actual expansion plan for NTT and moderate assumptions for price and demand developments.

The second implemented policy component is the renewable goal, which prescribes a minimal share of renewable energy in generated electricity. The renewable ratio was set to an ambitious value in relation to the ratio calculated in the BAU scenario and in respect of the governmental renewable goals.

The time horizon is the end of the time span which is observed with the model and the calibration year defines until which year the model is fed with input data for planned capacities. For the BAU scenario for example the time horizon as well as the calibration is 2020 as detailed expansion planning data is available until then.

The scenario which can be considered as the base scenario is the so called reference scenario. Similarly to the BAU scenario it is based upon moderate assumptions for demand and price developments. But the time horizon in the reference scenario is set to 2032 and the calibration to 2012. So this scenario represents the optimal system development based on the current system configuration and knowledge base.

Regions

For modeling purposes NTT was divided into ten regions (see Fig. 1). The regions were chosen according to the regional alignment and the technic-administrative division of NTT. The subdivision into regions allows assigning specific properties to different regions as well as observing the interdependencies between the regions. Crucial differences among the regions in the NTT model are the electricity demand and the potential of renewable energy resources. The trade of coal and oil based fuels was also integrated in the model. For regions with appropriate harbors direct import of these energy carriers by ship was modeled, whereas regions without such a harbor obtain them by bilateral trade with neighbor regions over land.

Temporal structure

As shown in Table 1 the time horizon of the different scenarios varies, but mostly the system behavior until 2032 was observed. To reduce the computational resources several years were merged to periods. This means that actions in the model can only be taken for a complete period, so actions affect all years in one period instead of single years. Fig. 2 shows the subdivision of the time horizon until 2032 with the representative naming of the model periods.

The model time is further divided on two different levels as shown in Fig. 3. Below the annual stage seasonal and daily time divisions were integrated. This distinction allows a differentiated mapping of system characteristics and model behaviors. On seasonal level two slices, the wet season and the dry season, of six months duration each were included accordingly to the climate in NTT. The seasonal subdivision is affecting water gauges and sun hours per day and thus the potential of these energy sources. On daily level four slices were implemented for modeling diurnal features. Contrary to the seasonal periods, the daily slices have different lengths. The diurnal division allows a further distinction of the availability of solar power and besides, a daily load pattern can be defined. Fig. 4 depicts the load pattern used for the NTT model with the four diurnal time slices. The fractions of the average demand are plotted over the day hours. A constant value is assigned to each of the time slices.

Reference energy system

The reference energy system is the sum of all processes and the links which connect the processes. In order to map the differing characteristics, each of the ten model regions has its own reference energy system. Processes receive a commodity as input, transform it and deliver another commodity as output. The ratio of incoming to outgoing commodities mostly defines the efficiency of the process. Fig. 5 shows an excerpt of the reference energy system for the NTT model. From the left to the right the production chain for electricity is shown. The first layer of this chain contains the energy sources which are either procured by import in case of fossil fuels or available to a limited extent in case of renewable energy sources. Electricity was implemented on three different levels, i.e. high voltage (HV), representing 70 kV level, low voltage (LV), representing 10–1 kV level, and demand level (DMD), representing 220 V level. According to the demand structure of NTT[2] the entire electrical energy in all regions is delivered on 220 V level. Power stations deliver electricity mostly on high or low voltage level depending on their unit size. Coal fired plants for example deliver electricity on high voltage level. In contrast, solar power units were modeled to deliver electricity on either low voltage or demand level in order to represent solar panels which are installed near housings.

The transformation process between high and low voltage level represents electrical substations and the distribution system describes all necessary facilities, e.g. transformers and electricity lines, to provide the consumers with electric energy on lowest level. Trade of electricity between neighboring regions is executed on high voltage level. The costs of these lines are defined for each pair of adjacent regions and depend on their alignment.

Fossil fired plants emit both CO_2 and electricity as output. With this feature the CO_2 tracking was implemented in the NTT energy model.

As shown in Fig. 5, for each type of generation technology different plant options were defined. Table 3 lists the available options for each generation category. Technology options of a certain category mainly differ in their size and the afflicted costs. But in case of oil-fired plants also the type of fuel varies, since high speed diesel (HSD) and marine fuel oil (MFO) were included. For new generation capacities lumpy

[1] The Clean Development Mechanism is a flexible mechanism defined in the Kyoto Protocol which allows emission reduction projects to earn certified emission reduction credits (Klepper and Peterson, 2006).

[2] According to PT PLN (2011) over 86% of the electricity in NTT is demanded on low voltage level.

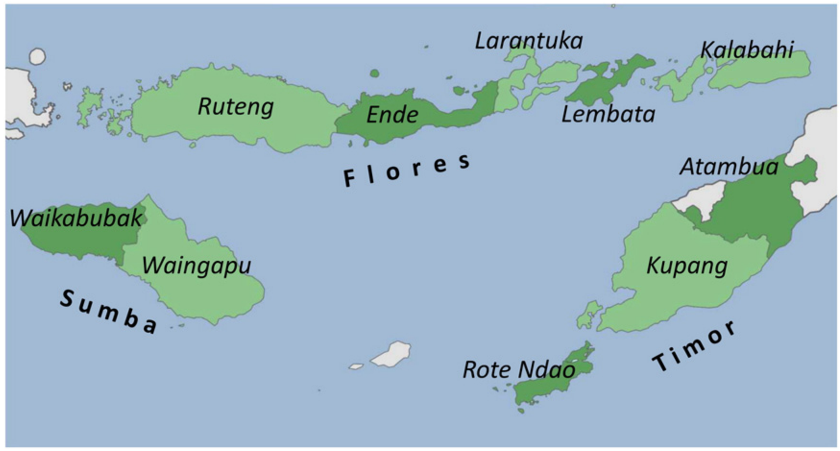

Fig. 1. Subdivision of NTT into the ten model regions allocated to either Sumba, Flores or Timor.

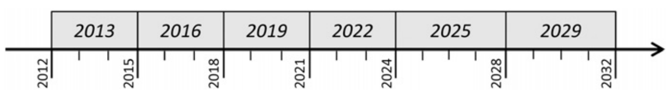

Fig. 2. Time periods of the NTT energy model, named after a central year in the particular period.

investment is generally applied, so new capacities can only be added in given block sizes. Only for the smallest available plant options of certain generation categories arbitrary capacity amounts can be added. The block size for the lumpy investment differs for each technology. For oil-fired plants, solar power units and wind turbines one option with continuous capacity sizes instead of discrete block sizes is available. These options are afflicted with the highest costs and represent the smallest units of the particular generation category.

Model data

The data which underlie the model are based on various sources in order to specify the properties of the generation and demand structure of NTT adequately. For the definition of the technical and economic parameters for generation technologies both global and local data sources were compared. Table 4 shows the parameters for geothermal power stations, the chosen values are based on PT PLN (2008), Alisjahbana et al. (2010), Kaplan (2008) among others.

For the fuel price development three scenario options were implemented (see Table 1). The constant values were set to the actual prices for coal and oil at the beginning of the modeled time span. The gradient of the increasing fuel prices was defined depending on the historical data. Scenario option “high” for oil-based fuel for example is linearly increasing with the average gradient of the oil price during the last 20 years. The values for the coal price options were set in an equivalent manner.

For the electricity demand of the model regions and model years three different growth options were defined. The medium growth option is based on the forecasted electricity demand for NTT given in PT PLN (2012). Since these data only cover the period until 2021, the demand in the model years after 2021 was derived by second order extrapolation. The medium demand data were the base for the definition of low (75% of medium demand) and high demand (135%).

The renewable energy potential was defined for every energy source and region. For the underlying data of the energy potential several sources for wind, solar energy, hydro energy and geothermal energy were evaluated. For the definition of the geothermal and hydro energy reserves proven data from field studies were used. The potential of wind and solar energy was defined based on the area of each region as well as on solar radiation values and data from the wind atlas respectively. Table 5 shows the potential for renewable energy of the model regions which underlie the model. The potential of geothermal energy sources was assumed to grow over time as more adequate locations are assumed to be discovered progressively.

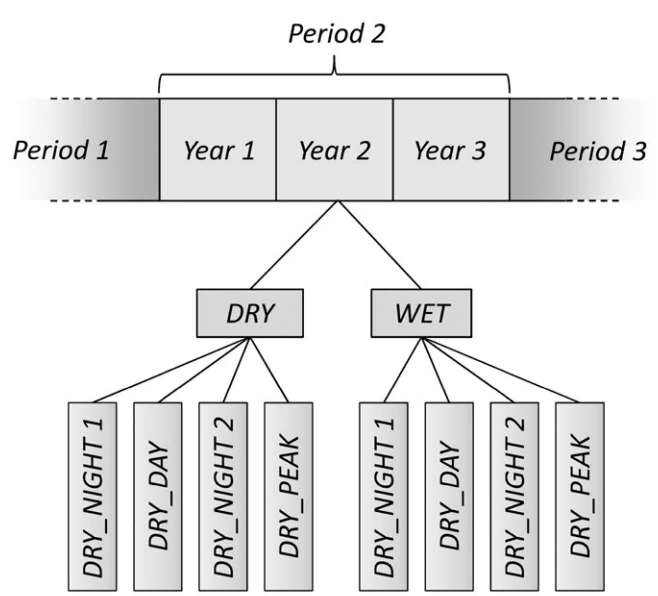

Fig. 3. Temporal model structure shown for the central year of the second model period.

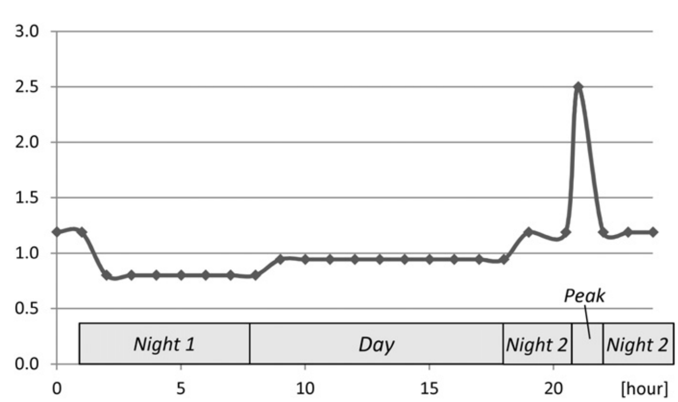

Fig. 4. Daily load pattern over the daily hours; Night 1, Day, Night 2 and Peak comprise 7, 10, 6.5 and 0.5 h respectively.

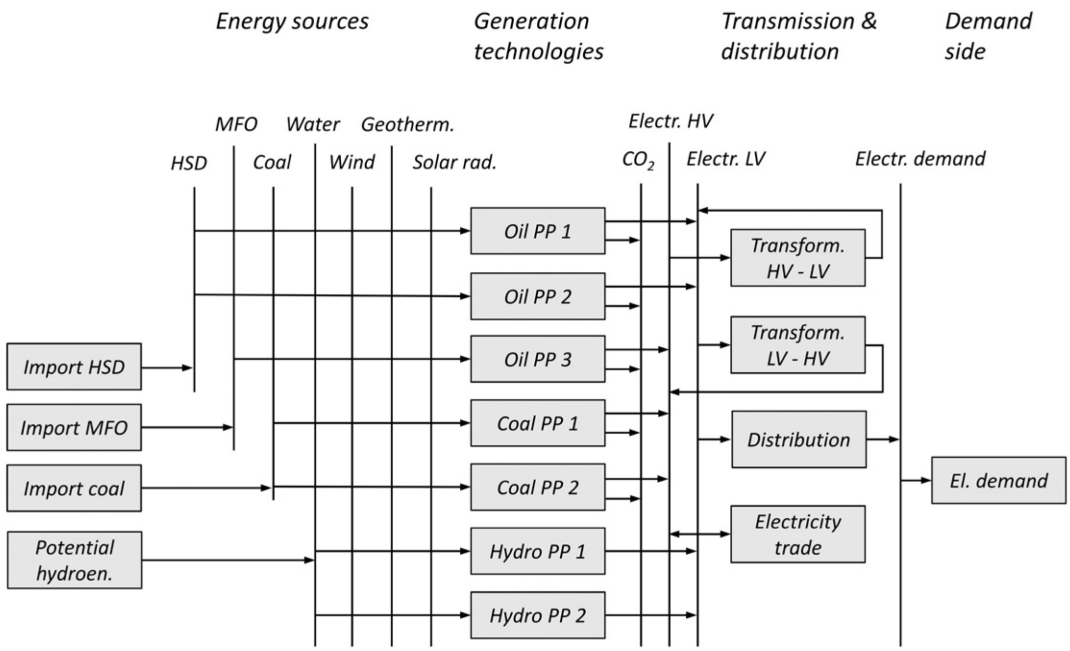

Fig. 5. Excerpt of the reference energy system showing the generation technologies for oil, coal and hydropower (geothermal, solar and wind technologies are omitted).

Beside the renewable energy potential itself, the usability of each renewable energy source is affected by the availability of these energy sources. The availability was defined on daily, seasonal or general level for each energy source as shown in Table 6. While the availability for solar energy differs on daily and seasonal level, the value for hydro energy is defined seasonally and the geothermal availability is constant. In contrast to solar and hydro energy, the availability of wind energy is randomly distributed.

For solar energy there are diurnal limits as well as a general limitation. At night no electricity can be produced from solar energy and in the wet season there are limitations due to less sunshine hours per day. The general limitation is based on the weather dependent uncertainty. This means that during day in the wet season the availability of solar energy for example is:

$$Availability = 0.9\,x\,0.9 = 0.81.$$

Results and discussion

For evaluating the different scenarios and their specific settings, the results of the scenarios were compared among each other and set in relation to the reference scenario. Subsequently, a theoretical comparison to the assumed results with other model approaches is presented and the validation of the model is explained.

Model results

The analyses of the model results can be done from various points of view. Fig. 6 shows the electrical energy produced by the different energy carriers for the reference energy scenario. The generated electricity is plotted for each of the model years explained in 'Temporal structure'. The dominating role taken by coal fired plants origins from the higher reliability compared to the renewable technologies such as wind or solar power and the lower fuel costs compared to oil fired plants. Especially in region Kupang electricity is mainly generated by coal as there and in its adjacent regions no significant resources of hydro and geothermal energy are available. In contrast to that, geothermal and hydro energy are prevailing for electricity generation in the northern and western regions of NTT with their high geothermal and hydro energy potentials. The preference of these renewable energy sources is caused by the good reliability and the low variable costs since fuel costs are avoided. After 2016 the electricity generated by hydro stations is not substantially increasing as the resources are nearly exploited. Wind energy is only utilized after 2025 due to the underlying increasing price of fossil fuels when the high coal price makes wind turbines more profitable.

Fig. 7 shows the same type of diagram for the renewable scenario with a stipulated share of renewable energy sources after 2025 (compare Table 2). Thus, the use of coal is decreasing in 2025 and a fundamental amount of energy is generated by wind turbines. Compared to the reference scenario there is a slight switch from geothermal energy to wind energy. For fulfilling the renewable energy restrictions a certain amount of wind turbine capacities is installed as the geothermal potential is not sufficient. Since the appearance of wind is modeled in a stochastic manner these capacities have to be higher than they would suffice for continuously available energy sources. As these capacities

Table 3
Block sizes of generation technologies, for oil-fired plants, wind turbines and solar power units the smallest technology options are available continuously instead of discretely.

Oil-fired plant	Coal-fired plant	Hydro power plant	Wind turbine	Geothermal power plant	Solar power unit
–	6 MW	0,5 MW	–	2 MW	–
1 MW	16 MW	1 MW	0.5 MW	5 MW	0.2 MW
6 MW		8 MW	2 MW		

Table 4
Technical and economic parameters for geothermal power stations.

		Geoth. 1	Geoth. 2
Electrical output	[kW]	2000	5000
Technical lifetime	[years]	30	30
Investment costs	[USD/kW]	2500	2200
Fixed costs	[USD/(kW, a)]	80	70
Variable costs	[cent/kWh]	1	0.9
Construction time	[years]	2	3
Annual availability		0.9	0.9
Fuel type	HSD/MFO/Coal	–	–
Plant output	HV/LV/DMD	LV	HV

Table 5
Potential of renewable energy sources.

Region	Hydro	Wind	Solar	Geothermal '12	Geothermal '31
Waikabubak	4.0	48.0	30.0	0.0	0.0
Waingapu	5.0	48.0	30.0	0.0	0.0
Kupang	4.0	48.0	30.0	0.0	0.0
Atambua	0.5	40.0	24.0	0.0	0.0
Ende	10.0	40.0	24.0	14.7	42.0
Ruteng	21.0	48.0	30.0	23.0	65.0
Kalabahi	0.1	32.0	18.0	16.0	45.0
Lembata	0.0	32.0	18.0	4.1	11.5
Larantuka	0.0	32.0	18.0	3.0	9.0
Rote Ndao	0.0	32.0	18.0	0.0	0.0
NTT	**44.6**	**400.0**	**240.0**	**59.9**	**172.5**

Table 6
Availability of renewable energy sources.

		Hydro	Wind	Solar	Geothermal
Availability	Night_1	–	–	0	–
	Day	–	–	1	–
	Night_2	–	–	0	–
	Peak	–	–	0	–
	Dry-season	0.6	–	1	–
	Wet-season	1	–	0.9	–
	General	1	0.5	0.9	1

produce more electricity in times of medium and high wind, geothermal plants would work temporarily limited and thus not commercially.

Even though the electrical energy generated by each source shows low values for oil fired power stations, Fig. 8 reveals their significance for the supply structure. This diagram shows the totally installed capacity for each available generation technology of the reference scenario over the modeling years. Oil fired generators have the highest share in the installed capacities followed by coal fired plants and then the renewables. These high capacities are used in peaking times for serving the demand, but the overall electricity generation is comparably low. This application results from the low investment costs of the oil fired generators but the relatively high fuel costs.

Further insights about the modeled energy system are gained when looking at the electricity price development. In Fig. 9 the price for delivered electrical energy in the reference scenario is plotted in relation to the price of base year 2013 for the three summarized model regions Flores, Sumba and Timor (compare to Fig. 1). The lower electricity price for Flores is based on the high potential and use of geothermal energy. Since the renewable potentials of Timor are low, the extensive use of fossil fuels causes higher prices. The overall NTT price grows over time due to the assumed price increase of fossil fuels.

The development of the CO_2 emissions varied for each scenario depending on the particular boundary conditions. Fig. 10 shows a diagram of the CO_2 emissions over the modeled years for the defined analysis scenarios. In the first half of the modeled time span it shows rather similar values for all scenarios except for the BAU case. The emissions in this scenario represent the expected values for NTT according to the current expansion plan. The first significant deviation among the other scenarios can be seen around year 2023, as these scenarios require a certain minimal share of renewable energy from 2025 on. In about 2026 the influence of the decreasing investment prices in the learning scenario results into a shift to renewables and its effect on the CO_2 emissions is evident. With this scenario the pivotal relation between investment prices for the different renewable energy technologies and the fuel prices can be detected clearly. The development of the emissions in the CDM scenario reveals a rather small impact of this mechanism based on the underlying model data for the emission saving gratifications.

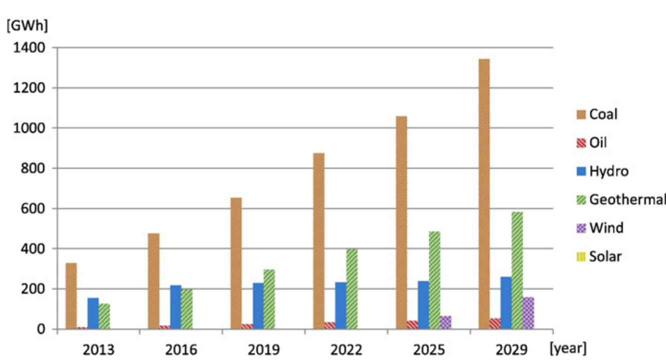

Fig. 6. Electricity generated per energy source and period—reference scenario.

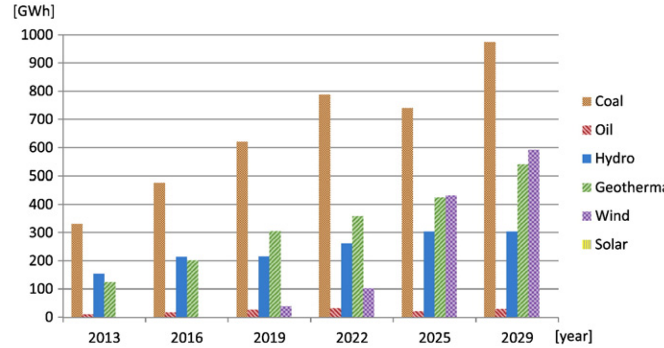

Fig. 7. Electricity generated per energy source and period—renewable scenario.

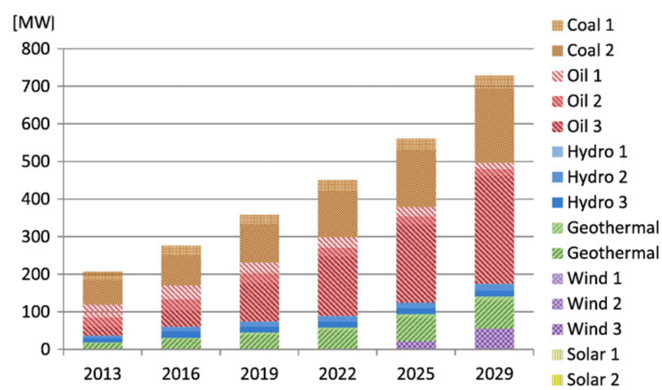

Fig. 8. Totally installed capacity per technology in each period—reference scenario.

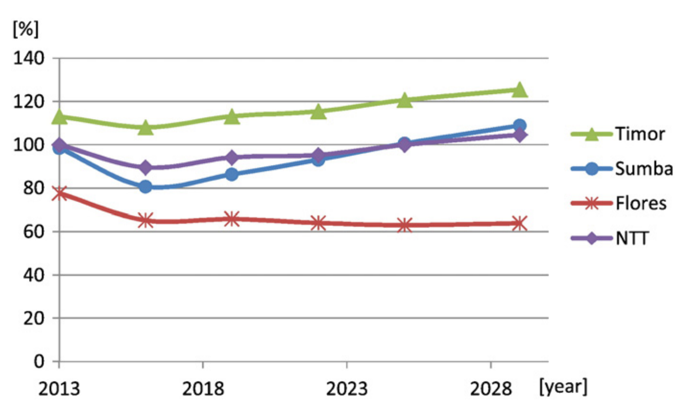

Fig. 9. Electricity price development per region in relation to the overall price in 2013–reference scenario.

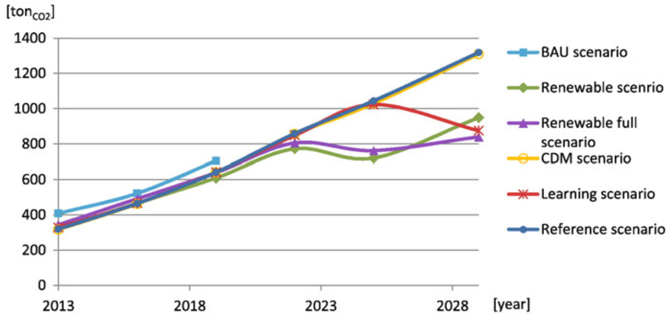

Fig. 10. CO_2 emissions for the defined scenario cases with a significant impact of the renewable goal from 2025 on.

Discussion and validation

In contrast to the implemented NTT model with a simulation model the participants of the energy system could be mapped in a more independent manner. With such a model approach the behavior of independent power producers on the electricity market in NTT could for example be observed. However, for NTT it was intended to find cost optimized configurations of the energy system and thus simulation models were not considered as appropriate.

The results of the NTT model would differ if a myopic modeling approach, as described in 'State of the art and related work', had been used. Rising fuel prices and reducing technology costs would not have been taken into account for model decisions. Compared to the results presented in Fig. 8 a myopic approach would probably result in a shift to more coal fired plants as the decision to build such plants in early model years would not consider the rising production costs for later years. However, the idea of the NTT model was to implement a tool to evaluate an efficient energy system for the entire observed time horizon, so a perfect-foresight model was chosen.

The validation of the NTT model was performed with two different approaches. On the one hand a qualitative validation approach, the extreme value validation, and on the other hand a quantitative evaluation, the back-testing, were applied. With the extreme value validation the plausibility of the model's response on rather extreme boundary conditions is observed and evaluated. Therefore two validation scenarios were defined with combinations of e.g. rather extreme assumption for price developments of fuel or investment costs for renewables. The results of the validation scenarios showed a reasonable response of the model on these extreme boundaries.

For back-testing the NTT model was calibrated with the existing system capacities, e.g. transmission or generation capacities, of the past years. The model covered the period from 2009 until 2011. The electricity price which was calculated by the model for this period (approx. 22 cent/kWh) showed a minor deviation to the actual electricity price in these times (between 23 and 25 cent/kWh). It can be stated that both validation approaches confirmed the reliability of the model and its realistic behavior.

Conclusions

The results for the reference scenario show a favorable fast expansion of geothermal and hydro power capacities. Economic reasonable application of wind turbines and especially solar panels is only reached with a significant increase of fossil fuel prices or decrease of wind turbine and solar panel costs. The generation by coal is preferable in regions with low renewable capacities and oil-fired generators should not be used for serving base or medium load, but might be useful during peak load.

In future applications the generation, transmission and distribution technologies can be extended or additional technologies can be integrated, such as facilities for storage processes or solar thermal power units. The regional or temporal resolution might be increased for more detailed mappings of the demand structure, the natural energy resource availability or technological properties, if data on the particular level of detail is available. Additionally, other sectors, such as traffic, can be included in the model. The demand might be modeled for different voltage levels or even energy services, such as air-conditioning.

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