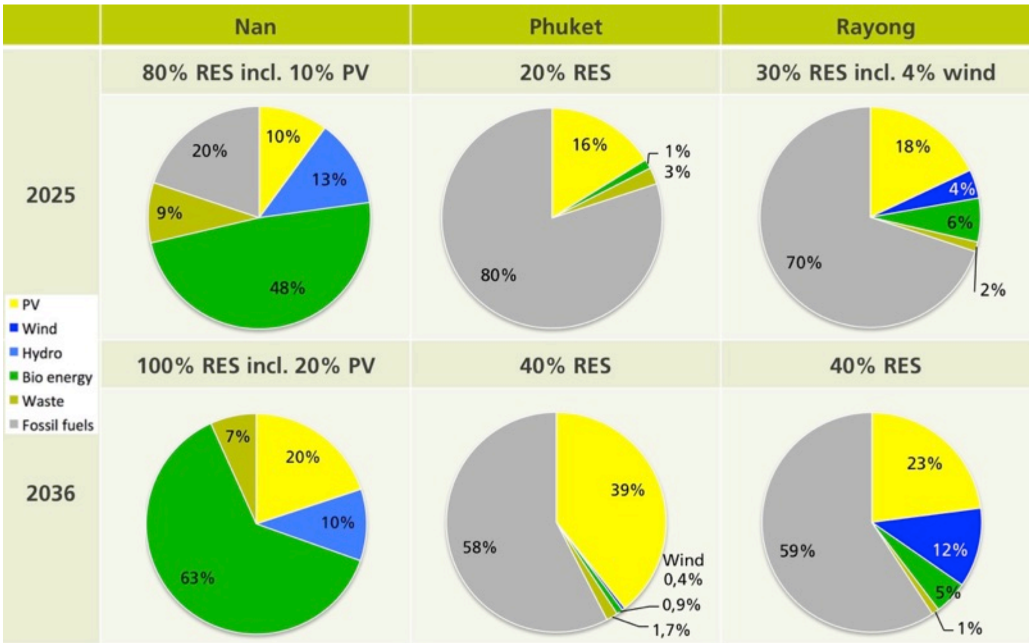
FRAUNHOFER-INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

RENEWABLE ENERGY SCENARIOS FOR THE THAI PROVINCES PHUKET, RAYONG, AND NAN

FINAL REPORT OF THE PROJECT »RES4THAI«



Distribution of electricity generation by source for recommended scenarios

FINAL REPORT
OF THE PROJECT RES4THAI

This study has been conducted by the Fraunhofer Institute for Solar Energy Systems (ISE), Germany, and was commissioned by the Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH which is implementing the project "Support to the Development and Implementation of the Thai Climate Change Policy (CCA)" commissioned by the German Ministry for the Environment, Nature protection, Building and Nuclear Safety (BMUB). The study was supported by the Joint Graduate School of Energy and Environment (JGSEE) as a local consultant. The input data was carefully selected in close cooperation with the Thai Ministry of Energy and experts from the target provinces Nan, Phuket, and Rayong.

Authors: Gerhard Stryi-Hipp, Annette Steingrube, Sattaya Narmsara

Freiburg, Germany, 3 December 2015

Fraunhofer Institute for Solar Energy Systems ISE, Freiburg

With a staff of about 1300, the Fraunhofer Institute for Solar Energy Systems ISE, located in Freiburg, is the largest solar energy research institute in Europe. Fraunhofer ISE is committed to promoting sustainable, economic, safe and socially just energy supply systems based on renewable energies. Focusing on energy efficiency, energy conversion, energy distribution and energy storage, the institute provides the technological foundations for supplying energy efficiently and on an environmentally sound basis in industrialized, threshold and developing countries throughout the world. Therefore the institute develops materials, components, systems and processes in twelve business areas. In addition, the Fraunhofer ISE disposes of several accredited testing centers as well as further service facilities. The institute is a member of the Fraunhofer-Gesellschaft, the leading organization for applied research in Europe.

The Fraunhofer ISE supports cities and regions in the development and implementation of forward-looking energy systems by providing innovative technologies and system solutions. As part of a comprehensive Smart City and Region strategy, the institute is specialized in deriving sustainable system concepts. The institute calculates scenarios for secure and cost-effective urban and regional energy systems based on high share of renewable energies with self-developed computer tools and develops implementation roadmaps to achieve the transformation of the energy systems efficiently and successfully. Further, the Smart City experts accompany lighthouse projects in cities and monitor the progress of the transformation process. Fraunhofer ISE is a strong and competent partner for energy transformation projects on the municipal and regional level and conduct Smart City and Smart Region projects in Germany and abroad, e.g. in Thailand and China.

Table of contents

Abbreviations

€	Euro
AEDP	Alternative Energy Development Plan
฿	Baht
BAU	Business as usual
CCA	Support to the Development and Implementation of the Thai Climate Change Policy (project implemented by GIZ)
EE	Energy efficiency
EE+	Energy efficiency plus
EGAT	Electricity Generation Authority of Thailand
GDP	Gross Domestic Product
IPP	Independent Power Procuder
LCOE	Levelized cost of energy
MEA	Metropolitan Electricity Authority
PDP 2015	Power Development Plan 2015
PEA	Provincial Power Authority
PV	Photovoltaic
RES	Renewable Energy Sources
SPP	Small Power Producers

Remark

The calculations provided in the report are made für different target years. It is taken into consideration, that the value of currencies will change over time, however, to make the currency values easily comparable, all values are given in today's values ($฿_{2015}$, $€_{2015}$). To ease the reading, the year of value of the currency is not shown in the report, but all currency values given are today's values.

1
Motivation and aim of the study

Today, Thailand’s energy system depends largely on fossil fuels. In 2013, a total of 177,398 GWh of electricity was generated in the country and imported. 87.9% was generated by fossil fuels, 3.1% by hydro power and 1.9% by other sources, which are mainly renewable energy sources (RES), including municipal waste incineration. Therefore 5.0% was generated from RES within the country. In addition, 7.1% of electricity was imported, which is mainly generated by hydro power [EPPO 2014, p. 110]. The main data of electricity generation and consumption in Thailand for the year 2013 are shown in Fig. 2. In 2014, the share of RES on electricity generation and import was increased to 8%, reducing the share of natural gas to 64% [Pichalai 2015].

At the same time the RES potential of Thailand is abundant. This is especially true in the case of solar energy and bioenergy. In Thailand’s “Power Development Plan 2015” (PDP 2015) the goals for the electricity system are set out for the year 2036. Within the PDP 2015 it is stated that 15% - 20% of Thailand’s electricity demand shall be generated by RES, depending on the scenario chosen (Business as usual (BAU), or energy efficiency (EE)) [Pichalai 2015]. The electricity generation development according to the EE scenario of PDP 2015 is shown in Fig. 1.

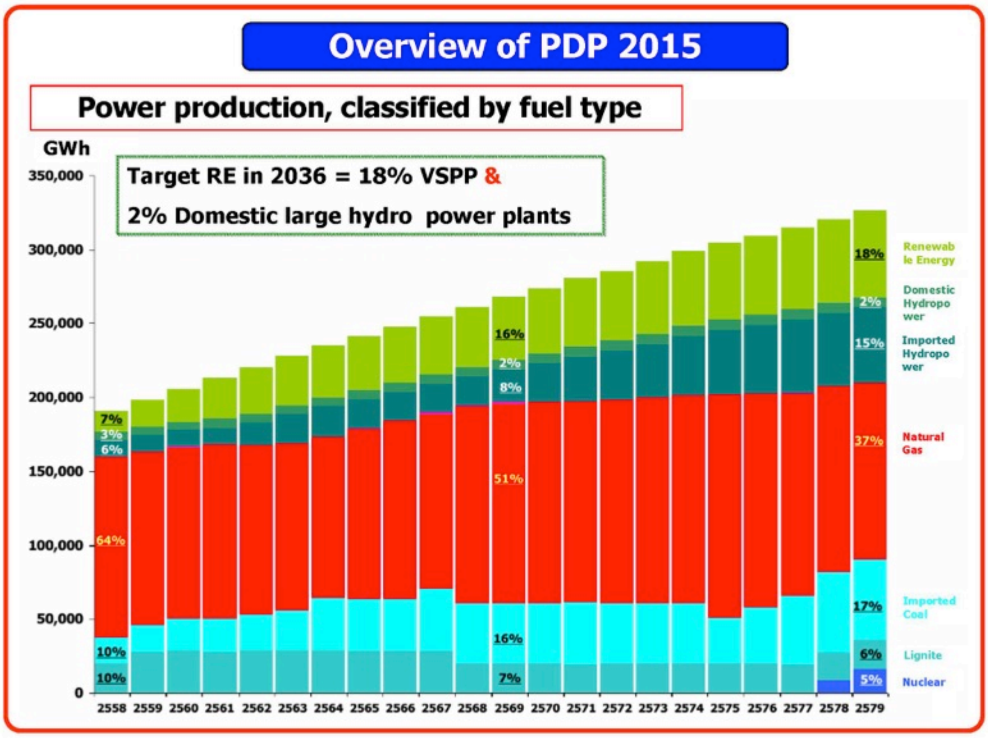


Fig. 1: Electricity generation development from 2015 to 2036 according the energy efficiency scenario of PDP 2015 [Sathienyanon 2015]

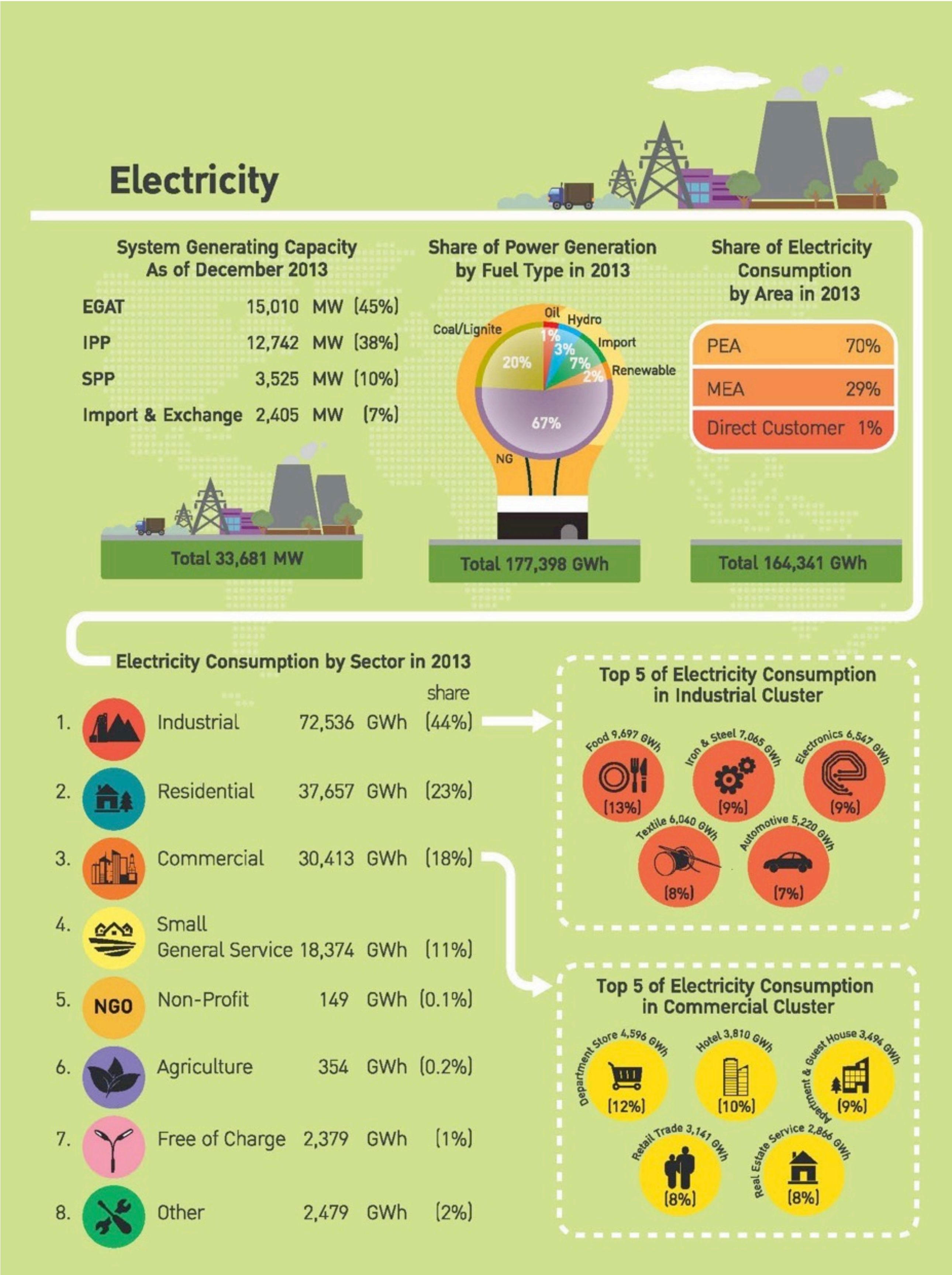


Fig. 2: Electricity generation and consumption of Thailand 2013 [EPPO 2014]

Thailand is already a leading player in the field of RES in South-East Asia and aims to become more independent from gas and coal by further increasing its share of RES in the coming years. Against that background it is necessary to evaluate, how the targets set by the PDP 2015 can be achieved.

Due to the expected increase of the electricity demand in Thailand the amount of fossil fuels and the related CO_2-emissions are bound to significantly increase until 2036 according to the PDP scenarios, even if the share of RES increases and the energy efficiency scenario is considered (see Fig. 1). Since the dependency on fossil fuels and the related costs could become a challenge and the global trend of decarbonisation due to climate change could increase the pressure to reduce CO_2-emissions, it is advisable to evaluate, if the share of RES can be increased faster and to a higher level as set by the PDP 2015.

This study provides input to this discussion by evaluating the potential use of RES on a provincial level. The aim of the study is to evaluate, to which extend locally available RES can contribute to meet local electricity demand. For three Thai provinces, Rayong, Phuket, and Nan, it is calculated what share of the electricity demand could be provided by RES locally from the province's resources. Furthermore, the most cost effective electricity mix is evaluated.

Due to the available RES, solar energy as well as partly wind energy and bioenergy must play an important role within a sustainable energy system in Thailand. Therefore, it is necessary to evaluate how the integration of the variable energy sources into the electricity system can be achieved without reducing the security of electricity supply. The dynamic effects of variable electricity generation will have an increasing influence on the energy system with the growing share of these sources. This means that it is not sufficient to calculate the annual energy yield of the different RES to identify their role in the energy system. **To take the dynamics of RES into consideration, it is necessary to do temporal highly resolved modelling to provide a more accurate outlook for the energy system** including wind and PV as compared to other forecasting tools.

Based on the use of the energy model "KomMod", which was developed by Fraunhofer ISE and allows for such temporal highly resolved modelling, this study is able to answer the following questions:

- Is it possible, to achieve a RES share of 20%, 40%, 60%, 80% and 100% provided locally in the province? If yes, what would be the most cost effective energy mix for each scenario?
- Which capacity of each RES is needed for the different scenarios, how much electricity is delivered by each RES and what are the costs of these energy systems?

- Which electrical storage capacity is needed to assure a secure electricity supply for each hour of the year for the different scenarios?
- How much electricity import into the province is needed and how much electricity is exported for each scenario?

In each scenario the electricity demand of the province and the costs of energy technologies as well as the fuels are used as input parameters. These parameters are changing over time, therefore the target year must be clearly defined and the electricity demand as well as the costs must be forecasted for the target year set. As a result, for each target year different values are used.

In this study, all calculations are done for two target years, the year 2036, which is the final year of the PDP 2015 and thus considered a long-term target year, and the year 2025, which is considered a short-term target year.

The modelling tool follows a consequent cost oriented approach: it always identifies the least cost option to achieve a specific goal, e.g. 40% RES. For each province, this study therefore provides **cost-optimal scenarios** which are suggested by the model, solely based on least cost optimization. In some cases, especially when only low shares of RES are aimed for, only one specific RES is considered by the model (see for example the case of Nan). However, it can be expected, that in reality other RES will be used, too, since investors decide on their technology choices not only according to the costs, but also to other preferences, especially if the price differences are small. Therefore, this study provides in addition to the least-cost scenarios one **recommended scenario** for each province which is considered realistic, since it takes into account also additional benefits of the use of specific RES, like rooftop PV systems, which generate electricity on-site what can be regarded as additional advantage for building owners.

This study has been commissioned by the Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH which is implementing the project "Support to the Development and Implementation of the Thai Climate Change Policy (CCA)" commissioned by the German Ministry for the Environment, Nature protection, Building and Nuclear Safety (BMUB). The Fraunhofer Institute for Solare Energy Systems (ISE) served as international consultant in the development of the scenarios supported by the Joint Graduate School of Energy and Environment (JGSEE) as a local consultant. The input data was carefully selected in close cooperation with the Thai Ministry of Energy and experts of the target provinces Nan, Rayong and Phuket.

2
Methodology and scenarios

2.1
The Energy Model KomMod

The optimization calculations are conducted with the energy systems optimization model KomMod[1], a computer tool developed by Fraunhofer ISE. The model is a **techno-economical bottom up model** which identifies the most cost effective technical solution for the given boundary conditions. KomMod is capable to consider the energy demand for electricity, heating, cooling and local transport. Since in Thailand electricity is the main energy carrier, heating demand is rather low and cooling is already included in electricity demand, this study covers the electricity sector only and optimizes the electricity systems of the three Thai provinces Nan, Rayong and Phuket.

KomMod is developed to calculate energy systems for cities, communities and regions. It uses the advantage, that in such localized cases it is not necessary to consider the capacity of the electrical grid, especially the transmission grid. KomMod is able to optimize the structure of an energy system, especially when dynamic components play an important role, e.g. when high shares of variable RES and electrical batteries are used. The cost-optimal configuration of all generators, converters, and batteries is identified under the condition that the electricity demand can be securely covered for each hour of the year with this structure of the electricity system. This is what is meant by the term **temporal high resolution** and it is what makes the approach of the study different from existing simulations in Thailand. Simultaneously to the structure also the operation strategy of power plants and batteries is optimized. The expected demand of electricity in the target year is used as input data in the form of an hourly time serie.

The calculations are made for arbitrary years in the future, in this study the **target years 2025 and 2036** have been selected and the different scenarios are calculated for both target years. For both years electricity demand profiles are forecasted based on several assumptions and calculations for the three provinces. In addition, the costs of the power plants and the fuels are forecasted for the target years based on available studies and used as input data for modelling.

[1] KomMod stands for „Kommunales Energiesystemmodell“ which means Urban Energy System Model

Obviously, the results of the calculations depend on the assumptions made and the input data chosen, such as the RES potential, costs, efficiencies (of the energy technologies and fuels) as well as the demand profiles of the target years. **The assumptions were carefully made and take into account official studies and targets. To provide maximum transparency all assumptions used in this study are provided in detail in the Annex**. **Subsequently, it should be noted that KomMod results are not projections of the future but the optimal system configuration according to the input data and assumptions used**.

The **calculations are specifically made for each of the three provinces**. This means, that only the RES potential and the electricity demand of the province, for which the calculation is made, is taken into account. It is assumed, that the electricity demand, which is not provided by local RES, is covered by fossil fuels. Since the fossil power plants are centralized and connected with transmission lines to the provinces, the model is not considering the place, where the fossil power plants are installed, within the province or outside the province. Furthermore it is also not considered that a share of the electricity imported into the province, is generated by renewable energy (e.g. by hydro power). As a result, in this study **all electricity, which is not generated by RES locally within the province is regarded as generated by fossil fuels** without making a destinction whether the electricity is generated by fossil fuels in the province or is imported.

Energy systems are becoming increasingly complex by increasing the types of energy sources, integrating variable energy sources and batteries, and due to new smart technologies. Therefore, the use of modelling tools like KomMod is recommended, to understand the possible options to develop an energy system and to identify a technically feasible and the most cost-effective solution. However, it must be noted that if framework conditions change, e.g. electricity demand is growing faster or energy imports are more costly than expected, the calculations should be adapted. However, with a growing share of local RES, the dependency on such exogenous factors and therefore the dependency from international energy prices and energy source availabilities decreases.

Identifying a sound and optimized energy system for a target year is a necessary first step and delivered within this study for Nan, Phuket, and Rayong. As a second step a roadmap for implementation must be developed on how this energy system can be achieved – which is not part of this study.

2.2
Calculated Scenarios

Two sets of scenarios are calculated in this study for two different target years for each of the provinces. Since the share of RES which can be achieved within 10 years is limited, the scenarios for **2025** are calculated only for a **limited share of RES**, while the scenarios for the target year **2036** are calculated **up to a maximum share of RES**, which can be reached.

The scenarios have been chosen for the provinces of **Phuket, Rayong and Nan**. Phuket has been chosen as a priority by the Ministry of Energy, while the CCA project has been working with the provinces Nan and Rayong since many years. The selection of provinces aims to provide a valid sample: Phuket is a major tourist destination with high visitor numbers which consume a lot of energy in a locally confined space (the island of Phuket). Nan serves as a more rural example in the North of Thailand with less demand and a solid bioenergy potential, while Rayong is the powerhouse of Thailand, with many existing power plants and high industrial demand for electricity.

For each province and each target year a scenario is calculated with today's RES share and the electricity demand and energy costs of the target year. This provides a reference with which the results of the scenarios with increased shares of RES can be compared and is thus called **Reference (Ref) scenario**.

For each province and each target year different scenarios with different RES shares are then being calculated to provide an overview of what is possible and what the economic implications of the different scenarios are. The scenarios are being evaluated up to the technical maximum share, usually starting at 20% and moving up to 100% where possible.

In addition to these different RES share scenarios, where the RES share is provided as an input value, a **cost optimium scenario** is calculated, where the RES share, which leads to the lowest electricity costs of the entire electricity system, is a result of the calculation. The cost optimum secenario purely looks at cost for the assessment in the specific target year. However, higher shares of RES are recommended due to the reasons described in the introduction so in addition to the cost optimum scenario one **recommended scenario** for each province taking into account additional benefits of RES are being provided.

The already existing RES power plants as well as the power plants, which are known to be built in the near future have been considered in the scenarios, as far as this information was available.

A crucial variable in determining the scenarios is the electricity demand forecast for the target year. In order to reflect on potential demand variations it was decided to distinguish three different **demand forecasts**. The "**business as usual electricity demand" (BAU) forecast** is using the demand forecast of the BAU scenario of the PDP 2015. In the BAU forecast it is expected, that the electricity demand will increase by 41% until 2025 and by 99% until 2036 in comparison to 2015 in Thailand. Since the main sectors of electricity demand in the three provinces are different, the main influencing factors Gross Domestic Product (GDP), number of tourists, and growth of population have different influence on the electricity demand in the provinces. In this study it is assumed, that the residential electricity demand will grow proportional to population growth multiplied with the GDP growth rate, the service electricity demand will grow proportional to the tourism growth rate and the industry electricity demand will grow propotional to the GDP growth rate. Since the electricity demands in the provinces are known related to these sectors, the entire electricity demand for the target year was calculated based on these assumptions. As a result, in Nan the electricity demand will grow by 39% and 95%, in Phuket by 40% and 94%, and in Rayong by 57% and 142% until 2025 and 2036 respectively. No special energy efficiency measures are taken into account, therefore the BAU electricity demand forecast expresses the highest electricity demand perceivable – however, given the Government priorities targets on energy efficiency increases it doesn't describe a very likely development.

More realistically in terms of energy consumption is the **"energy efficiency demand" (EE) forecast**, which is using the forecast of the electricity demand of the efficiency scenario of PDP 2015. The EE forecast expects electricity demand to increase by 35% until 2025 and 65% until 2036 (see Fig. 3) for Thailand. According the methodology described before, the electricity demand will grow in the EE forecasts in Nan by 33% and 62%, in Phuket by 35% and 61%, and in Rayong by 51% and 101% until 2025 and 2036 respectively.

For comparative reasons, and since Germany is aiming to cut the electricity demand of the country by half by 2050, a more ambitious electricity demand forecast for Thailand is offered. Due to the expected growth of population and GDP of Thailand, a reduction of electricity demand in comparison to today's demand seems not realistic, however, to stabilize the electricity demand on today's level could be regarded as ambitious goal. Therefore, a third forecast named **"energy efficiency plus demand" (EE+) forecast** ist used. Within the EE+ forecast, the electricity demand will remain at today's level and not increase further, this means that the growth in demand will be fully compensated by efficiency measures in generation, distribution and consumption of electricity.

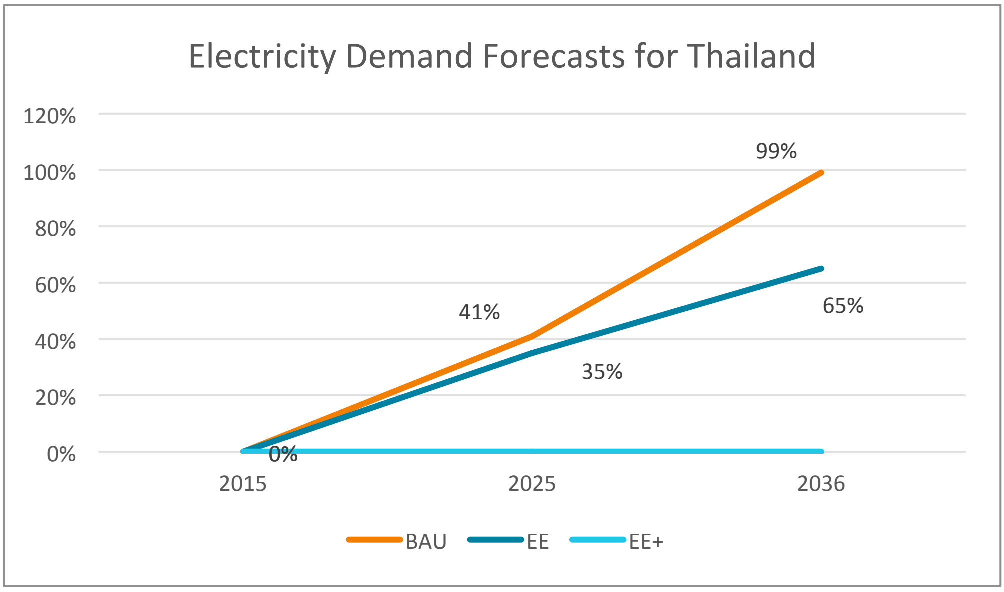


Fig. 3: Electricity demand forecasts for Thailand according PDP 2015 (BAU and EE), and based on this study (EE+)

Table 1 gives an overview, which parameters are varied in the different scenarios.

Table 1: Overview of scenario variations

Province	Year	Demand forecasts	Scenarios
Nan Phuket Rayong	2025 2036	BAU EE EE+	Ref 20% RES 40% RES 60% RES 80% RES 90% RES cost optimum recommended

3
Modelling results

In the following chapters the modelling results are shown for the different scenarios for Nan (chapter 3.1), Phuket (chapter 3.2) and Rayong (chapter 3.3). The recommended scenarios are calculated based on the EE forecasts since the BAU forecasts don't seem to be a realistic option.

All costs are shown in Baht and Euro, while an exchange rate of 1 Euro to 37.3 Baht is used (as of July 2015).

3.1 Nan scenarios

Nan is characterized by low density in terms of population and industry, resulting in relatively low electricity demand in the province. Nan benefits from huge bioenergy potential. As fuel costs for bioenergy are relatively low in Thailand (see 5.3.1) and bioenergy is storable, it will be the main RES in Nan. A high PV potential exists in Nan as well, but since the LCOE for PV is higher, the model prefers bioenergy, as the least cost option chosen. According the available data, the wind speed is low in Nan, therefore the wind LCOE are high and wind is not chosen by the model (see 5.2.1).

3.1.1 Nan scenarios 2025

In Nan, a hydro power plant of 5.5 MW capacity is currently under construction. It is expected that it will produce 48 GWh electricity per year, which is about 12.7% of the expected electricity demand under the EE forecast for 2025. According available data no further hydro power potential exists. Since the LCOE of bioenergy and waste is lower than the LCOE of PV and wind, only bioenergy and waste is chosen as RES by the model in addition to the existing hydro power plant. In the 2025 EE cost optimum scenario, 77% RES is used, which is very high and shows, that also from an economic point of view a fast increase of RES is recommended.

It is most likely, that not only bioenergy plants will be built but also PV systems will be set up by investors in Nan province due to the advantage of decentralized generation and the comparable costs of PV to bioenergy. Given the dynamic development of PV in Thailand, the policy priorities of the government and the additional benefits of using PV like the decentralized generation on buildings, the supply to remote areas, and no direct CO_2 emissions, the installation of PV is very realistic in Nan as well. Therefore the recommended scenario for 2025 is a 80% RES scenario including 10% PV.

Table 2 shows the electricity generated in the different scenarios by the different energy sources and the total electricity demand in 2025 according to BAU, EE, and EE+ demand forecasts. Wind is not chosen in any of the scenarios and PV only plays a role in the recommended scenario.

Table 2: NAN scenarios 2025 BAU, EE, and EE+, electricity generated by fuels

Electricity in GWh	**PV**	**Wind**	**Hydro**	**Bio energy**	**Waste**	**Fossil fuels**	**Total pro-duced**
BAU electricity demand forecast							
Ref	0	0	48	0	0	345	393
20% RES	0	0	48	8	23	314	393
40% RES	0	0	48	75	35	236	393
60% RES	0	0	48	153	35	157	393
77% RES cost optimum	0	0	48	220	35	90	393
100% RES	0	0	48	314	30	0	393
EE electricity demand forecast							
Ref	0	0	48	0	0	329	377
20% RES	0	0	48	8	19	301	377
40% RES	0	0	48	70	33	226	377
60% RES	0	0	48	145	33	151	377
77% RES cost optimum	0	0	48	209	33	87	377
80% RES incl. 10% PV recommended	**38**	**0**	**48**	**183**	**33**	**75**	**377**
100% RES	0	0	48	300	29	0	377
EE+ electricity demand forecast							
Ref	0	0	48	0	0	234	282
20% RES	0	0	48	8	1	226	282
40% RES	0	0	48	38	26	169	282
60% RES	0	0	48	95	26	113	282
75% RES cost optimum	0	0	48	138	26	69	282
100% RES	0	0	48	211	23	0	282

In the recommended scenario the LCOE of PV is already lower than the LCOE of fossil fuels, which underlines the assumption that a minimum share of 10%

PV of the electricity demand will be generated by PV. Detailed data of the recommended scenario for 2025 are shown in Table 3.

Table 3: Nan recommended scenario EE 2025: 80% RES incl. 10% PV, data overview

	Unit	**PV**	**Hydro**	**Bio energy**	**Waste**	**Fossil fuels**
Installed capacity	MW	31	5.5	22.8	4.2	49.8
Electr. generated	GWh	38	48	183	33	75
Share on electr.		10%	12.7%	48%	8.7%	20%
LCOE	Baht/kWh	2.9	1.0	1.7	1.6	4.2
LCOE	€ct/kWh	7.9	2.6	4.6	4.2	11.2
PV modules area	km²	0.16				
Full load hours	h/a	1,206	8,760	8,000	8,000	
Used potential		1.3%	100%	27.5%	35%	
	Battery capacity installed: 0 MWh					

3.1.2 Nan scenarios 2036

In 2036, the electricity demand is expected to be higher and the LCOE for RES is expected to be lower than in 2025. Bioenergy will still be the cheapest technology and the main energy source. PV and Wind energy would not be used if the least cost scenario is chosen in 2036. 100 % RES can be reached under BAU, EE and EE+ forecasts without PV and wind. But as in 2025 it is recommended to aim for a mix of RES, in this case 100% RES including 20% PV is recommended. It can be assumed, that this energy system is more likely and more robust since the RES are more distributed.

To reach a 100% RES energy system in 2036, for all demand forecasts the installation of batteries is necessary. This reflects on the one hand the higher attractiveness of batteries due to lower costs in 2036 and on the other hand that bioenergy power plants must have a minimum number of full load hours to be achieved to run them efficiently. Both reasons lead to the installation of batteries. The cost optimal energy system comes with 86% RES both under BAU and EE and 84% under EE+ electricity demand forecast. Table 4 shows the electricity generated under the different demand forecasts in the different RES scenarios.

Table 4: NAN scenarios 2036 BAU, EE, and EE+, electricity generated by fuels

Electricity in GWh	PV	Wind	Hydro	Bio energy	Waste	Fossil fuels	Batte-ries (MWh)	Total pro-duced
BAU electricity demand forecast								
Ref	0	0	48	0	0	504	0	552
20% RES	0	0	48	14	49	441	0	552
40% RES	0	0	48	124	49	331	0	552
60% RES	0	0	48	234	49	221	0	552
86% RES cost optimum	0	0	48	379	47	77	53	552
100% RES	0	0	48	463	41	0	166	552
EE electricity demand forecast								
Ref	0	0	48	0	0	409	0	457
20% RES	0	0	48	8	36	366	0	457
40% RES	0	0	48	95	40	274	0	457
60% RES	0	0	48	186	40	183	0	457
86% RES cost optimum	0	0	48	305	39	65	44	457
100% RES	0	0	48	375	34	0	138	457
100% RES incl. 20% PV recommended	**91**	**0**	**48**	**287**	**31**	**0**	**160**	**457**
EE+ electricity demand forecast								
Ref	0	0	48	0	0	235	0	283
20% RES	0	0	48	8	1	226	0	283
40% RES	0	0	48	39	26	170	0	283
60% RES	0	0	48	95	26	113	0	283
84% RES cost optimum	0	0	48	165	26	45	28	283
100% RES	0	0	48	212	23	0	88	283
100% RES incl. 20% PV	57	0	48	158	20	0	103	283

Table 5 shows the detailed data of the recommended scenario for EE forecast in 2036 with 100% RES including 20% PV electricity. Since PV will have only marginal higher LCOE (2.6 Baht/kWh) than bioenergy (2.5 Baht/kWh), it is very likely that also PV will be built. The reasons are the interest of home owners to become more independent by generating electricity with PV rooftop systems on their homes and the aim to have a more diversified and robust scenario. For the EE+ demand forecast a similar table can be found in the Annex.

Table 5: NAN recommended scenario 2036 EE:
100% RES incl. 20% PV, data overview

	Unit	PV	Hydro	Bio energy	Waste
Installed capacity	MW	75.8	5.5	55.3	3.8
Electr. generated	GWh	91	48.0	287	31
Share on electr.		20%	10.5%	63%	6.8%
LCOE	Baht/kWh	2.6	1.1	2.5	1.7
LCOE	€ct/kWh	6.4	2.7	6.2	4.3
PV modules area	km²	0.38			
Full load hours	h/a	1,206	8,760	5,912	8,000
Used potential		3.2%	100%	43.2%	38.6%
	Battery capacity installed: 160 MWh				

Fig. 4 shows the electricity mix by source for all 2036 scenarios under the EE demand forecast. Electricity from hydro and waste are used in all scenarios, the share is replacing fossil fuels with growing RES shares. PV is only used in the recommended scenario, where the use of 20% PV is given as a boundary condition.

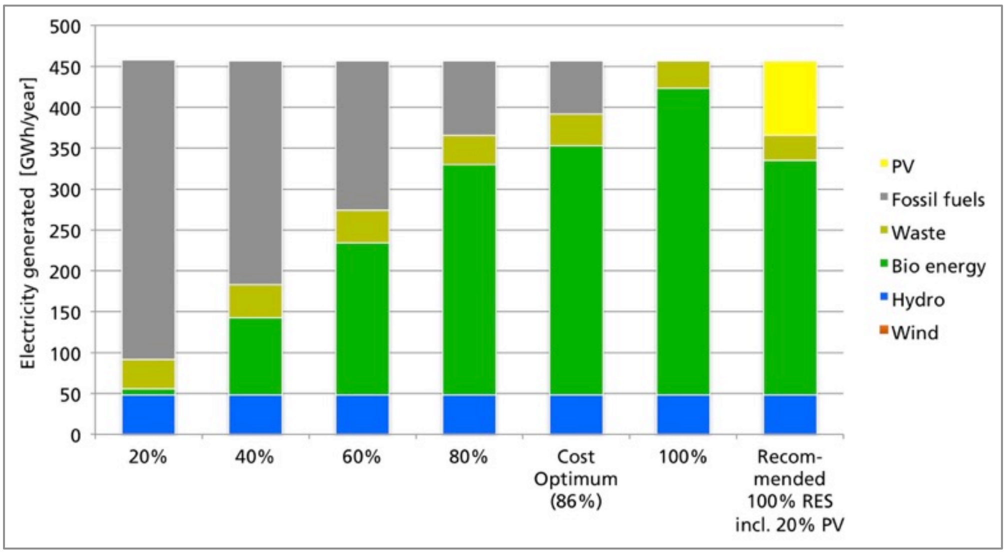


Fig. 4: Nan scenarios 2036 EE overview,
electricity generated by sources

3.1.3 Costs and CO_2 emissions for Nan scenarios

The total annual costs of electricity generation for all demand forecasts and RES scenarios for 2025 and 2036 are calculated and shown in Fig. 5. For Nan the cost optimum comes with high RES shares of 75% - 77% for 2025 and 84% - 86% for 2036. Today's energy system (Ref scenario) is the most expensive one.

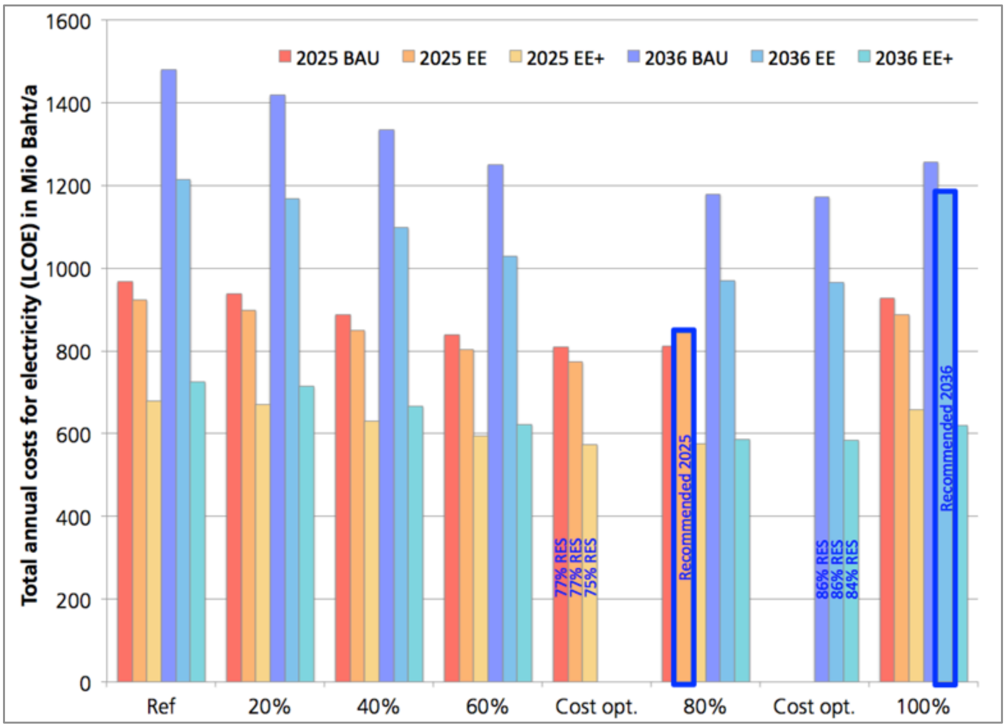


Fig. 5: Total annual costs for electricity in Nan for different demand forecasts and RES shares in 2025 and 2036

With increasing RES share the costs are decreasing, however, close to 100% RES the installation of batteries is necessary to assure minimum number of full load hours which increases the costs again. The recommended scenarios for 2025 and 2036, which include a share of 10% PV and 20% PV respectively, are earmarked. The recommended scenario for 2025 has, due to higher LCOE of PV in comparison to bioenergy, 9% higher costs in comparison to the scenario without PV. In recommended scenario for 2036, the PV LCOE are similar to bioenergy, however, the 20% PV share requires a higher battery capacity, therefore the costs are 15% higher than the 100% RES scenario without PV (which is not shown). The CO_2 emissions of all scenarios are shown in Table 6. The recommended scenarios including PV lead to a lower emission than scenarios with the same RES share but without PV.

Table 6: CO_2 emissions in Nan for different scenarios

t CO_2 / a	**Ref**	**20%**	**40%**	**60%**	**80%**	**100%**	**cost opt.**	**rec.**
2025 BAU	203	209	197	179	151	114	159	
2025 EE	194	198	188	171	144	108	171	131
2025 EE+	140	140	140	127	105	79	115	
2036 BAU	295	306	281	256	218	164	203	
2036 EE	241	249	231	210	179	134	167	106
2036 EE+	140	140	140	127	107	79	102	

cost opt. = cost optimum, rec. = recommended

3.2 Phuket

The situation in Phuket looks very different to Nan. While Nan disposes of a significant bioenergy potential the same is rather low in Phuket. The wind energy potential is not bad as far as wind speeds are concerned, however, there is almost no suitable place available to erect wind power plants on the island. Therefore, PV on rooftops is almost the only RES and will become the major local energy source supported with some smaller bioenergy and waste incineration capacities.

3.2.1 Phuket scenarios 2025

Today, a waste incineration power plant is in operation in Phuket and produces about 80 GWh electricity per year. In 2025, this will correspond to 2% of the electricity demand under BAU electricity demand forecast.

Table 7: Phuket scenarios 2025 BAU, EE, and EE+, electricity generated by fuels

Electricity in GWh	PV	Wind	Bio energy	Waste	Fossil fuels	Batte-ries (MWh)	Total pro-duced
BAU electricity demand forecast							
Ref	0	0	0	80	3,164	0	3,244
4% RES cost optimum	0	0	44	80	3,120	0	3,244
20% RES	524	0	44	80	2,596	0	3,244
40% RES	1,389	19	44	80	1,947	156	3,479
EE electricity demand forecast							
Ref	0	0	0	80	3,031	0	3,111
4% RES cost optimum	0	0	44	80	2,987	0	3,111
20% RES recommended	**498**	**0**	**44**	**80**	**2,489**	**0**	**3,111**
40% RES	1,321	19	44	80	1,867	142	3,331
EE+ electricity demand forecast							
Ref	0	0	0	80	2,231	0	2,311
5% RES cost optimum	0	0	44	80	2,186	0	2,311
20% RES	337	0	44	80	1,849	0	2,311
40% RES	931	19	44	80	1,386	40	2,462

In Table 7 the scenarios up to 40% RES are shown. With 44 GWh the bioenergy potential and with 80 GWh the waste potential are already fully used. To achieve a specific RES target, the remaining RES electricity will be provided by PV. Only in the 40% RES scenario, 19 GWh electricity is generated by wind power (less than 1% of the electricity demand). By increasing the efficiency and therefore reducing the electricity demand (EE+ instead of EE demand forecast), the installed PV capacity can be reduced significantly.

It is recommended, to aim for 20% RES by 2025 under the EE demand forecast. This can be achieved by exploiting the waste and bioenergy potential, but mainly by using PV rooftops. 383 MW PV capacity must be installed, which meet the electricity demand by 16%. PV electricity will be only slightly (2.8 Baht/kWh) more expensive than electricity from fossil fuels (2.6 Baht/kWh).

Table 8: Phuket recommended scenario 2025 EE, 20% RES, data overview

	Unit	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**
Installed capacity	MW	383	0	5.52	10.04	512
Electr. generated	GWh	498	0	44	80	2,489
Share on electr.		16%	0%	1.4%	2.6%	80%
LCOE	Baht/kWh	2.8		1.7	1.6	2.6
LCOE	€ct/kWh	7.4		4.4	4.2	7.0
PV modules area	km²	1.9				
Full load hours	h/a	1,297		8,000	8,000	
Used potential		22%		100%	100%	
	Battery capacity installed: 0 MWh					

3.2.2 Phuket scenarios 2036

Since the only reasonable RES potential is PV, Phuket can only partly be supplied by RES harvested on the island itself. Table 9 shows, that at 40% and higher RES shares, batteries must be installed, since PV electricity is generated during day and must be stored for use in the evening. By reducing the electricity demand in the EE and EE+ forecast, PV and battery capacities can be reduced, but still batteries are necessary. Under the BAU forecast the electricity demand is expected to double until 2036, under EE an increase of 60% is expected and under EE+ the electricity will remain on today's level. Due to the different levels of electricity demand, with the same PV capacity different shares of RES can be reached in the three demand forecasts.

Table 9: Phuket scenarios 2036 BAU, EE, and EE+, electricity generated by fuels

Electricity in GWh	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**	**Batte-ries (MWh)**	**Total pro-duced**
BAU electricity demand forecast							
Ref	0	0	0	80	4,409	0	4,489
10% RES cost optimum	335	0	44	80	4,030	0	4,489
20% RES	773	0	44	80	3,592	0	4,489
40% RES	1,838	19	44	80	2,694	724	4,675
EE electricity demand forecast							
Ref	0	0	0	80	3,642	0	3,722
12% RES cost optimum	335	0	44	80	3,262	0	3,722
20% RES	620	0	44	80	2,977	0	3,722
40% RES recommended	**1,507**	**19**	**44**	**80**	**2,233**	**495**	**3,883**
60%	2,090	19	44	80	1,490	5909	3,723
EE+ electricity demand forecast							
Ref	0	0	0	80	2,231	0	2,311
20% RES cost optimum	338	0	44	80	1,849	0	2,311
40% RES	862	19	44	80	1,387	212	2,392
60% RES	1,463	19	44	80	925	1,792	2,531
80% RES	1,984	19	44	80	463	3,766	2,590
90% RES	2,090	19	44	80	233	6,433	2,466

Table 9 shows, that a high share on RES up to 90% can be achieved with high PV and battery capacities. The batteries are necessary, because the model does not allow export and re-import of RES electricity generated on the island. However, since Phuket is connected with the mainland by a cable and import and export of electricity is technically feasible, a high RES target can be achieved at lower costs by cooperating with the mainland and importing RES electricity from wind or biomass in the evening instead of installing high battery capacities in Phuket. Therefore, it is recommended to install some battery capacities on the island for self consumption of buildings, resorts, districts or villages, but increase the RES share further by importing RES instead of further increasing the battery capacity. Therefore the 40% RES scenario is recommended.

It can be further seen in Table 9, that the expected electricity demand significantly determines the share of RES that can be reached in Phuket: under BAU 40%, under EE 60% and under EE+ even 90% RES could be reached. Already in the BAU scenario the share of RES is significantly higher for Phuket compared to what the Thai PDP and AEDP are aiming for in 2036 for entire Thailand.

For some scenarios (BAU 40% RES, EE 40% RES, and EE+ above 40% RES) the total electricity which needs to be produced is higher than in the lower RES shares scenarios. This is due to the fact that some electricity generated by RES cannot be used at the time of generation, however, building up more battery capacity would be not ecnomomic. Therefore this additional electricity produced cannot be used.

The cost optimal scenario is determined by the model to be at 10% RES under BAU, 12% RES under EE and 20% RES under EE+ demand forecast. LCOE for PV in 2036 are lower than LCOE for fossil power plants.

For 2036, it is recommended to aim 40% RES generated on the Phuket island under EE electricity demand forecast. This corresponds to the installation of 1,194 MW PV, 10 MW wind, 10 MW waste and 6 MW bioenergy power generation capacity. In addition, a battery capacity of 495 MWh is necessary. The detailed data are shown in Table 10. The battery capacity helps to balance electricity demand and supply locally on building, resort, and municipal level.

Table 10: Phuket recommended scenario EE 2036: 40% RES, data overview

	Unit	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**
Installed capacity	MW	1,194	10	6	10	500
Electr. generated	GWh	1,507	19	44	80	2,233
Share on electr.		36%	0.5%	1.1%	2.1%	60%
LCOE	Baht/kWh	2.5	3.8	1.9	1.8	3.0
LCOE	€ct/kWh	6.2	9.4	4.7	4.4	7.6
PV modules area	km²	6.0				
Full load hours	h/a	1,251	1,947	7,330	7,864	
Used potential		70%	100%	100%	100%	
	Battery capacity installed: 495 MWh					

Fig. 6 provides an overview on the electricity generated by sources for all 2036 scenarios under the EE demand forecast. It can be clearly seen, that PV will be the dominating RES source in each scenario, while the contribution of waste and bio energy is very small. Batteries are needed from the 40% RES scenario on, if it is not allowed to export the PV electricity generated.

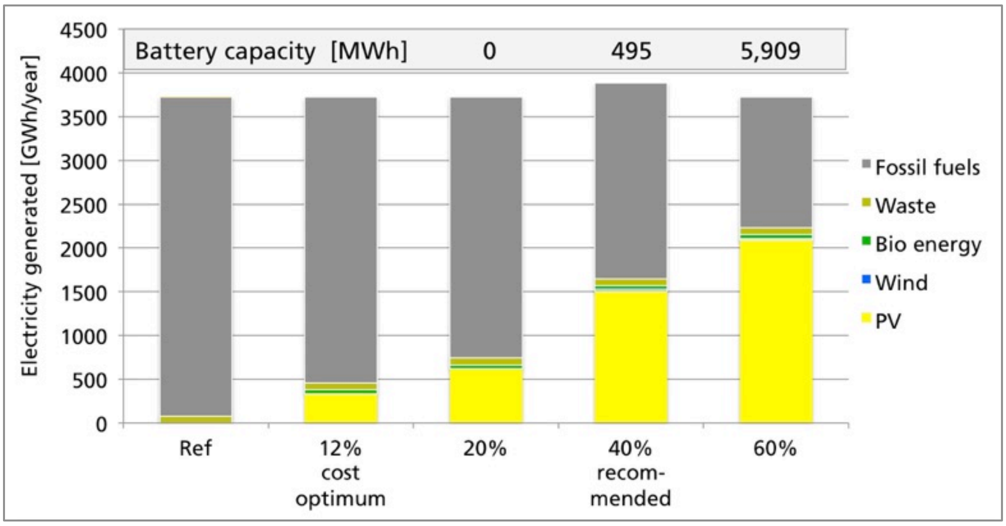


Fig. 6: Phuket scenarios 2036 EE overview, electricity generated by sources

3.2.3 Costs and CO_2 emissions for Phuket

Fig. 7 shows the total annual costs for electricity generation in Phuket (under BAU, EE, EE+ forecasts) for 2025 and 2036 as well as for different RES share scenarios. In the reference scenario the level of costs is proportional to the electricity demand of the 6 scenarios (2025 BAU, 2025 EE, 2025 EE+, 2036 BAU, 2036 EE, 2036 EE+). The recommended scenarios for 2025 and 2036 are earmarked.

In the 2025 scenarios, LCOE for PV are only slightly higher than for electricity from fossil fuels, the electricity costs are therefore only slightly increasing with increasing RES share until batteries are needed to further increase the RES share. This point is reached between 20% and 40% RES in the 2025 scenarios. In the 2036 scenarios, LCOE for PV electricity is even lower than for electricity from fossil fuels. Therefore total costs are first declining with growing RES shares. In addition, batteries are expected to be cheaper in 2036 than in 2025 and additional costs for batteries are compensated by cheaper PV costs until a specific point. Therefore the total costs increase significantly only above 20% RES in the 2036 scenarios.

The calculations for RES shares higher than 40% increase the demand of battery capacities significantly. This is not reasonable since it is increasing the costs substantially while at the same time electricity could be imported to the island by an electric cable.

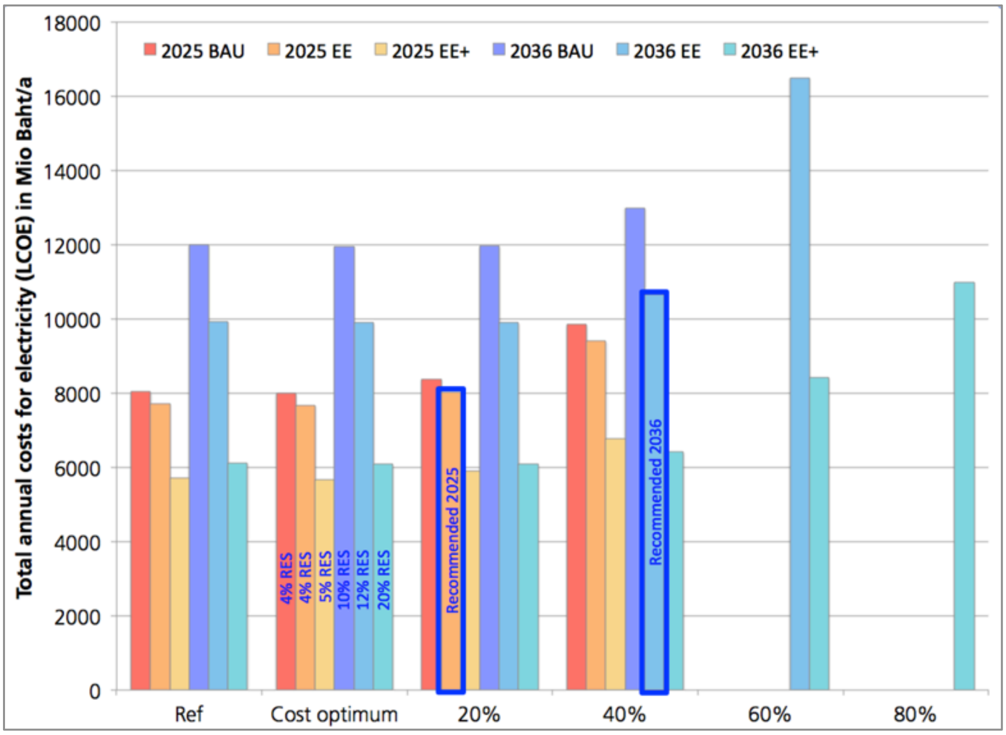


Fig. 7: Total annual costs for electricity generation in Phuket for different demand forecasts and RES scenarios in 2025 and 2036

For RES shares above 40% it is recommended to cooperate with the provinces on the mainland and import RES electricity or biomass from there. The RES share could also be further increased by building up offshore wind parks. But since data on the offshore wind potential are not available, couldn't be taken into account.

CO_2 emissions are always lower with higher RES share as shown in Table 11. In the EE+ scenario for 90% RES they are only at 17% in comparison to the reference scenario.

Table 11: CO_2 emissions in Phuket for different scenarios

$t\ CO_2 / a$	Ref	cost opt.	20%	40%	60%	80%	90%	rec.
2025 BAU	1,780	1,770	1,552	1,230				
2025 EE	1,708	1,698	1,491	1,185				1,491
2025 EE+	1,274	1,264	1,123	913				
2036 BAU	2,465	2,315	2,133	1,632				
2036 EE	2,047	1,897	1,779	1,375	920			1,375
2036 EE+	1,274	1,124	1,123	889	605	379	223	

cost opt. = cost optimum, rec. = recommended

3.3
Rayong

Rayong's RES potentials are more balanced than in Phuket. Next to a significant PV potential, wind and bioenergy is available as well. However, due to the fact, that Rayong has the highest electricity demand of the three provinces which is 4.4 times the demand of Phuket and 36 times of Nan, the bioenergy potential is quite low in relation to the demand. To reach high RES shares, PV and wind will become the dominating RES, however also the PV potential is limited and the average wind speed is not very high.

3.3.1 Rayong scenarios 2025

By increasing the RES share, first the bioenergy and waste potential will be used, followed by the PV potential. At 40% RES, wind power is used because it is cheaper than combining PV with batteries (see Table 12).

Table 12: Rayong scenarios 2025 BAU, EE, and EE+, electricity generated by fuel types

Electricity in GWh	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**	**Batte-ries (MWh)**	**Total produ ced**
BAU energy demand forecast							
Ref	0	0	79	28	14,185	0	14,292
8% RES cost optimum	0	0	917	203	13,173	0	14,292
20% RES	1,739	0	917	203	11,434	0	14,292
40% RES	4,242	601	917	203	8,576	0	14,292
EE electricity demand forecast							
Ref	0	0	79	28	13,599	0	13,706
8% RES cost optimum	0	0	917	203	12,587	0	13,706
20% RES	1,622	0	917	203	10,956	0	13,706
30% RES incl. 4% wind recommended	**2,399**	**600**	**917**	**203**	**9,595**	**0**	**13,713**
40% RES	4,208	406	917	203	8,224	0	13,706
EE+ electricity demand forecast							
Ref	0	0	79	28	8,991	0	9,098
12% RES cost optimum	0	0	917	203	7,979	0	9,098
20% RES	700	0	917	203	7,279	0	9,098
40% RES	2,603	0	917	203	5459	0	9,182

Only average wind velocity data for Rayong are available which were used for modelling. It can be assumed, that there are wind sites close to the sea which shows higher average wind velocity and therefore lower costs to generate wind electricity. Therefore the wind potential should be further evaluated in detail.

It is recommended to set an ambitious goal for Rayong of 30% RES for 2025 including a share of 4% wind. The wind capacity would not be chosen by the model, however it is recommended to already include a minimum wind capacity to build up a more robust energy system. In the recommended scenario PV contributes with 17.5%, wind with 4.4%, bioenergy with 6.7%, waste with 1.5%, and fossil fuels with 70% to electricity generation. The detailed data is shown in Table 13.

Table 13: Rayong recommended scenario EE 2025: 30% RES incl. 4% wind, data overview

	Unit	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**
Installed capacity	MW	1,833	442	115	25	2,082
Electr. generated	GWh	2,399	600	917	203	9,595
Share in electr.		17.5%	4.4%	6.7%	1.5%	70%
LCOE	Baht/kWh	2.7	4.6	1.6	1.6	2.2
LCOE	€ct/kWh	7.3	12.4	4.3	4.2	6.0
PV modules area	km²	9.2				
Full load hours	h/a	1,310	1,357	8,000	8,000	
Used potential		54%	5%	100%	100%	
	Battery capacity installed: 0 MWh					

3.3.2 Rayong scenarios 2036

In 2036 a maximum of 40% RES can be achieved under BAU, 60% RES under EE and 90% under EE+ electricity demand forecast (see Table 14). Since the share of fluctuating electricity generation by PV and wind is very high in these maximum RES scenarios, significant battery capacities would be needed to store electricity. In the maximum scenario more electricity must be produced since a significant amount of excess electricity from PV and wind cannot be used at the time of generation.

As for the year 2036 it is interesting to observe that according to the KomMod calculations higher RES shares than what is stipulated in PDP and AEDP are possible at reasonable costs.

Table 14: Rayong scenarios 2036 BAU, EE, EE+, electricity generated by fuels

Electricity in GWh	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**	**Batte-ries (MWh)**	**Total pro-duced**
BAU electricity demand forecast							
Ref	0	0	79	28	21,943	0	22,050
20% RES cost optimum	3,290	0	917	203	17,640	0	22,050
40% RES	4,242	3,908	917	203	13,230	1,640	22,500
EE electricity demand forecast							
Ref	0	0	79	28	18,172	0	18,279
20% RES cost optimum	2,536	0	917	203	14,624	0	18,279
40% RES recommended	**4,242**	**2,167**	**917**	**203**	**10,968**	**751**	**19,248**
60% RES	4,242	8,654	917	203	7,314	10,000	21,330
EE+ electricity demand forecast							
Ref	0	0	79	28	8,992	0	9,099
20% RES	700	0	917	203	7,279	0	9,099
30% RES cost optimum	1,576	0	917	203	6,404	0	9,099
40% RES	2,604	0	917	203	5,459	0	9,099
60% RES	4,242	534	917	203	3,640	3,329	9,536
80% RES	4,242	2,603	917	203	1,822	9,638	9,787
90% RES	4,242	7,125	917	203	913	10,000	13,400

As already observed in Phuket, in 2036 the LCOE for PV is with 2.5 Baht/kWh slightly lower than for fossil fuels with 2.6 Baht/kWh. As the wind power plants have little full load hours their LCOE are higher and this potential is only used when batteries would be necessary to further increase the share of PV.

Table 15 shows the detailed data on the recommended scenario with 40% RES under the EE forecast. With 3,380 MW PV capacity the potential of PV is fully used as well as the bioenergy and waste potential. Though the wind velocity is rather low and 11.7% of the electricity demand is met by 1,597 MW wind capacity, only 18% of the wind potential is used. Also this fact underlines the importance to evaluate the wind potential more in detail and evaluate, if on specific areas the wind velocity is not higher and therefore the wind LCOE lower than assumed up to now. PV has the highest share on electricity generation from RES and it can be assumed that most of the PV capacity will be installed on rooftops.

Table 15: Rayong recommended scenario EE 2036: 40% RES, overview data

	Unit	**PV**	**Wind**	**Bio energy**	**Waste**	**Fossil fuels**
Installed capacity	MW	3,380	1,597	123	25	
Electr. generated	GWh	4,242	2,167	917	203	10,968
Share on electr.		22.9%	11.7%	5.0%	1.1%	59.3%
LCOE	Baht/kWh	2.5	5.1	1.8	1.7	2.6
LCOE	€ct/kWh	6.3	12.8	4.6	4.3	6.4
PV modules area	km²	16.9				
Full load hours	h/a	1,250	1,357	7,625	8,000	
Used potential		100%	18%	100%	100%	
	Battery capacity installed: 751 MWh					

In the recommended scenario, 22,9% electricity is generated by PV and 11.7% by wind, therefore almost 35% of the electricity is generated by varying RES with only a rather little battery capacity of 751 MWh. This proves that a significant share of varying RES can be integrated in existing electricity systems without changing the grid infrastructure significantly and without installing high battery capacities.

Fig. 8 gives an overview on the electricity generation by sources for all scenarios in Rayong for 2036. It can be seen, that biomass and waste is always used, followed by PV and, after the PV capacity is fully used, followed by wind power. A low battery capacity is needed in the recommended 40% RES scenario, but the battery capacity must increase strongly to reach RES shares higher than 40%.

The batteries are needed, since the model regards the province as island, where the export of excess electricity from RES is not allowed. In reality, the electricity networks of the Thai provinces are well connected, therefore, these battery capacities would not be needed. However, it should be evaluated how the electricity generation profiles of the provinces are fitting to each other.

As already discussed in Phuket, also for Rayong it is obvious that with stronger energy efficiency from BAU to EE and from EE to EE+ demand forecasts, the possible RES shares can significantly be increased by installing the same RES capacities. Therefore, it is recommended to evaluate the possibility of decoupling GDP growth and electricity demand by energy efficiency measures.

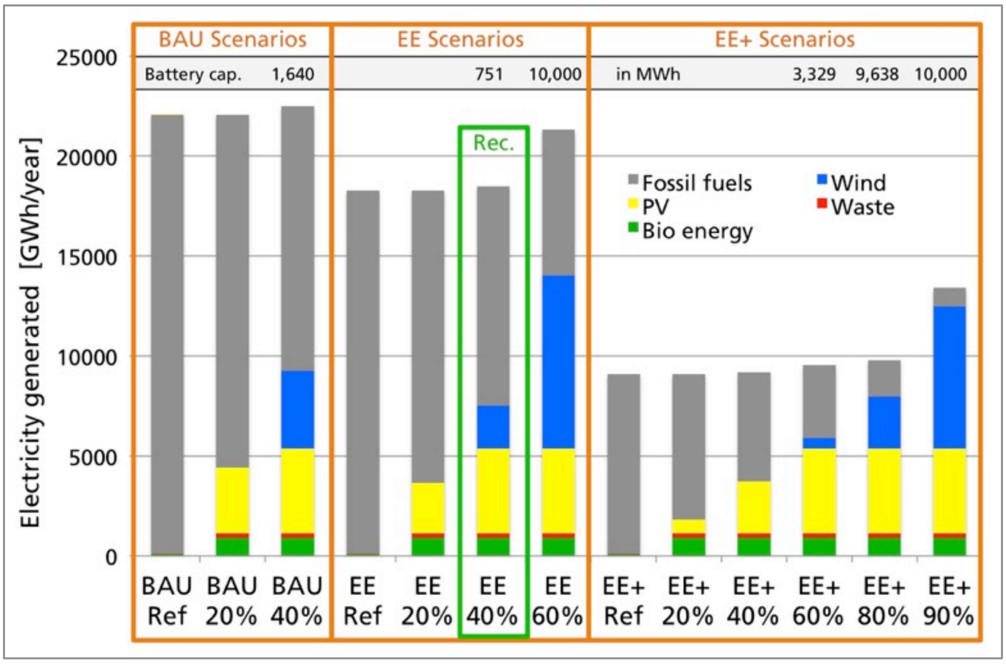


Fig. 8: Rayong scenarios 2036 BAU, EE, and EE+ overview, electricity generated by sources

3.3.3 Costs and CO_2 emissions for Rayong

The lowest total annual LCOE costs for the electricity generation in Rayong can be found in 2025 at 8% (BAU and EE) and 12% RES (EE+), in 2036 at 20% (BAU and EE) and 30% RES (EE+). As shown in Fig. 9 the total annual costs under the EE forecast are in the same range up to about 30% RES and at 40% RES they are only slightly higher than in the reference scenario. Therefore it is recommended to set a target of 30% RES for 2025 already including 600 MW wind capacity and a target of 40% RES for 2036. The lower target for 2025 takes into account, that it needs some time to build up the market.

The cost optimum scenarios are in 2025 only at 8% and 12% RES, but in 2036 at 20% and 30%. The reason is, that LCOE of PV electricity is in 2025 higher as of electricity from fossil fuels (see Table 13). However, in 2036 it is expected, that PV electricity will be cheaper than electricity from fossil fuels (see Table 15), therefore the cost optimum is found, where the PV potential is fully used.

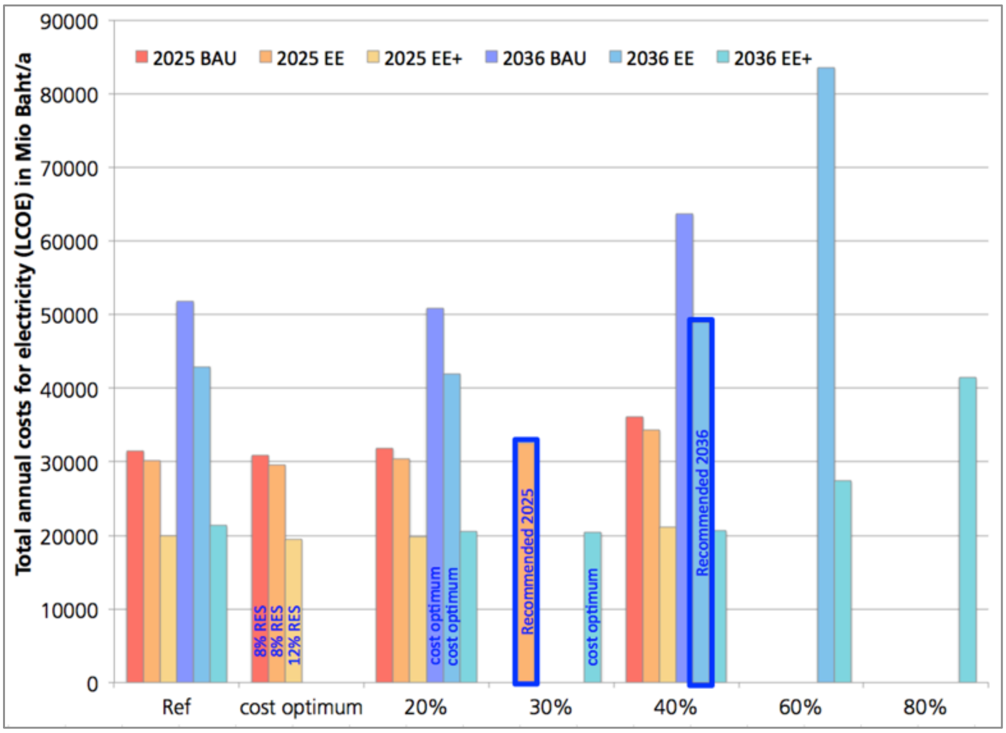


Fig. 9: Total annual costs for electricity in Rayong for different demand scenarios and RES shares for 2025 and 2036

Table 16 shows the CO_2 emissions related to the different scenarios. Again the emissions are significantly lower with higher RES shares and improved efficiency. In the recommended 40% RES scenario for 2036 under the EE demand forecast the CO_2 emissions of 10,441 t/a are 42% lower than in the reference scenario under BAU demand forecast with 17,891 t/a. Therefore to pursue ambitious renewable energy goals and implement a consequent energy efficiency policy is an effective combination to mitigate climate change.

Table 16: CO_2 emissions in Rayong for different scenarios

t CO_2/a	Ref	20%	40%	60%	80%	cost opt.	Rec.
2025 BAU	11,589	10,115	8,270			11,284	
2025 EE	11,113	9,717	7,919			10,808	8,982
2025 EE+	7,363	6,587	5,416			7,058	
2036 BAU	17,891	15,384	12,446			15,487	
2036 EE	14,827	12,820	10,441	7,015		12,785	10,441
2036 EE+	7,363	6,587	5,416	3,677	2,121	6,022	

cost opt. = cost optimium, rec. = recommended

3.4
Times series

The structure of the energy systems is optimized by KomMod by matching demand and supply in each hour of the year. In this chapter some time series in an hourly resolution are presented as a modelling result. The examples show, how the power plants are working together. The time series are available for all 8,760 hours of the year, but only a few time series are presented.

3.4.1 Time series Nan

Fig. 10 shows with 100% RES without PV shows, that the batteries are used to reduce the peak load which must be met by the bioenergy plant. The recommended scenario shown in Fig. 11 includes PV electricity, which at least partly covers the peak demand during lunch time.

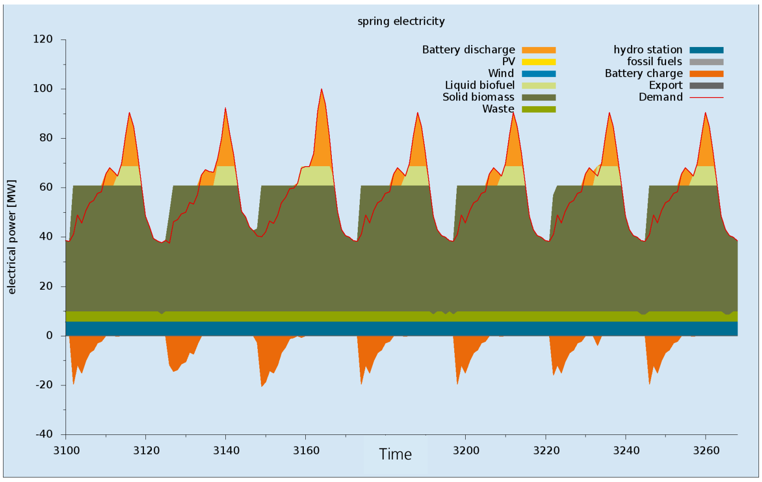


Fig. 10: Nan scenario 2036 EE: 100% RES (without PV), time series for one week in spring

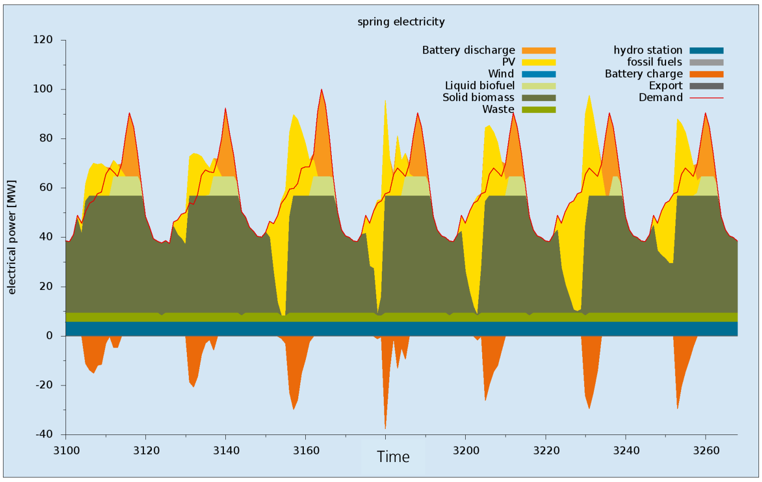


Fig. 11: Nan recommended scenario 2036 EE: 100% RES incl. 20% PV, time series for one week in spring

3.4.2 Phuket time series

Fig. 12 shows the time series for one week in summer of the recommended scenario for Phuket for 2036 in the EE forecast with 40% RES. On sunny days the solar electricity generated exceeds the electricity demand and the excess electricity is stored in batteries for use during night time (battery charging: minus values, discharching: positive values, colour: orange). However, due to costs only a limited battery capacity is installed and most of the excess electricity is exported (negative values, colour: dark grey). If the RES share is further increased to 60%, mainly by PV capacity, a significantly higher battery capacity must be installed. As shown in Fig. 13, about half of the solar electricity generated during day must be stored in batteries for use in the evening and during night time.

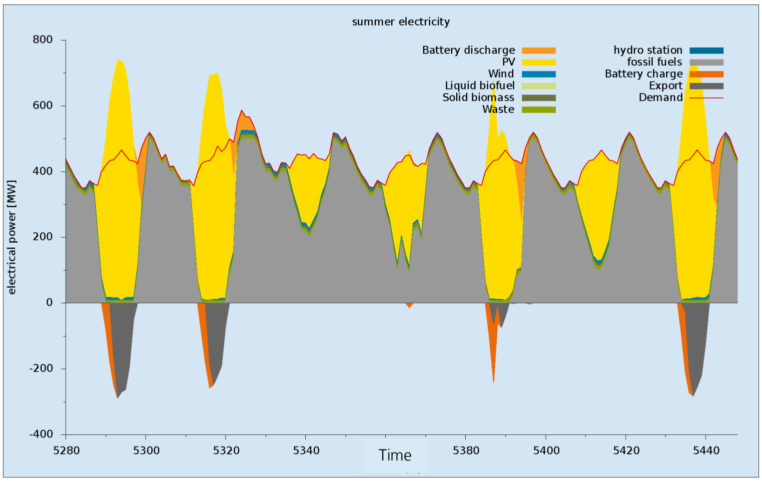


Fig. 12: Phuket recommended scenario 2036 EE 40% RES, time series for one week in summer

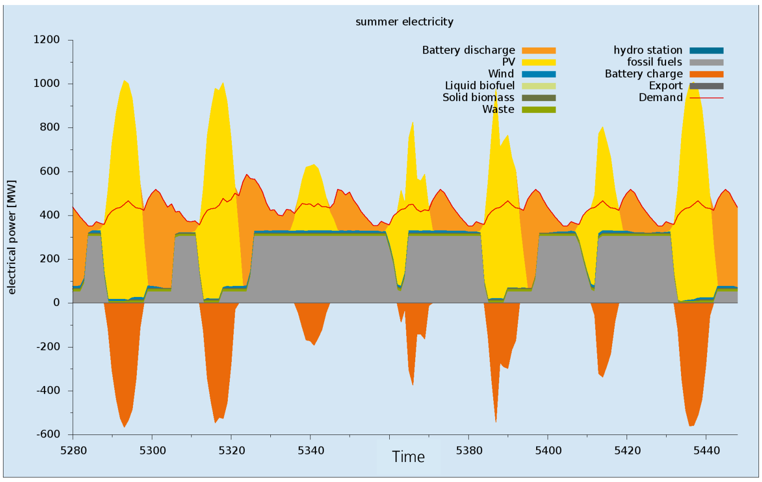


Fig. 13: Phuket scenario 2036 EE: 60% RES, times series for one week in summer

3.4.3 Rayong time series

Fig. 14 shows the time series of the recommended scenario for 2025 EE of 30% RES with 4% wind. During day time PV electricity covers the complete additional load to the base load level of about 1000 MW. Around lunchtime almost the entire demand is covered, however, in the morning and in the afternoon only a part of the demand is met. Wind has only small shares and also biomass is only playing a minor role in covering the demand. The 30% RES scenario shows almost no excess electricity generated, therefore batteries are not needed. Fig. 15 shows the time series for the recommended 40% RES scenario in for 2036. Wind and PV are complementing each other well especially around hour 260 and hour 350. While PV is producing electricity around noon the wind is here blowing in the evening. But if PV and wind is generating electricity at the same time as around hour 400, excess electricity is generated and must be stored, exported or cannot be used.

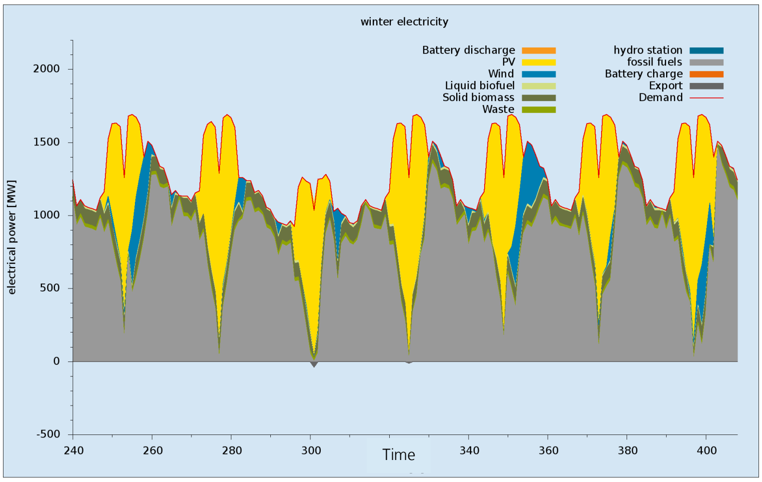


Fig. 14: Rayong recommended scenario 2025 EE 30% RES incl. 4% wind, time series for one week in winter

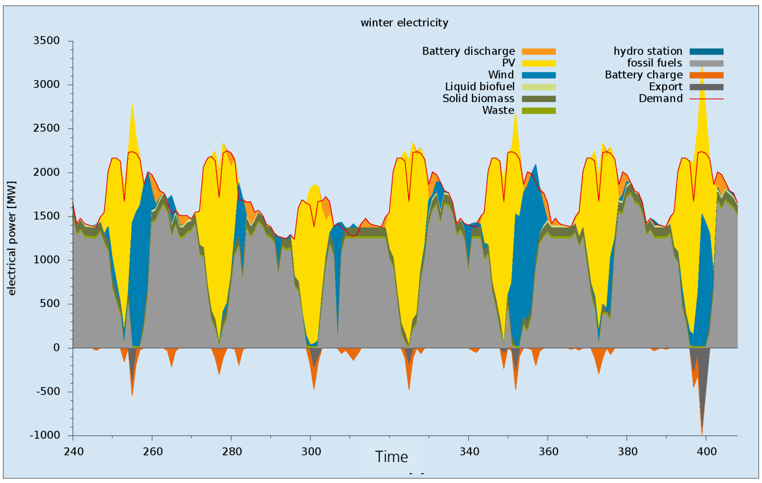


Fig. 15: Rayong recommended scenario 2036 EE 40% RES, time series for one week in winter

4
Recommendations

4.1
Target setting

Based on the modelling results presented, recommendations for ambitious, but realistically achievable RES targets are derived, which consider that the market growth until 2025 is limited by limited market capacities and that the RES share in 2036 should not be too far from the cost optimum.

In Nan, the biomass potential is quite big, therefore 100% RES can be achieved in 2036. The RES potentials in Phuket and Rayong are limited and the electricity demand density is relatively high, therefore only 40% of the electricity demand can be met by RES from the province at reasonable costs in the EE electricity demand forecast, which is used for the recommended scenarios. Table 17 shows the recommended RES targets for 2025 and 2036. If a RES source is especially mentioned like "100% RES incl. 20% PV" for Nan in 2036, the least cost scenario to reach 100% RES would not include PV capacities, however, 20% PV is included in the recommendation since the additional costs are relatively low and the recommended scenario is more realistic since the RES used are more distributed and the PV deployment policy of Thailand is reflected as well.

Table 17: Overview of recommended RES targets for the three provinces for 2025 and 2036 under the EE electricity demand forecast

Province	Target year	Recommended RES scenarios
Nan	2025	80% RES incl. 10% PV
	2036	100% RES incl. 20% PV
Phuket	2025	20% RES
	2036	40% RES
Rayong	2025	30% RES incl. 4% wind
	2036	40% RES

The recommended targets are higher than what PDP and AEDP stipulate for the entire country. Since it is shown, that these RES shares can be achieved and the scenarios are technically feasible and economically doable, these three provinces could become front runners with higher RES targets than the other provinces of Thailand.

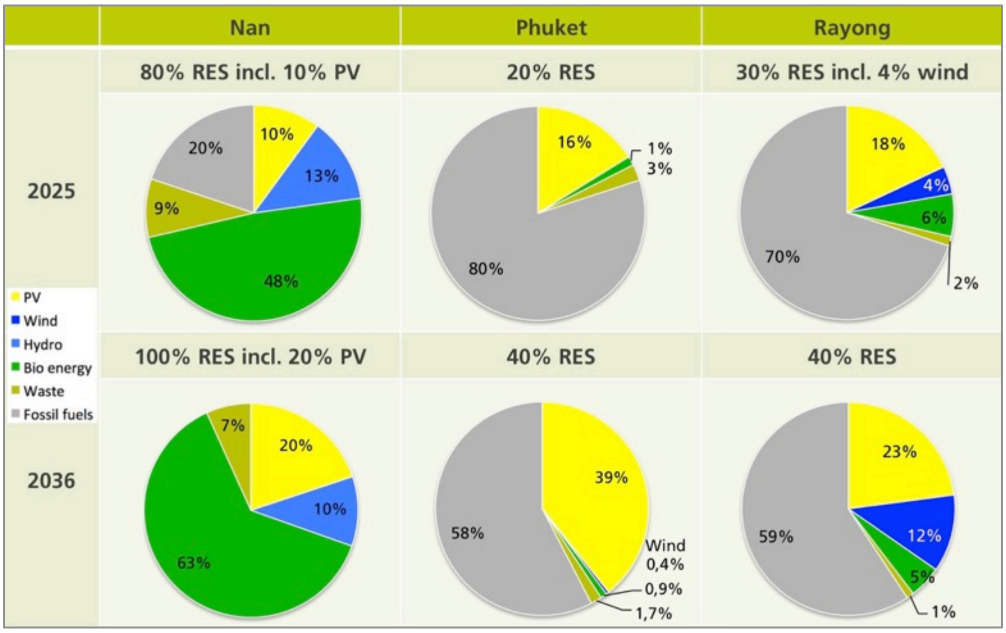


Fig. 16: Overview of the recommended scenarios for the three provinces, shares of the different sources to electricity generation

Fig. 16 shows the recommended scenarios with the distribution of the different sources in regard to their share on electricity generation. It is obvious, that the optimal solutions depend a lot on the available potentials on the different renewable energy sources and especially their distribution. In addition the relation of demand and supply plays an important role. Nan is in a very comfortable situation with low demand and high RES potential including bioenergy. This is in contradiction to Phuket and Rayong. Both have limited RES resources in comparison to their high energy demand, therefore they can achieve about 40% RES share from own resources, but have to cooperate with other provinces to increase this share significantly. Phuket is mainly dependent on solar energy, while Rayong has a better distribution of RES resources, which reduces the need to install battery capacities and allows in general to build up a more robust system.

The recommendations for 2036 for Phuket and Rayong still depend on 60% electricity from fossil fuels. Long-term it is expected, that higher RES targets in the electricity mix of Phuket and Rayong must be achieved as well, due to climate change or energy supply difficulties. Therefore it is important to evaluate, from which Thai regions Phuket and Rayong could be supplied with RES in addition to own resources which are limited as shown.

4.2 Recommended measures

Based on the presented results of the study, on the experiences from other projects and on the feedback from Thai experts and stakeholders during the project, the following recommendations are being suggested:

1. **Target setting on provincial level:** As a starting point for the transition towards sustainable low carbon energy systems, province governments together with the national government should agree on ambitious targets for the provinces.
2. **Target setting on municipal level:** The targets should be also set for local municipalities from provincial government together with the local authorities. This helps to ensure ownership of local communities.
3. **Roadmaps:** Based on the mid-term to long-term goals, a roadmap for the coming 3-5 years should be developed, as guideline for the implementation of measures to achieve the goals.
4. **Energy efficiency makes the difference**: All scenarios show what a siginificant difference energy efficiency measures play. Reducing energy demand by using energy efficiently is key in reaching higher RES shares or reach the same RES share at lower costs. Appropriate energy efficiency measures need to be defined on national, provincial and local level.
5. **Capacity building:** Local activities are crucial to implement energy efficiency and RES projects in the provinces, capacity building measures are necessary to support local actors by building up know-how.
6. **Lighthouse projects:** Only a few experiences with renewable energy and energy efficiency projects exist on the local level in the provinces yet. To motivate local actors further in becoming active supporters of the transformation of their energy system, lighthouse projects using reliable and safe technologies are important, e.g. small PV systems on public buildings (i.e. schools, city halls) to display the technology, demonstrate the functionality and reliability and make all stakeholder more familiar with RES.
7. **Improve data on RES potential:** Some of the input data on the RES potentials are somehow uncertain, e.g. the solar rooftop potential and the average wind velocity at specific locations. It is recommended to evaluate the local RES and EE potentials (PV, wind, hydro, bioenergy, geothermal and energy efficiency) in more detail parallel to the development of implementation plans.

8. **Implement monitoring:** To evaluate, if the transformation of the provincial energy system is developing successfully, a monitoring concept is needed and should be developed and implemented. Annual reporting about key performance factors and energy balances for the provinces is suggested. The results should be reported regularly to give the national level as well as the local actors a feedback on the development.
9. **Building up a market for decentralized PV rooftop systems:** Since PV will become in future cheaper than electricity from fossil power plants and is one of the main RES of Thailand, the PV market should be systematically built up. Therefore, a deployment program especially for PV rooftop systems tackling existing barriers should be implemented.
10. **Nan:** Nan is a sparsely populated province with low energy demand. The scenarios show that it could be a showcase for an energy sufficient province powered by 100% RES. A minimum share of PV should be defined and the wind energy potential should be evaluated further, so should the waste potential.
11. **Phuket**: Being a major tourist destination, Phuket is likely to grow further. All possible efforts should be made to conserve energy on the islands. With good energy efficiency measures, high shares of RE can be reached, based on solar PV rooftops and the use of batteries. Pilot projects would help to showcase the way for private investors such as resort owners. To build up a cooperation of Phuket with provinces on the mainland is recommended to further increase the RES share.
12. **Rayong**: The powerhouse of Thailand and especially its industry must be sure of a high reliability of power quality. But up to the level of 40% RES a reliable electricity supply by a mix of RES is possible and should be build up. Since the available data on wind potential are not very detailed yet, it is recommended to evaluate them further.

5
Data Processing

5.1
Electricity demand profiles

KomMod optimizes the structure of the electricity system for a given electricity demand profile and further boundary conditions. Therefore expected electricity demand profiles for the three provinces in the target years 2025 and 2036 must be compiled. To do the calculations and take into account the dynamic of the electricity system based on RES and batteries, the demand profiles must be provided in an hourly resolution for an entire year. To compile the expected demand profiles the demand profiles of the basis year are extrapolated by taking into consideration several development factors like growth rates of population, GDP, and tourism.

Since demand profiles in hourly resolution for an entire year are not available for the provinces, it was necessary to create demand profiles based on the available data. By the Provincial Electricity Authority (PEA) load profiles for 13 consumer categories are provided as average day profiles for each month differentiated for Workdays, Saturdays and Sundays. These profiles are available for the four Thai regions. Since the annual electricity demand of 2014 of the three provinces is known and the PDP provides electricity demand forecasts for entire Thailand, for each province an annual demand profile for the basis year 2014 was created and demand profiles for 2025 and for 2036 were compiled by taking into account the special structure of the electricity demand in the three provinces according the electricity consumer categories. The methodology used is described in the following paragraphs.

5.1.1 Workflow and methodology

For each province data on monthly total electrical consumption for each of the 13 consumer categories are available from 2012 to 2014. The 13 consumer categories are shown in Table 18.

Table 18: Consumer categories for load profiles provided by PEA

#	Category	Note
1	Small residential service	Household consumer < 150 units
2	Large residential service	Household consumer > 150 units
3	Small general service	< 30 kW
4	Medium general service	30 kW - 1000 kW < 250000 units in 3 months
5	Large general service	> 1000 kW > 250000 units in 3 months

6	Specific business service	Hotels, > 30 kW
7	Non-profit organizations	Administrative organization
8	Water pumping for agriculture	
9	Temporary service	Short term without registration
10	Public buildings	
11	Public lighting	
12	No-charge service	
13	Others	

In order to generate annual electricity demand profiles in hourly resolution over 8,760 hours, average load profiles for Workdays, Saturdays, and Sundays for every month and for each consumer type are used which are provided by PEA on their website. These profiles are available for four regions of Thailand: North, Central, East, and South. The standard load profiles for Workdays, Saturdays and Sundays in April 2014 are shown in Fig. 17 for the Region South. It can be seen, that the residential demand peak is in the evening, when the family is at home, only on Saturday also in the afternoon the demand is higher due to activities at home.

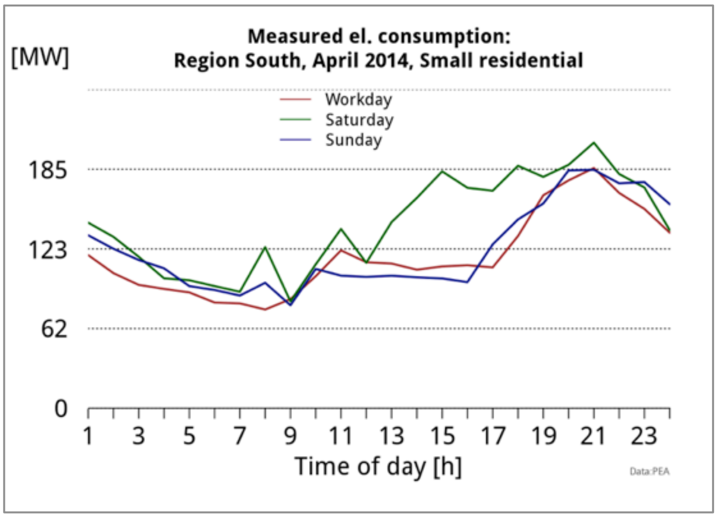


Fig. 17: Exemplary average day load profiles as provided by PEA, Region South, April 2014, consumer category "Small residential"

Total electrical consumption per month was combined with load profiles of typical days (Workdays, Saturdays, Sundays) to compile an annual load profile for 2014 for each province. In a second step, the load profiles for each consumer category were multiplied with the relevant development factors. The entire methodology is displayed in Fig. 18.

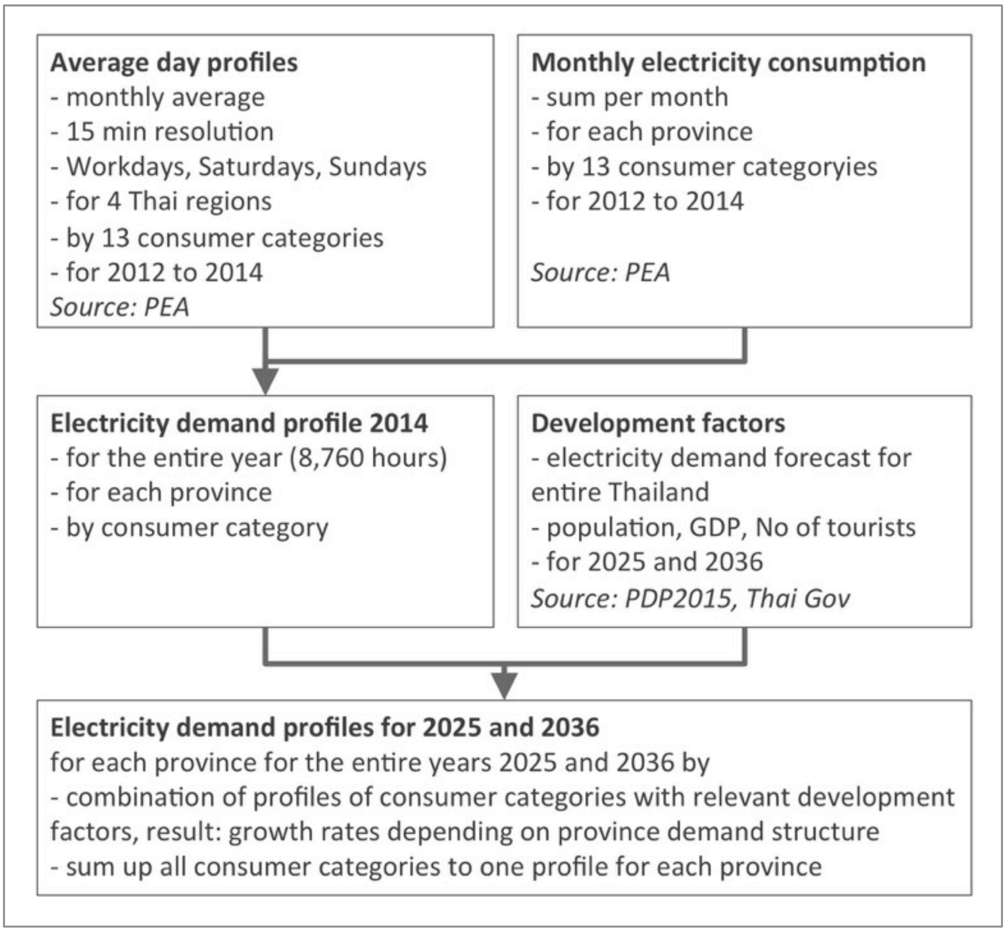


Fig. 18: Methodology to compile electricity demand profiles

5.1.2 Annual electrical consumption

Fig. 19 shows the electricity demand of Nan province for the years 2012, 2013, and 2014 for the 13 consumer categories as defined in Table 18. Nan is a rural area with electricity demand mainly for small and large residential services, this means private households. In the same dimension is the demand of small and medium general services, this means shops and small enterprises. The demand of all other categories is very low which reflects the rural structure of the province.

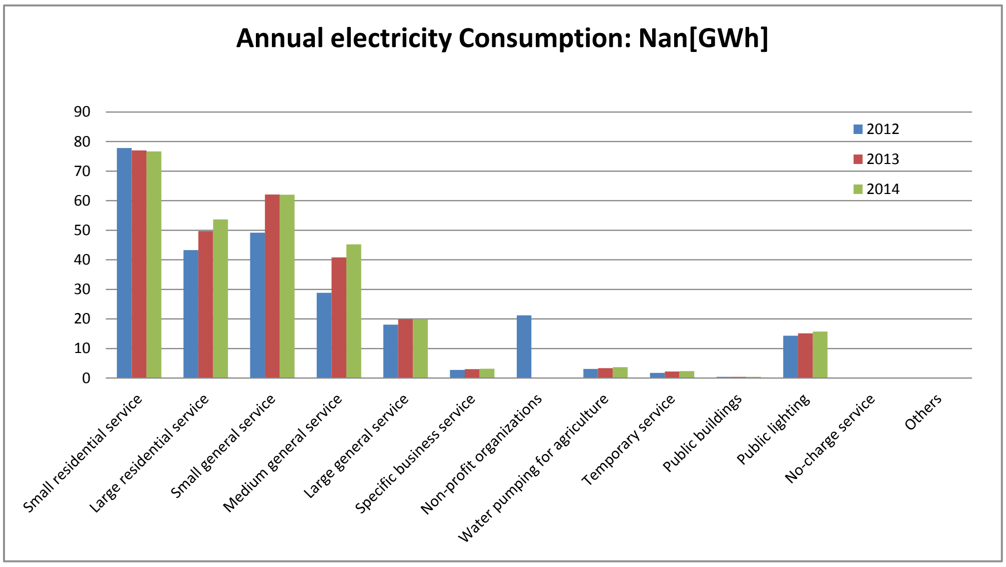


Fig. 19: Annual electricity consumption of Nan for different consumer categories for the years 2012, 2013, and 2014

Fig. 20 shows the annual electrical consumption for Phuket by all 13 consumer types for 2012, 2013, and 2014. The high shares of the consumer types "Large residential service" and „Specific business service" which represents hotels and tourism facilities shows the relevance of the tourism sector. It is important to realize the difference in the scale, the electricity demand of the large residential service in Phuket with about 500 GWh is 10 times the demand of the large residential service in Nan with about 50 GWh per year.

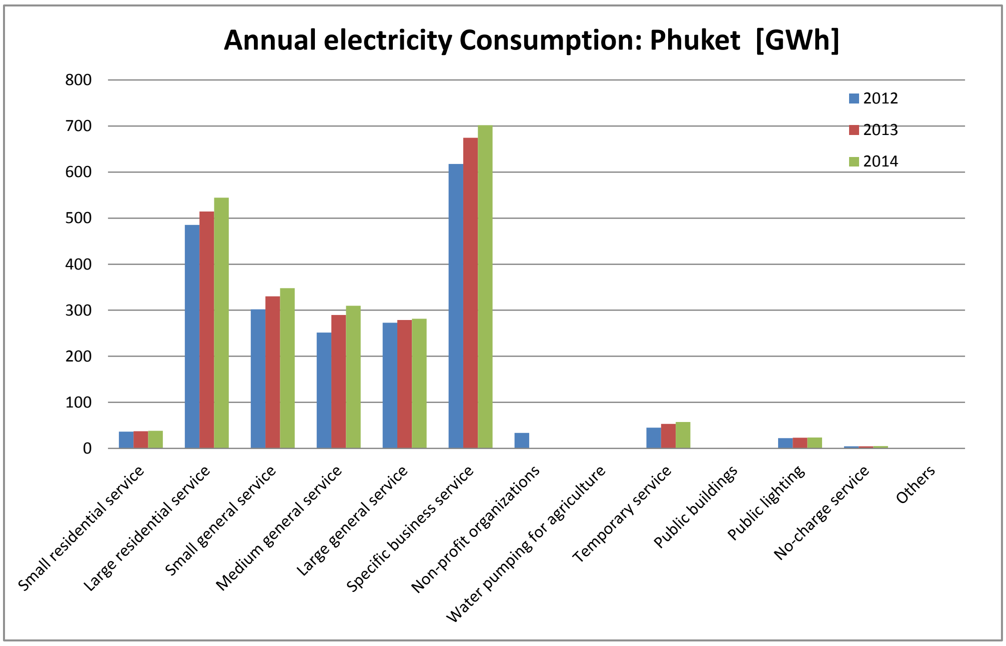


Fig. 20: Annual electricity consumption of Phuket for different consumer categories for the years 2012, 2013, and 2014

Rayong is dominated by the industrial sector. The consumer category "Large general service" has by far the biggest share of the total consumption. It is important to note, that the annual demand of the large residential service with about 500 GWh is in the same dimension as in Phuket, but the the overall demand is more than 4 times of the demand of Phuket.

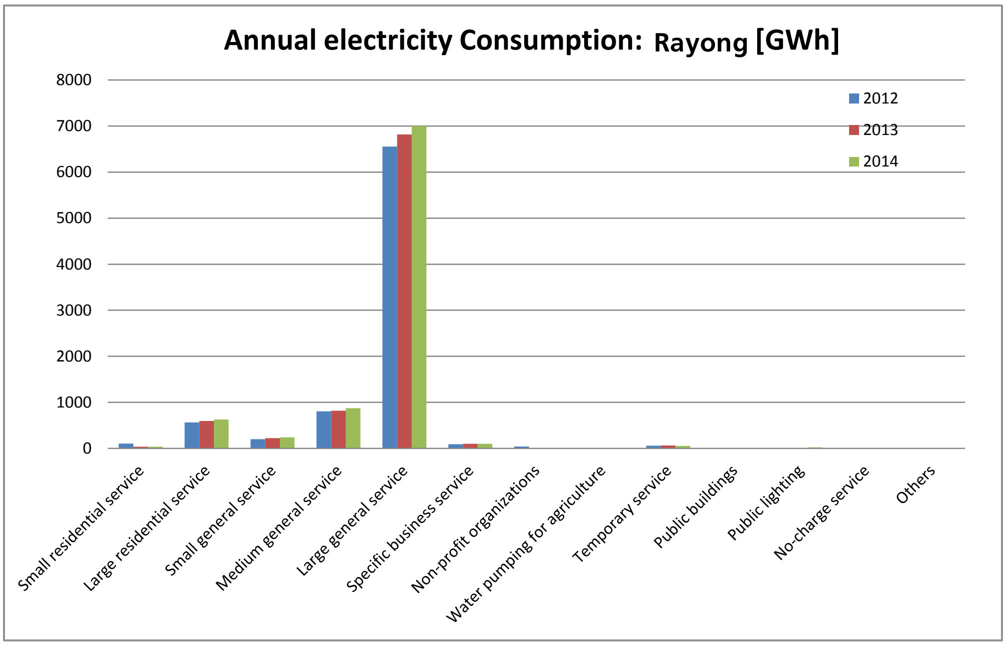


Fig. 21: Annual electricity consumption of Rayong for different consumer categories for the years 2012, 2013, and 2014

5.1.3 Indicators for the development of the electricity consumption

The forecasts of the electricity demand profiles for the three provinces for 2025 and 2036 were compiled in two steps. Firstly, the electricity demand forecasts of the PDP2015 for entire Thailand were used for the BAU and the EE forecasts.

In the second step, the demand forecasts were adapted to the specific conditions of the three provinces by taking into account the growth rates for population, GDP and tourism. This was done by multiplying the demand of each consumer category with the development factors as follows:

- Residential is proportional to GDP multiplied with population
- Small/medium general service is proportional to tourism development
- Industry and any other category are proportional to GDP

Table 19 shows the factors as result of these calculations for different consumer categories (residential = categories 1 and 2, general services = categories 3, 4, and 6, industry = category 5, and rest = categories 7 to 13 according Table 18). In the resulting factor for electricity demand it can be seen, that the differences of Nan and Phuket are low in comparison to entire Thailand, only the electricity demand of Rayong will grow significantly stronger than entire Thailand according the assumptions used. This is because of the dominating demand of industry (which is assumed propotional to GDP) and GDP is expected to grow faster than the energy demand. One could expect that the efficiency in the industry is stronger than in the average of Thailand (which is reflected by the EE forecast), however, this is not taken into account.

Table 19: Growth factors for different types of consumer categories for BAU and EE demand forecasts and target years 2025 and 2036

	Basis year				BAU electricity demand forecast							
	2014				2025				2036			
	Thailand	Nan	Rayong	Phuket	Thailand	Nan	Rayong	Phuket	Thailand	Nan	Rayong	Phuket
Electricity demand	**100**	**100**	**100**	**100**	**141**	**139**	**157**	**140**	**199**	**195**	**242**	**194**
- Residential	23	46	8	25		61	14	41		86	25	66
- General services	30	39	13	59		57	16	74		78	20	89
- Industry	44	7	77	12		10	123	19		15	193	30
- Rest	3	8	2	4		11	3	6		17	5	10
Development factors												
Tourism	100	100	100	100	125	147	125	125	150	200	150	150
GDP	100	100	100	100	154	140	160	160	232	210	250	250
Population	100	100	100	100	102	94	112	103	100	89	126	105
Efficiency	100	100	100	100	100	100	100	100	100	100	100	100
	Basis year				**EE electricity demand forecast**							
	2014				**2025**				**2036**			
	Thailand	Nan	Rayong	Phuket	Thailand	Nan	Rayong	Phuket	Thailand	Nan	Rayong	Phuket
Electricity demand	**100**	**100**	**100**	**100**	**135**	**133**	**151**	**135**	**165**	**162**	**201**	**161**
- Residential	23	46	8	25		58	14	39		71	21	54
- General services	30	39	13	59		55	16	71		65	16	73
- Industry	44	7	77	12		9	118	18		12	160	25
- Rest	3	8	2	4		11	3	6		14	4	8
Development factors												
Tourism	100	100	100	100	125	147	125	125	150	200	150	150
GDP	100	100	100	100	154	140	160	160	232	210	250	250
Population	100	100	100	100	102	94	112	103	100	89	126	105
Efficiency	100	100	100	100	96	96	96	96	83	83	83	83

5.1.3.1 Population development

The development of population for each province in Thailand is available from National Economic and Social Development Board. The number of population in each province differentiates over the years. In Nan the number of population is expected to decrease while the numbers in Phuket and Rayong is expected to increase. Expected development of population in the three provinces for the available years are shown in Table 20. The average resulting average growth rates are used for the calculations.

Table 20: Expected development of population in the three provinces

Province	2015	2025	2030	Average growth rate per year 2010 - 2030
Nan	443,100	419,000	404,600	- 0.55 %
Rayong	832,200	923,600	958,500	+ 1.07 %
Phuket	451,400	461,600	462,000	+ 0.23 %

5.1.3.2 GDP development

The Gross Domestic Product (GDP) represents the economic development which is closely related to industrial acitivities. It can be expected, that the electricity demand of the residential sector and the industry will grow with the GDP. The decoupling of GDP and electricity demand by improved energy efficiency is reflected separately by the EE (and EE+) demand forecast. The GDP development up to 2036 provided by PDP 2015 is used in this study and shown in Fig. 22.

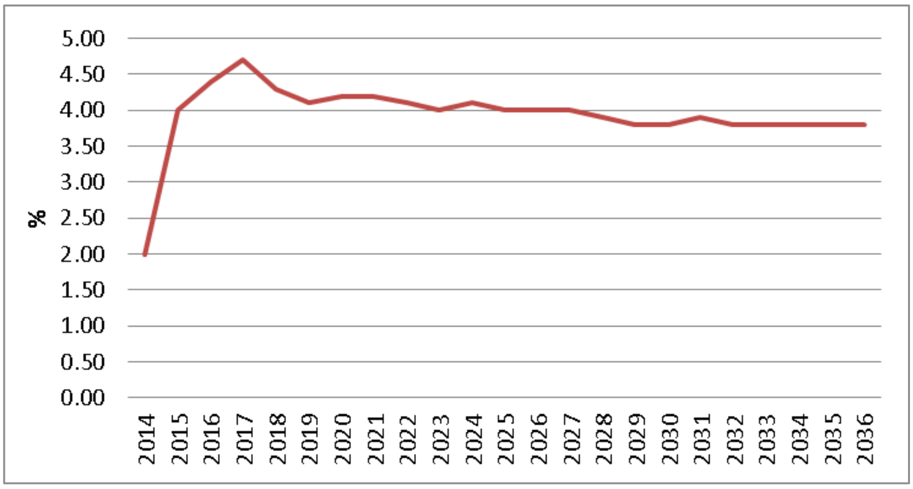
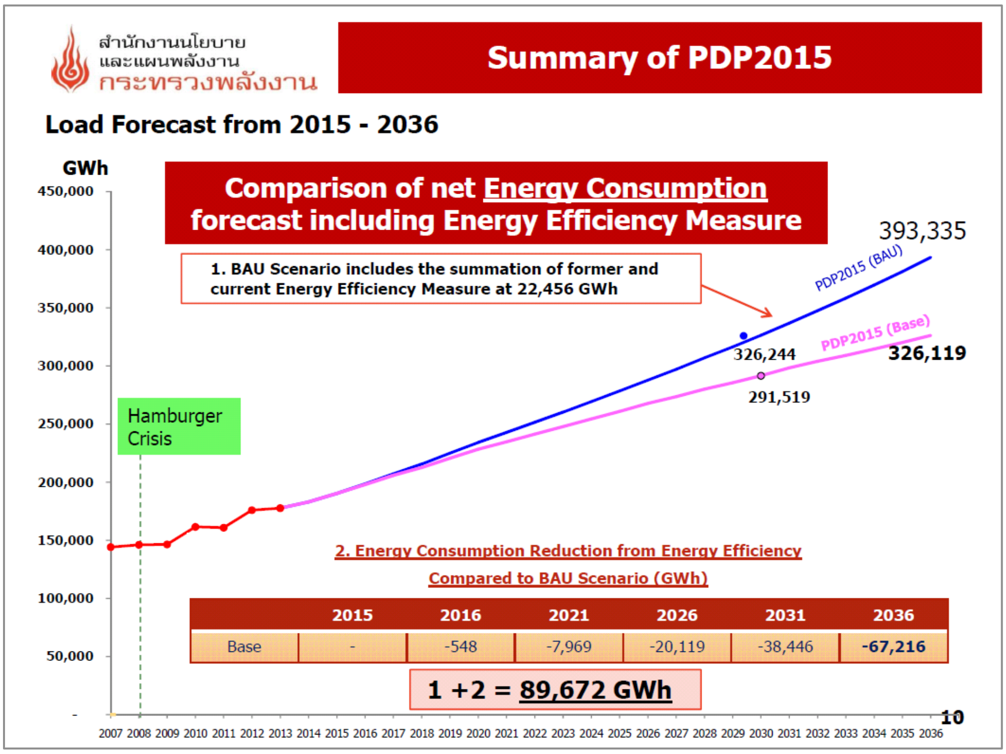


Fig. 22: Expected annual GDP growth rate until 2036 according PDP 2015

5.1.3.3 Energy efficiency development

The aim of the Thai government is to further improve energy efficiency and decouple GDP and electricity demand growth rates, therefore the energy efficiency (EE) forecast is used as a reference in this study. The BAU and the EE forecasts provided by PDP 2015 and used in this study are shown in the Fig. 23 (the EE forecast is named "Base").



	2015	2016	2021	2026	2031	2036
Base	-	-548	-7,969	-20,119	-38,446	-67,216

Fig. 23: Electricity consumption development for BAU and EE forecasts (EE scenario is named "Base"), according PDP 2015

5.1.3.4 Tourism development

Tourism plays an important role for Thailand's economy. According the data from National Tourism Authorities the numbers of tourists are increasing for the three provinces in the last years. Table 21 shows these numbers and that the average growth rate of tourists is the highest in Nan, however, Nan is at a very low level in comparison to Phuket and Rayong.

From Table 21 current average growth rates can be derived. But the increase of tourists is limited due to bearing capacity of provinces. Therefore it is assumed that the numbers of tourists in Nan could double compared to today's number. In Rayong and Phuket number of tourists could increase by 50% due to the high numbers which are already achieved. Fig. 24 shows possible tourism development curves for each province based on the current figures and the assumed increase potential.

Table 21: Development of visitors and guests 2011 - 2013

	2013	2012	2011	avg. annual growth rate
Nan				
Visitors	626,690	520,835	293,976	46%
Guest Arrivals of Acc. (Persons)	464,833	263,182	168,308	66%
Phuket				
Visitors	11,960,044	10,789,647	9,467,248	12%
Guest Arrivals of Acc. (Persons)	10,804,700	9,569,786	8,271,722	14%
Rayong				
Visitors	5,643,533	5,347,954	4,583,551	11%
Guest Arrivals of Acc. (Persons)	2,861,886	2,493,486	2,316,835	11%

Acc. = Accomodation

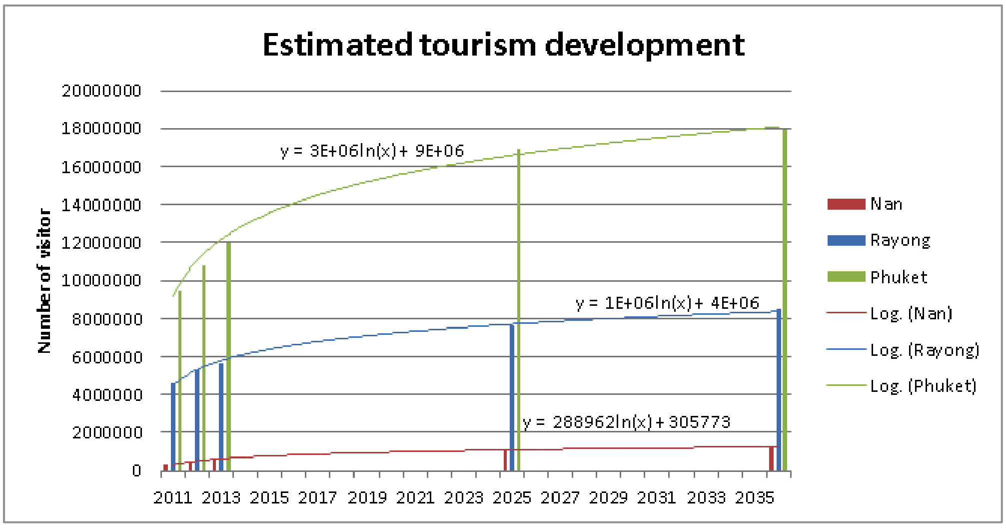


Fig. 24: Expected tourism development for each province

5.2
Renewable Energy Potentials

5.2.1
Weather and climate data

As the calculations in KomMod are on an hourly basis, also the weather and climate data must be entered into the model in an hourly resolution. For the calculations in this study the data is taken from Meteonorm [Meteonorm 2012]. The software provides weather and climate data from weather stations all over the world, either by measurements of a weather station or by interpolation of the data out of the weather stations that are closest.

Wind speed in Phuket

For Phuket there are two stations in Meteonorm available, one is at the airport in Phuket and the other one is in Phuket town. Besides the data from Meteonorm for Phuket there are measured wind speed data available from two weather stations on the island. One is Promthep station and one is Rawai station. Promthep and Rawai station are both in the very south of the island. The data for the two stations in the south are available for the years 2009-2014.

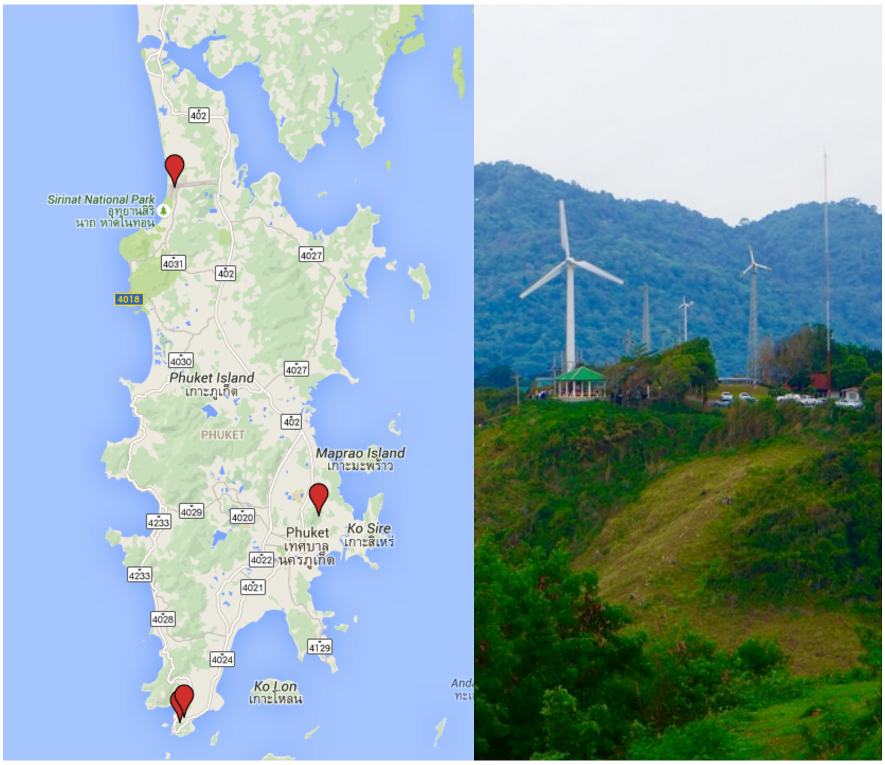


Fig. 25: Weather stations on Phuket (left, source: google maps)
Wind power plant at South Phuket with wind measurement towers (right)

A cross check was done between all four wind speed data sets. For the measured wind speed data from the two stations in the south first an average year is calculated by building the mean value of every hour out of the 5 years. Then the average wind speed for the whole year from the two Meteonorm stations and the two stations in the south are compared. For the Meteonorm data from Phuket airport station the mean wind speed over the whole year is 2.78 m/s, for the Meteonorm data from Phuket town the mean wind speed is 0.94 m/s.

For the Rawai station it is 3.65 m/s and for the Promthep station it is 4 m/s. All values are valid for ten meters height. The values from the stations in the south have been converted from 45 and 30 m height with the following formula:

$$v_1 = v_2 * \left(\frac{h_1}{h_2}\right)^{0,25}$$

For the two stations in the south of Phuket the average wind speed is approximately 1 m/s higher than at the Phuket airport station while the value for Phuket town is very low with only 0.94 m/s. It seems reasonable that the wind speed at the very south of the island is higher than in the north because at south the island is much more exposed to the wind, but the values for Phuket town seem very low compared to the others. It was decided to use the values of Phuket airport for the calculations out of two reasons: first, they seem reasonable compared to the values for the two stations in the south and there is a complete data set with values for every hour of one year while for the two stations in the south the measuring data are incomplete.

Wind speed in Rayong

For Rayong only data from Meteonorm are available. The weather station is located at the coastline of Rayong. The mean annual wind speed measured is 2.25 m/s. As there are no other measured wind speed data sets available a cross check with the mean annual wind speed out of the study [Manomaiphiboon et al. 2014] is done. Here the annual wind speed in ten meters height is 3 m/s. This value is nearly one m/s higher. As no other hourly data is available the Meteonorm data is taken, but further measures on wind speed should be done before considering the installation of wind turbines in Rayong.

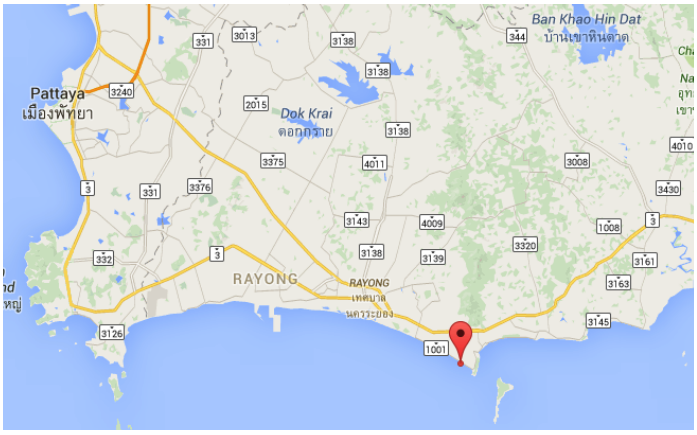


Fig. 26: Location of weather station in Rayong (source: Google maps)

Wind speed in Nan

In Nan there is no weather station of Meteonorm existing and the climate data of other stations nearby are used for interpolation. A point in the middle of the province east of the capital is chosen. The annual mean wind speed that is calculated for this point by Meteonorm is 0.28 m/s. A cross check with the study [Manomaiphiboon et al. 2014] provides an annual mean wind speed of 2.27 m/s which is much higher. The data from Meteonorm are taken for the calculations as no other hourly wind speed data are available. However, it is recommended to do more detailed studies to evaluate the wind potential in a sound way.

Fig. 27: Location of the climate data measurement point in Nan (source: Google maps)

Solar irradiation and temperature

Beside from the wind speed two other time series with climate data are needed for the calculations. First the solar irradiation and second the temperature. For both factors the values in the three provinces are much more similar to each other and the different measured values from Meteonorm can be cross checked with each other. Following table shows the relevant climate factors as mean annual values.

Table 22: Overview weather data for the 3 provinces

	annual mean wind speed [m/s]	annual mean temperature [°C]	annual solar irradiation [kWh/(m²a)]
Phuket	2.78	28.31	1758
Rayong	2.25	28.57	1798
Nan	0.289	25.51	1597

5.2.2 Wind potential

For the wind potential in the province of Phuket the data from the study "Analysis and Comparison of overall wind resource potentials from important wind maps of Thailand" [Manomaiphiboon et al. 2014] has been used. In this study the research team has conducted technical potentials for whole Thailand on the spatial level of Tambons (sub-districts). As data source for the wind speed four different types of wind maps have been evaluated. These wind maps show the wind speed on a yearly basis. Additionally the feasibility of land use has been examined by excluding all land that cannot be used for the installation of wind turbines.

As a result, three different technical wind potentials are presented, the potential without land exclusion (TP0), the potential after land exclusion (TP), and the potential of wind turbines that are from the point of view of the study authors economically feasible (TPcf20). Economically feasible is defined in this study, that the wind turbines have at least a capacity factor above 20 %, which means they have more than 1,752 full load hours per year. The economically feasible potential is only 1.7 % of the technical potential TP, which is a very low level. The study uses the median of the four wind maps to calculate the potentials, however, it is mentioned that the four wind maps show quite different values, which is an indication of the high uncertainty of the data.

Due to the uncertainties in the basic data used and the huge differences between the technical and economically feasible potentials, it is recommended to further evaluate the wind potentials more in detail in the provinces by theoretical studies but also by wind speed measurements.

KomMod is using the technical potential TP and calculates the cost effectiveness of wind turbines endogenously. The electricity generated by the wind turbines is modelled by using hourly wind speed data of the examined year and the resulting LCOE is calculated by using investment and maintenance costs.

Table 23 shows the wind potentials for Thailand and the three regions according the wind study. For Phuket the TP potential is nearly zero since on the coastline the housing is very dense and in the middle of the island there are hills and forests as well as plantations. In Rayong there is a high TP potential of 8,778 MW which results in 4,389 wind turbines of 2 MW each. For Nan the potential is even higher with 17,800 MW of installed wind power. But due to the rather low wind speed according the study the economically feasible potential is zero (see also 5.2.1).

Table 23: Wind energy potential for Phuket for different types of wind potential according [Manomaiphiboon et al. 2014]

Region	Unit	TP0	TP	TPcf20
Number of wind turbines				
Thailand	No	1,198,659	619,809	10,958
Nan	No	28,476	8,900	0
Phuket	No	1,293	5	0
Rayong	No	8,611	4,389	23
Installed power of wind turbines				
Thailand	MW	2,397,318	1,239,618	21,916
Nan	MW	56,952	17,800	0
Phuket	MW	2,586	10	0
Rayong	MW	17,222	8,778	46

TP0: technical potential without land exclusion

TP: technical potential after land exclusion

TPcf20: technical potential of wind turbines with over 1,752 full load hours

5.2.3
Photovoltaic potential

The PV potential is estimated by evaluating typical roof areas per household for different types of buildings in the provinces. The number of households by the nine types of buildings are provided for all three provinces by the statistical office [National statistical office 2000]. The share of the households per building type is shown in Table 24 for the three provinces.

Table 24: Types of buildings and number of households per building type

Phuket		
	Households	**Percent**
Total	163,057	100.0
Detached house	71,063	43.6
Town house/Duplex/Town Home	26,776	16.4
Condomenium/Mansion	3,956	2.4
Flat/Apartment/Hostel	11,976	7.3
Row house/Shop house/Row room	48,948	30.0
Room in house	254	0.2
Boat/Raft/Motor vehicle	9	0.0
Others	75	0.0

Rayong		
	Households	**Percent**
Total	**264,009**	**100.0**
Detached house	156,627	59.3
Town house/Duplex/Town Home	16,039	6.1
Condomenium/Mansion	2,650	1.0
Flat/Apartment/Hostel	5,733	2.2
Row house/Shop house/Row room	81,604	30.9
Room in house	197	0.1
Boat/Raft/Motor vehicle	27	0.0
Others	1,132	0.4

Nan		
	Households	**Percent**
Total	139,459	100.0
Detached house	132,929	95.3176
Town house/Duplex/Town Home	449	0.3
Condomenium/Mansion	139	0.1
Flat/Apartment/Hostel	1,789	1.3
Row house/Shop house/Row room	3,835	2.7
Room in house	63	0.0
Boat/Raft/Motor vehicle	100	0.1
Others	156	0.1

There are mainly three types of buildings, the detached house, the town house and the row house or shop house. Only these building types were taken to calculate the solar potential. For Phuket 90 % of all households are located in one of these three building types, for Rayong and Nan it is even higher with 96.3% and 98.3 %.

For these three building types it can be estimated that one household is located in one building and therefore that the number of households is equal to the number of buildings. In Fig. 28 photos of typical buildings of these three types are shown.

Fig. 28: Typical buildings of the three main buildings types in Thailand

For every building type the typical roof area was estimated using google maps and data of online real estate advertising. For the row and the shop house a typical ground/roof area was found with 12m*4 m = 48 m² and for the detached house it was estimated with 150 m² per household. It is assumed that in the average half of the roof area can be used for PV installations.

Additionaly, installations can also take place on public and industrial buildings. According [Therdyothin] 3.02 million small commercial buildings and 14.77 million residential buildings exists in Thailand in 2015. Therefore the number of small commercial buildings is about 20 % of the residential buildings. As a rather conservative assumption (since roofs of commercial buildings are usually much larger than of residential buildings) the PV rooftop potential on commercial and industrial buildings is 20 % of the residential potential. This leads to the overall PV rooftop potentials shown in Table 25

Table 25: Overall PV potential in the three provinces

	Nan	**Phuket**	**Rayong**
PV potential on residential rooftops	2,014 MW	1,429 MW	2,818 MW
Total PV rooftop potential	**2,417 MW**	**1,715 MW**	**3,382 MW**

As plausibility check, the PV potentials were compared with PV potentials of regions with the same population density in Germany, provided by the solar cataster of the German state Baden Württemberg [LUBW 2015]. The reason for this approach is, that the density of population influences the type of buildings (e.g. single family homes or high rise buildings) a lot. The PV potential per inhabitant for these regions was calculated for the corresponding Thai province. In Table 26 the result for this approach is shown.

Table 26: PV potential in the three Thai provinces calculated using PV density of similar regions in Germany

		Nan	**Phuket**	**Rayong**
Population density of Thai region	inh/km^2	0.42	6.57	1.90
Corresponding B-W region		MTK**	Schorndorf	Rottweil*
Population density of B-W region	inh/km^2	1.02	6.92	1.80
PV potential per inhabitant in the B-W region	MW/inh	6.20	3.30	3.65
PV potential of Thai province by using German potential/inh	**MW**	**3,955**	**1,667**	**3,288**

* a mean value from more than one region is taken
** MTK = Main Tauber Kreis is the least dense region
in the German state of Baden-Wuerttemberg (B-W)

For Phuket and Rayong both methods lead to similar figures. For Nan the potential derived from the comparison with a German region is quite higher. This verifies the results of the method of calculating rooftop areas, which can be seen as minimum potential.

To take into account the orientation of the PV modules, the PV potential was divided into different cardinal directions and different tilt angles. The rooftops are assumed to be directed 40 % towards south, 30 % towards west, and 30% towards east. Typical pitched roof angle is about 35° while the optimal tilt angle with the highes PV yield is 10° for Thailand. It is expected that for flat roofs and low pitched roofs this tilt angle is chosen. It is assumed that half of the PV systems in every of the three directions are tilted by 35° and half of the systems are tilted by 10°.

The approach described is a good first guess. If the implementation of higher PV capacities in the provinces is planned, a more detailed evaluation of the PV potential is recommended. Solar catasters, which identify PV rooftop potentials per building are well known in Germany and could be helpful for Thailand as well. This shall motivate house owners to do investments in PV systems on their houses.

About the potential of ground mounted PV no information is available for Thailand. For Phuket this potential will be rather small as the island is densely populated. But for Nan and Rayong ground mounted PV systems are an interesting option as the land exclusion from the wind potential study has shown. There are areas to install wind turbines which can most probably also be used for the installation of photovoltaic modules. Further research is recommended to evaluate the potentials of ground mounted PV systems.

5.2.4
Biomass and waste potential

The biomass and waste potentials for the three regions were provided by JGSEE divided by different kinds of biomass:

Solid biomass

- Industrial sugarcane (top trashier, bagasse)
- Rice (Husk, Straw)
- Maize (stalk top leaves, cob)
- Cassava (stalk, root)
- Oil Palm (frond, fibre, shell, empty bunches)
- Coconuts (shell, husk, frond, empty bunches)
- Cotton (stalk)
- Soybeans (stalk, leaves, shell)
- Sorghum (leaves, stem)
- Para rubber (charcoal, fuel wood, frond leaves, saw dust)
- Pineapple (stalk)

Waste

- Animal waste
- Industrial waste water
- Municipal solid waste

Liquid biofuels

- Oil palm
- Coconuts
- Cassava
- Molasses

For the calculations in KomMod the potential was summarized to three different types of power plants according to the main three biomass categories:

- Bioenergy power plants (burning the solid biomass)
- Waste power plant
- Liquid biofuel power plant

Bioenergy power plants are in this first approach modelled as steam power plants which burn solid biomass. They can only be built in a certain scale due to efficiency and investment costs reasons. This means that the biomass must be transported from a larger region to the power plant to be combusted.

Biogas can be produced locally and combusted in small CHP plants. For the production of biogas, the solid biomass must be fermented, which is only possible for biomass with low share of cellulose and lignin. Since there is not enough information available which share of solid biomass is usable for biogas production, further research is necessary to clarify this potential.

Waste potential in Phuket

For the waste potentials two different sources of information are available. On the one hand the yearly amount of waste was provided together with the biomass potentials by JGSEE, on the other hand in project workshops in the Thai provinces it has been stated that the amount of electricity that is produced by the existing waste power plant in Phuket is 220 MWh/a. In the given information about the waste potential from the two different sources are summed up in Table 27. It can be seen that the produced electricity per year differs not so much between the two different sources. As the values provided by JGSEE are from 2013 and the values from the workshop from 2015, the newer values were taken.

Table 27: Comparison of waste potentials in Phuket according different sources

	Unit	**JGSEE** (of 2013)	**Feedback at workshop in Phuket** (of 2015)
Amount of waste per year	t/a	139,749	255,500*
Amount of energy in waste	MWh/a	430,833	
Produced electricity per day	MWh/d		220
Produced electricity per year	MWh/a	64,625	80,300

* 700 t/d were reported

Waste potentials in Rayong and Nan

As in Rayong and Nan no waste power plants are in operation only rough estimations about the waste potentials were provided at the workshops in the provinces. For both provinces it was stated that the amount of waste is 300 t per day. As Rayong has more industry and also a higher population the amount of waste will be most probably higher there and the given value seems underestimated. Because of that for Rayong and Nan the amounts of waste from JGSEE are taken.

For all three provinces an increase of inhabitants is predicted for the future that would normally also lead to higher amounts of waste. On the other hand it can be expected that in the future waste prevention will be intensified. Therefore it is assumed that the potentials will remain the same as of today.

Biomass and waste power plants

Bioenergy and waste power plants are typically larger plants. Liquid biofuels can be used to run smaller CHP plants. For solid biomass the efficiency of power plants today is 23 % according to the Department of Alternative Energy Development and Efficiency of the Ministry of Energy. It is assumed that the efficiency will rise in the next ten to twenty years to the nowadays German level of efficiency of 30 %. The technical data and the potentials of the three different biomass and waste power plant types are shown in Table 28.

Table 28: Technical data and potentials of bioenergy power plants

	bioenergy powerplants	waste power plants	liquid biofuel power plants
electric efficiency	0.3	0.15	0.4
rated power of one plant [MW]	10-20	10-20	0.5-1
electrical potential Phuket [GWh]	42.1	80.3	1.4
electrical potential Rayong [GWh]	787	202	129
electrical potential Nan [GWh]	867	95	7.9

The electrical efficiency of waste power plants is about 15 % [BUND 2010] today. It is assumed that this value remains the same in future. The electrical efficiency of the waste power plant which is in operation in Phuket is about 13% (own calculations based on data taken from [Pjttechnology 2013]). The efficiency for the liquid biofuel CHP plants is taken from [ASUE 2011]. Since the waste power plant is already in operation in Phuket, in the modelling it is assumed that this plant runs in every scenario.

5.2.5 Hydro power potential

In Nan a hydro power plant is under construction and operation start is expected end of 2015. The rated power of the plant will be 10 MW. As the plant is not running yet and no information about full load hours and efficiencies are available, it is assumed that the power plant has 4,800 full load hours per year as hydro power plants have nowadays on average [AEE 2013]. It is further assumed that the plant is running steadily for the whole year. This leads to an average power of the plant of 5.47 MW.

$$P_{delivered} = P_{rated} * \frac{t_{full\ load}}{t_{year}} = 10\ MW * \frac{4800\ h}{8760\ h} = 5.47\ MW$$

5.2.6
Conventional power plants

The scenarios are calculated for different shares of RES. It is assumed that the electricity demand not met by RES will be met by coal and natural gas power plants in the same relation as they are installed today in Thailand, this means 4.7 MW of natural gas power plants in relation to 1 MW of coal power plants. As in Nan and Phuket no conventional power plants are installed today, these shares are taken for these two provinces. In Rayong there are both coal and natural gas power plants installed. Since for 1 MW natural gas power plants 1 MW coal power plants are installed, this relation is taken for Rayong.

The today's efficiencies of the conventional power plants are taken from [Power Plant Performance Benchmarking Workshop]. For natural gas power plants the efficiency is 48.6 % and for coal power plants the efficiency is 39 %. Since some of these power plants are still operating in 2025 and 2036, it is assumed that the efficiency will stay the same.

5.3
Costs

5.3.1
Costs of the different power plant types

To do the modelling, the investments costs for the different power plant types must be estimated for the different target years. For the steam and the moter power plants a cost growth rate a little bit higher than the inflation rate is taken. This is since no cost decrease due to learning rates is expected for this power plants, but the material costs to build them have risen in the last years. This results in an increase rate from 2.5 %/a. Price estimations which show similar developments can be found in [AEE 2012]. Price estimations for wind energy power plants are also taken from this study.

For PV modules further price reductions due to learning effects are expected in the coming years, the price assumptions are taken from the study [Mayer et al. 2015]. In addition it is assumed that the price for PV systems, which is today in Thailand higher than in a lot of other countries due to a rather small market, will go down to the German level in the near future because of a strong market growth.

For batteries even higher learning rates than for PV are expected by the experts. In this study not the most aggressive price reduction rate is assumed as for example is expected by [Fuhs 2014], but still a strong price decrease is foreseen.

The costs for the hydro power plants are taken from [Dumont et al. 2011] and for biomass power plants from [Heinrich et al. 2002]. Table 29 provides an overview on the cost assumptions used in this study.

Table 29: Investment costs for batteries and power plants in 2015, 2025 and 2036

	Investment costs in 2015 [$€_{2015}$/kW] / [$€_{2015}$/kWh]	Investment costs in 2025 [$€_{2015}$/kW] / [$€_{2015}$/kWh]	Investment costs in 2036 [$€_{2015}$/kW] / [$€_{2015}$/kWh]
Battery	1445	642	263
bioenergy power plant	2350	2420	2499
waster power plant	3300	3398	3510
liquid biofuels power plant	1500	1545	1595
Photovoltaic modules	1330	926	753
wind power plant	1330	1370	1414
coal power plant	1650	1699	1755
natural gas power plant	1000	1030	1063
water power plant	3300	3398	3510

	Investment costs in 2015 [THB_{2015}/kW] / [THB_{2015}/kWh]	Investment costs in 2025 [THB_{2015}/kW] / [THB_{2015}/kWh]	Investment costs in 2036 [THB_{2015}/kW] / [THB_{2015}/kWh]
Battery	53913	23951	9804
bioenergy power plant	87679	90286	93245
waster power plant	123123	126785	130940
liquid biofuels power plant	55965	57630	59518
Photovoltaic modules	49622	34549	28094
wind power plant	49622	51098	52773
coal power plant	61562	63393	65470
natural gas power plant	37310	38420	39679
water power plant	123123	126785	130940

The investment costs for batteries are provided per kWh, for the power plants per kW

Besides the investments costs there are costs for maintenance which are set to 3 %/a of the investment costs. The fuel costs for the different types of biomass, natural gas and coal are given in Table 30.

Table 30: Fuel costs in 2015 and their growth rates

	Fuel Costs 2015 [€/kWh_{fuel}]	Fuel Costs 2015 [THB/kWh_{fuel}]	annual growth rate [%/a]
solid biomass	see Table 32	see Table 32	2.2
waste	0	0	2.2
liquid biofuels	see Table 32	see Table 32	2.2
coal	0.0083	0.31	3
natural gas	0.023	0.858	3

The natural gas and coal costs are taken from [Wangjiraniran et al. 2013]. For waste the price is according this source 0.00982 €/kWh but in [Siemers et al. 2009] the price is -0.00263 €/kWh, so it is even negative. Because of that it is assumed that waste is provided for free. The prices for different kinds of biomass are provided by [Siemers et al. 2009]. In Table 31 the different price ranges are shown. The amounts of the different kinds of biomass are given for the three provinces and based on this information a mean fuel price for every province was calculated. As the price is not given for all the biomass sorts in the provinces, a mean fuel price is taken for the ones where no price information in available.

Table 31: Fuel costs for different kinds of biomass

in €/kWh fuel	Low	High	Default
Rice husk	0.00176	0.00703	0.00585
Rice straw	0.00410	0.00937	0.00732
Bagasse	0.00146	0.00293	0.00205
field rest	0.00176	0.00703	0.00439
empty fruit bunch EFB	0.00023	0.00047	0.00146
oil palm fibre	0.00176	0.00410	0.00293
oil palm shells	0.00878	0.01288	0.00995
wood chips (para rubber)	0.00234	0.00585	0.00410

in THB/kWh fuel	Low	High	Default
Rice husk	0.06553	0.26211	0.21842
Rice straw	0.15290	0.34948	0.27303
Bagasse	0.05461	0.10921	0.07645
field rest	0.06553	0.26211	0.16382
empty fruit bunch EFB	0.00874	0.01747	0.05461
oil palm fibre	0.06553	0.15290	0.10921
oil palm shells	0.32764	0.48053	0.37132
wood chips (para rubber)	0.08737	0.21842	0.15290

This leads to the biomass prices in Table 32 for the three provinces. For liquid biofuels the same price is assumed as no price information is available.

Table 32: fuel costs for biomass in the three provinces

	Fuel price biomass [€/kWh]	Fuel price biomass [THB/kWh]
Phuket	0.00423	0.15770
Rayong	0.00471	0.17563
Nan	0.00536	0.20000

For bioenergy fuels the price increase is assumed the same than the inflation rate, For the conventional energy fuels a slight increase by 3 %/a is estimated.

5.3.2
General economic characteristics

The inflation rate in Thailand from 2009 up to 2014 is shown in Table 33. The median for this period is 2.2 %/a which is used for the calculations. As effective interest rate 7 %/a is taken.

Table 33: Inflation rate in Thailand between 2009 and 2014 (Source: international monetary fund)

year	2009	2010	2011	2012	2013	2014
inflation rate [%/a]	-0.8	3.3	3.8	3	2.2	1.9

6 Annex

6.1 Costs and CO_2 emissions of Nan

	Ref	20%	40%	60%	80%	100%	Cost opt.	Rec.
Total annual costs in Baht [Mio Baht/a]								
2025 BAU	967	939	888	840	811	928	809	
2025 EE	924	899	850	804	776	888	774	844
2025 EE+	680	670	630	595	576	659	574	
2036 BAU	1,480	1,418	1,335	1,251	1,179	1,256	1,172	1,437
2036 EE	1,214	1,169	1,099	1,030	970	1,031	965	1181
2036 EE+	725	714	666	623	587	619	584	712
Total annual costs in Euro [Mio €/a]								
2025 BAU	25.9	25.2	23.8	22.5	21.7	24.9	21.7	
2025 EE	24.8	24.1	22.8	21.5	22.6	23.8	20.7	22.6
2025 EE+	18.2	18.0	16.9	16.0	15.5	17.7	15.4	
2036 BAU	39.7	38	35.8	33.5	31.6	33.7	31.4	38.5
2036 EE	32.5	31.3	29.5	27.6	26	27.6	25.9	31.7
2036 EE+	19.4	19.1	17.8	16.7	15.7	16.6	15.7	19.1
CO_2 emissions [t/a]								
2025 BAU	203	209	197	179	151	114	159	
2025 EE	194	198	188	171	144	108	171	131
2025 EE+	140	140	140	127	105	79	115	
2036 BAU	295	306	281	256	218	164	203	130
2036 EE	241	249	231	210	179	134	167	106
2036 EE+	140	140	140	127	107	79	102	61

6.2 Costs and CO2 emissions of Phuket

	Ref	20%	40%	60%	80%	90%	Cost opt.	Rec.
Costs [Mio Baht/a]								
2025 BAU	8,041	8,374	9,850				8,007	
2025 EE	7,709	8,023	9,405				7,675	8023
2025 EE+	5,709	5,908	6,770				5,675	
2036 BAU	12,009	11,971	13,000				11,964	
2036 EE	9,942	9,902	10,651	16,504			9,898	9902
2036 EE+	6,127	6,083	6,416	8,423	10,988	13,940	6,083	
Costs [Mio €/a]								
2025 BAU	215.5	224.5	264.0				214.6	
2025 EE	206.6	215.0	252.1				205.7	215.0
2025 EE+	153.0	158.3	181.5				152.1	
2036 BAU	321.9	320.8	348.4				320.7	
2036 EE	266.5	265.4	285.5	442.4			265.3	285.5
2036 EE+	164.2	163.0	172.0	225.8	294.5	373.6	163.0	
CO_2 emissions [t/a]								
2025 BAU	1,780	1,552	1,230				1,770	
2025 EE	1,708	1,491	1,185				1,698	1,491
2025 EE+	1,274	1,123	913				1,264	
2036 BAU	2,465	2,133	1,632				2,315	
2036 EE	2,047	1,779	1,375	920			1,897	1,375
2036 EE+	1,274	1,123	889	605	379	223	1,124	

6.3 Costs and CO_2 emissions of Rayong

	Ref	20%	40%	60%	80%	90%	Cost opt.	Rec.
Costs [Mio Baht/a]								
2025 BAU	31,437	31,823	36,153				30,875	
2025 EE	30,146	30,453	34,345				29,584	32,552
2025 EE+	19,993	19,799	21,179				19,430	
2036 BAU	51,790	50,868	63,734				50,867	
2036 EE	42,922	42,005	49,035	83,662			42,005	49,035
2036 EE+	21,331	20,548	20,636	27,425	41,451	62,720	20,440	
Costs [Mio €/a]								
2025 BAU	843	853	969				827	
2025 EE	808	816	920				793	872
2025 EE+	536	531	568				521	
2036 BAU	1,388	1,363	1,708				1,363	
2036 EE	1,150	1,126	1,314	2,242			1,126	1,314
2036 EE+	572	551	553	735	1111	1681	548	
CO_2 emissions [t/a]								
2025 BAU	11,589	10,115	8,270				11,284	
2025 EE	11,113	9,717	7,919				10,808	8,982
2025 EE+	7,363	6,587	5,416				7,058	
2036 BAU	17,891	15,384	12,446				15,487	
2036 EE	14,827	12,820	10,441	7,015			12,785	10,441
2036 EE+	7,363	6,587	5,416	3,677	2,121	1,244	6,022	

7 Reference List

Power Plant Performance Benchmarking Workshop. Energy Regulatory Commission and King Mongkut's University of Technology Thonburi.

Meteonorm. globale meteorologische Datenbank für Ingenieure, Planer und Ausbildung (2012). Version 7.1.0.105: Meteotest Genossenschaft.

AEE (2012): Studienvergleich: Investitionskosten erneuerbarer und fossiler Kraftwerke. pub. Agentur für erneuerbare Energien.

AEE (2013): Studienvergleich: Entwicklung der Volllaststunden von Kraftwerken in Deutschland. pub. Agentur für erneuerbare Energien.

ASUE (2011): BHKW Kenndaten 2011. pub. Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch e.V.

BUND (2010): Wege zu einer nachhalitgen Abfallwirtschaft. pub. Bund für Umwelt und Naturschutz Deutschland.

Dumont, Ulrich; Keuneke, Rita (2011): Vorbereitung und Begleitung der Erstellung des Erfahrungsberichtes 2011 gemäß § 65 EEG im Auftrag des Bundesministeriums für Umwelt Naturschutz und Reaktorsicherheit Vorhaben IId Spartenspezifisches Vorhaben Wasserkraft. Endbericht. pub. Ingenieurbüro Flocksmühle and Fichtner.

Fuhs, Michael (2014): Forecast 2030: stored electricity at $0.05/kWh. pub. pv-magazine.com. online available under http://www.pv-magazine.com/news/details/beitrag/forecast-2030--stored-electricity-at-005-kwh_100016581/, last checked on 08.09.2015.

Heinrich, Peter; Jaraus, Birgit (2002): Markt- und Kostenentwicklung der Stromerzeugung aus Biomasse. Gutachten. pub. Fichtner.

LUBW (2015): Potenzialatlas erneuerbare Energien. pub. Landesamt für Umwelt, Messungen und Naturschutz Baden-Württemberg, last checked on 11.09.2015.

Manomaiphiboon, Kasemsan; Paton, Carina; Assareh, Nosha (2014): Final Report. Analysis and Comparison of Overall Wind Resource Potentials from Important Wind Maps of Thailand. pub. The Joint Graduate School of Energy and Environment (JGSEE).

Mayer, Johannes; Philipps, Simon; Hussein, Noha Saad; Schlegl, Thomas; Senkpiel, Charlotte (2015): Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems. pub. Agora Energiewende.

National statistical office (2000): census data. pub. national statistical office Ministry of Information and Communication Technology. online available under http://web.nso.go.th/en/census/poph/cen_poph.htm, last checked on 11.09.2015.

Pjttechnology (2013): Phuket MSW incineration plant. pub. Pjttechnology. online available under https://www.youtube.com/watch?v=67Z10YpC6DU, last checked on 03.11.2015.

Siemers, Werner; Garivait, Savitri; Patumsawad, Suthum; Bonnet, Sebastien (2009): development of tools to estimate alternative strategies and options in using biomass for energy. Period from 1st January to 31th December 2008.

Therdyothin, Apichit. Current status of the building sector of Thailand. pub. Kings Mongkut's University of Technology Thonburi.

Wangjiraniran, Weerin; Nidhiritdhikrai, Raksanai; Eua-Arporn, Bundhit (2013): Scenarios on Power Generation in Thailand: Uncertainty of Nuclear and Coal Options. In: *EJ* 17 (3), S. 9–16. DOI: 10.4186/ej.2013.17.3.9.