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Sumba all renewable iconic island study
Investigation into a 100% renewable energy
supply of Sumba, Indonesia

Grid connected electricity generation
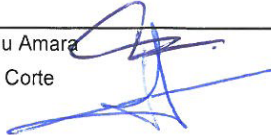**Final Report**

Arnhem, 12 April 2011

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KEMA Nederland B.V.

Research done on behalf of HIVOS

Hivos
people unlimited

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CONTENTS

1   INTRODUCTION

HIVOS, together with partners, has started a project to develop a show case for a 100% renewable energy island in Indonesia, an "iconic island". The aim of the project is to completely end the dependence on fossil fuels of this island, and to demonstrate and communicate the possibility thereof in the Netherlands, in Indonesia, and further. The project should on one hand provide energy to the island's population, and on the other hand also attract interest, cooperation and funding from institutions, companies and the public inside and outside Indonesia for replication. HIVOS asked KEMA to do an investigation into the grid connected electricity supply.

Goal of this investigation

The primary objective of the assignment is to assist the HIVOS in reviewing Sumba's Power Development Plan in light of the objective: to meet the current and future demand for electricity completely with sustainable energy to help ensure that Sumba has a secure, continuous and reliable power supply at the lowest possible cost.

Scope of the investigation

The scope of the study is to provide a high level advice on possible grid connected solutions for a 100% renewable electricity supply on the island of Sumba based on:

• Review of existing plans
• Data gathered based on questionnaires
• Local discussions with government and PLN
• Site visits for existing and future generation and transmission
• A least cost investment plan.

Network simulation is not within the scope of this study. For operation security additional investigations need to be made. As mentioned, the focus is only on electricity production and grid connection. HIVOS will commission other research for off grid situations and energy for transport.

Content of the report

This report contains the outlines and major variables of the least cost investment study. Chapter 2 describes the approach and methodology used in this study. The development of demand and supply are presented in Chapters 3 and 4. Furthermore, Chapter 5 incorporates the production planning for electricity while Chapter 6 summarizes the economic aspects of the least cost investigation in the electricity supply of Sumba. Finally, in Chapter 7 the conclusions and recommendations are summarized.

2 METHODOLOGY AND APPROACH

Least cost planning is used as methodology to determine a secure, continuous and reliable power supply at the lowest possible cost for Sumba based on 100% renewable energy. The least cost investigation has been made to determine the optimum scenario for an all renewable grid connected electricity supply in Sumba. In this case 'optimum' means a good balance between the cost of electricity supply, the reliability, environmental impact and social impact

The least cost investment study starts with the preparation of a demand and supply balance for the coming 15 years. Therefore a demand forecast and a resource assessment has been made. Based on this balance the need for additional capacity will be determined. Options for new capacity will be reviewed and a pre-selection of options for the generation portfolio will be made. These options will be used for scenarios for the future electricity supply and finally these scenarios will be evaluated. The suggested approach is illustrated below by Figure 2-1.
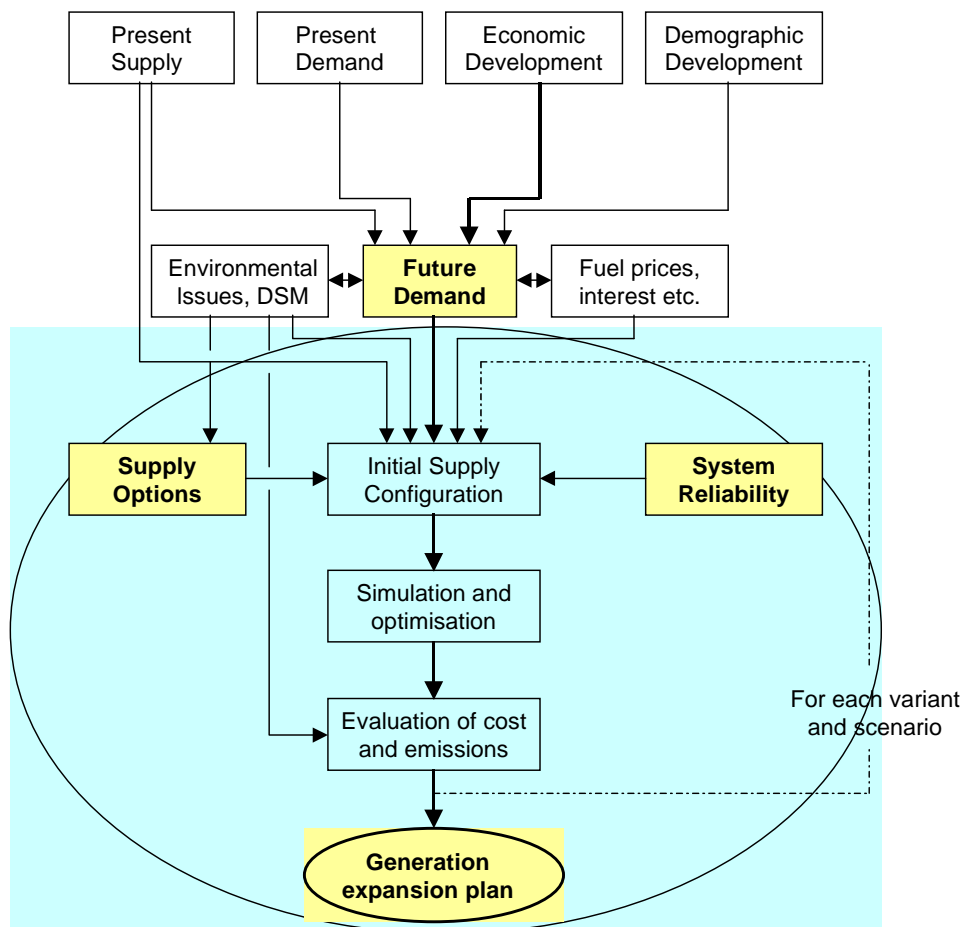
Figure 2-1   Overview of the Modelling Approach for the Least Cost Study

In the following, the details of the three main building blocks of this approach, that are "Future Demand", "Supply Options", and "System Reliability", are presented more detail.

Future Electricity Demand

The study prepares an electricity demand forecast for Sumba for the period 2011 to 2025 covering the following aspects:

- Forecasted aggregate, average and peak demand in Sumba for the period until end-2025, forecasting both annually and for sample weeks in each year in order to construct seasonal load profiles;
- Based on a simple approach;
- Reflecting three different scenarios – a base "most likely" case, a high and a low case.

The documentation of the used information, the applied assumptions, data and results are summarized in Chapter 3.

Supply Side Options

There are various technologies available to generate electricity in a renewable way including wind, hydro, solar and biomass sources. The modelling considers the unique set of characteristics of the candidates and arrives at a mix of future additions that provides the least cost outcome. Basis for the elaboration on the supply side options are proven technologies with promising potential contribution. Several of these renewable energy resources on Sumba have been described in the research by Winrock for Hivos[1]. The supply side analysis incorporates possible options for new construction, fuel switch of existing diesel plant and a transmission project (namely constructing of interconnection). It also covers the retirement of existing capacity in the cases where this capacity reaches its normal lifetime.

The production technologies are first checked outside (selection process see Chapter 4) and then in the optimisation algorithms of the modelling process (see Chapter 5). All state-of-the-art renewable technologies are investigated for electricity generation that are considered to be feasible for construction in Sumba.

The technologies are evaluated from the point of view of:
- Construction cost
- Efficiency
- Fuel availability and fuel prices
- Technical characteristics
- Operational practices
- Local circumstances.

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[1] Fuel Independent Renewable Energy Iconic Island", Winrock 2010

The selection process provides an indicative initial ranking of the existing supply options and is based on several performance indicators (e.g. average unit cost and utilisation) per unit and in order to quickly determine the feasibility of a certain investment to limit further modelling and calculations.

Generation System Reliability

Renewable resources like wind and solar but also hydro have a more or less intermittent character which considerably influences the reliability of the supply. Where unavailability of conventional resources can be solved by adding more resources, unavailability of wind, sun and water mostly cannot be solved by adding more turbines or solar panels. Other backup facilities will be necessary which are more reliable and can be turned on when required. Therefore scenarios will be defined based on intermittent and dispatchable resources.

Generation Expansion Plan

In the end the assessment results in a least cost generation expansion plan which contains the following main issues:

- Electricity demand forecast up to 2025
- Production expansion studies
- Transmission and transmission interconnections review
- Sensitivity and scenario analysis
- Conclusions and recommendations on production expansion

Actions undertaken

The following steps have been made to come to this report:

- Information gathering and review
- Preparation of the field mission
- Actual field mission together with HIVOS and Winrock
- Elaboration on data
- Modelling and execution of the Least cost planning
- Preparation of a Summary Report.

3   DEVELOPMENT OF DEMAND

The electricity supply of Sumba has the following main characteristics:

- There are two main grid systems, Waingapu and Waikabubak, and several small local networks;
- Most of the electricity (about 85%) is produced in diesel power plants, fuelled by diesel oil (light fuel oil), hydro power accounts for 15% of the annual generation;
- The PLN power plants in Sumba currently do not have enough reliable capacity to satisfy the demand. Therefore several rental diesel units support the present electricity supply.

PLN intends to interconnect the two main systems of Sumba in the near future. In this least cost investigation this interconnection is assumed to become reality in 2014.

This chapter describes the demand development of the interconnected electricity supply. First section is about the historic development and second section about the future demand.

3.1   Historical development of demand

The electricity demand in Sumba is relatively low compared to the per capita demand in Indonesia. Electrification ratio is about 30%. According to estimates of PLN, about 75% is used by households, 20% is commercial use and 5% is used by other like industry (see Figure 3-1). Of the domestic consumption about 70% is used for lighting.
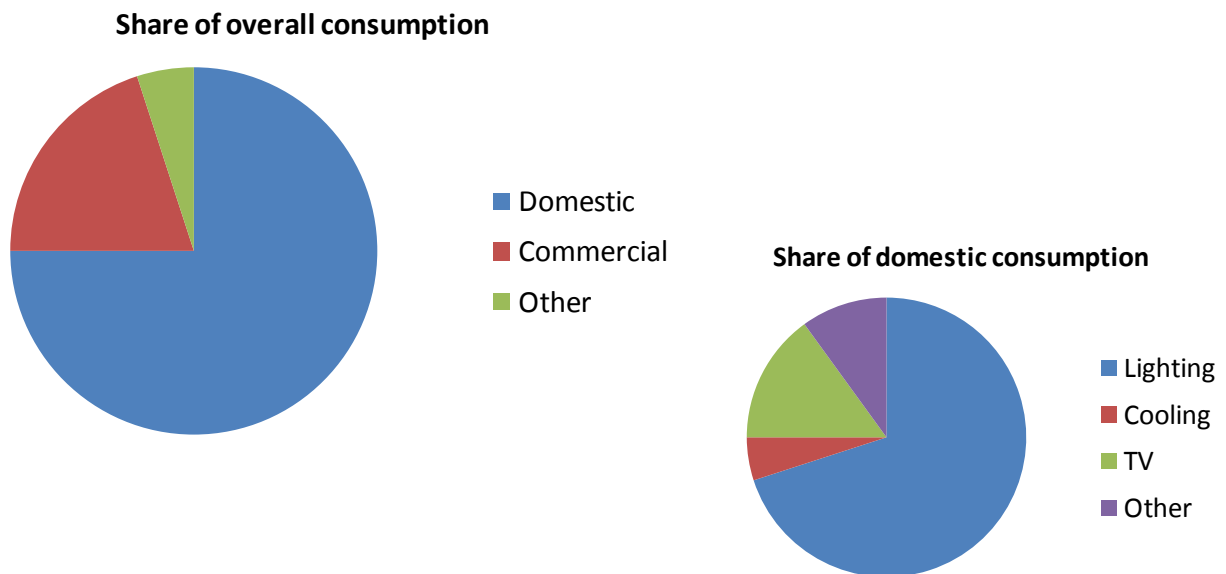
Figure 3-1   Origin of electricity consumption

The development during the last 10 years is shown in Figure 3-2.
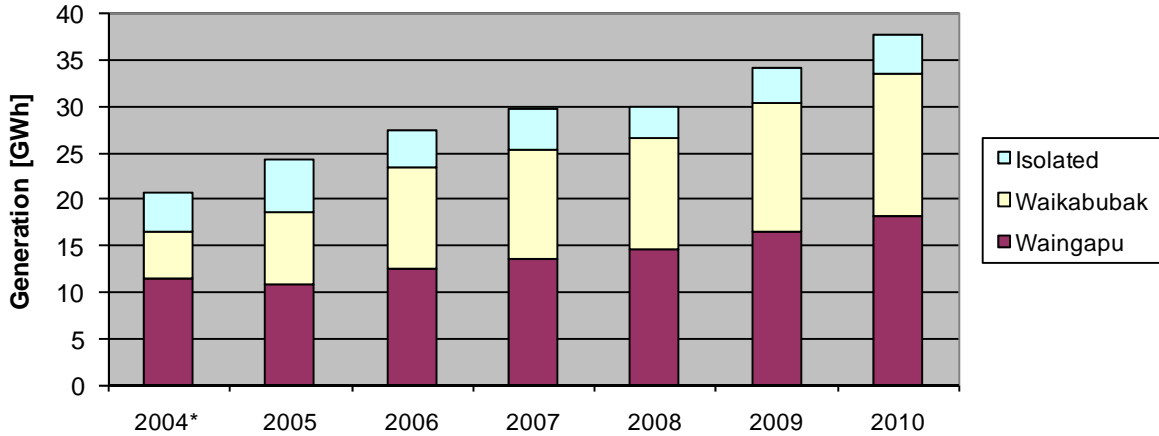
Figure 3-2   Historic development according to PLN (RUPTL 2010-2019)

The average growth during of the generation during the last 6 years has been 10%. Only in 2008 there has been almost no growth but 2009 showed a double growth.

For the least cost investigation not only the growth of the demand is important but also the shape of the demand. Especially for intermittent renewable resources the fluctuations of the demand can influence the possible contribution of these resources. Therefore the year and day patterns have been determined from the historical data. The annual pattern appears to be rather flat as can be observed form the next figure.
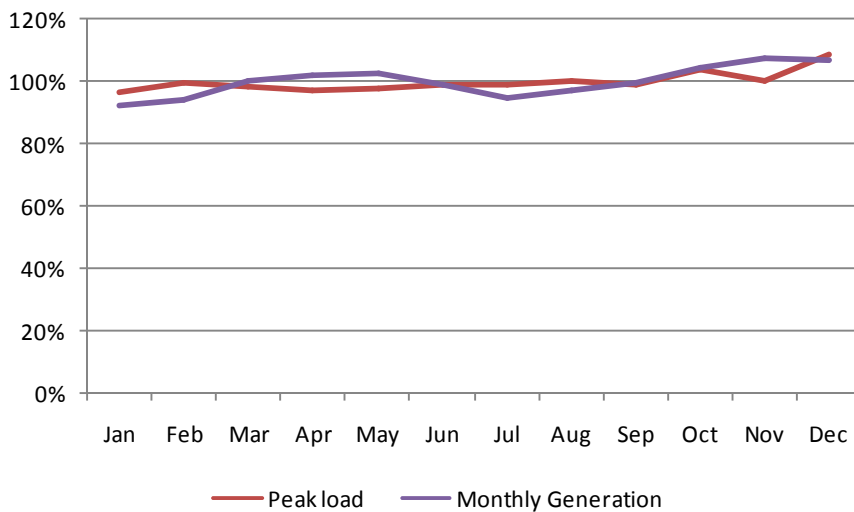
Figure 3-3   Annual pattern of peak load and monthly generation

The day patterns for the Waingapu system and the Waikabubak system are plotted in Figure 3-4 and Figure 3-5 for weekdays and weekend days both for the dry and the wet season.
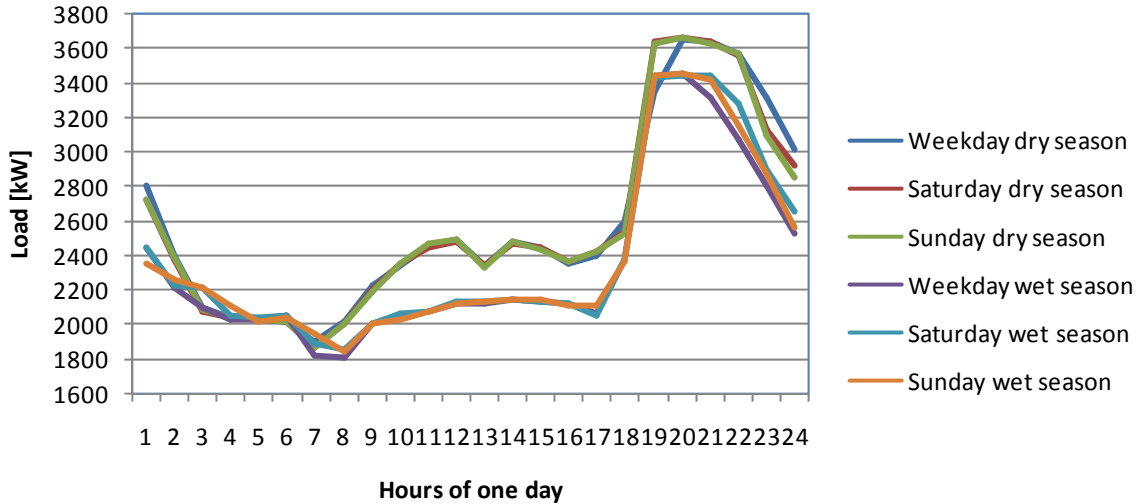
Figure 3-4   Day patterns of the Waingapu load for weekend and weekdays for the dry and the wet season
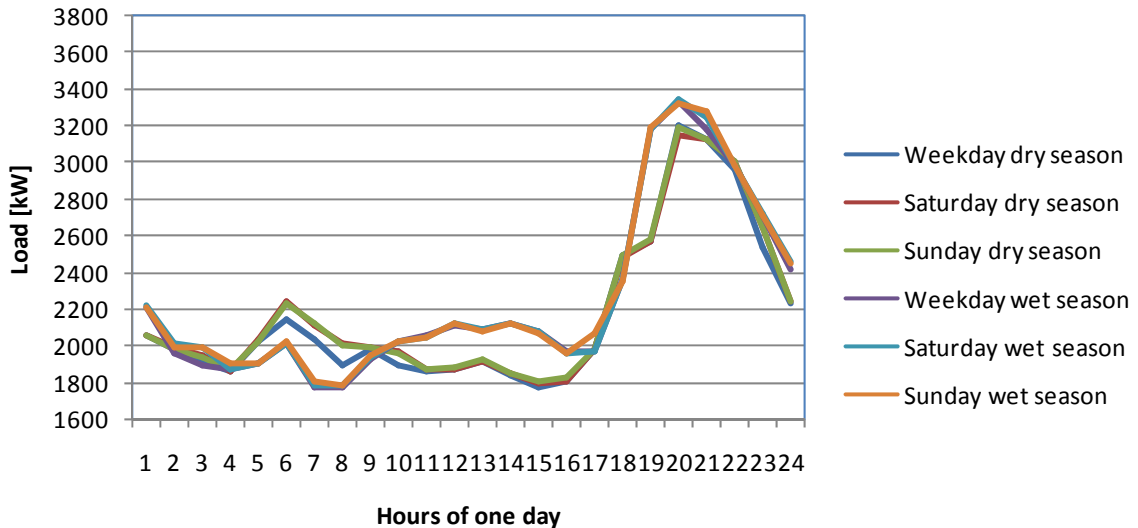
Figure 3-5   Day patterns of the Waikabubak load for weekend and weekdays for the dry and the wet season

Both systems show a clear evening peak during which the load is about 50% higher than during the days. There is little difference between week days and weekend days. The load in the dry season is 10 to 20% higher during the day and evening than in the wet season as a result of increase use of air conditioners in the dry season which is perceived to be more hot.

3.2 Demand forecast 2011-2025

The demand forecast is the basis of least cost planning and determines to a large extent the future supply. Accurate demand forecasting is very hard, especially in a fast developing environment. Since little data was available for a good demand forecast KEMA and HIVOS agreed to use the PLN demand forecast of the latest development plan RUPTL 2010-2019. The demand forecast of this plan is based on historical development and includes the PLN plans for electrification and the plans for connection of existing mini grids.

It is important to note that the demand forecast is not a goal in itself but rather a means to serve the overall objective of the least cost expansion plan. By defining a most likely base scenario together with a bandwidth of the possible development of the future demand, the least cost solution can be determined and tested for sensitivity regarding demand development. Therefore, besides a base scenario also a high and a low growth scenario have been defined as follows:

 i.   Base scenario
 ii.   High growth scenario with 50% more growth than base (i)
 iii. Low growth scenario with 50% less growth than base (i)

The considerable bandwidth has been chosen to see a clear effect of the influence of the demand on the results. It is expected that the future demand will develop between these scenarios. Based on the historical demand of the previous section and the assumption for demand growth a forecast has been made for 15 years. For the expected peak load this results in the three scenarios as shown in Figure 3-6.
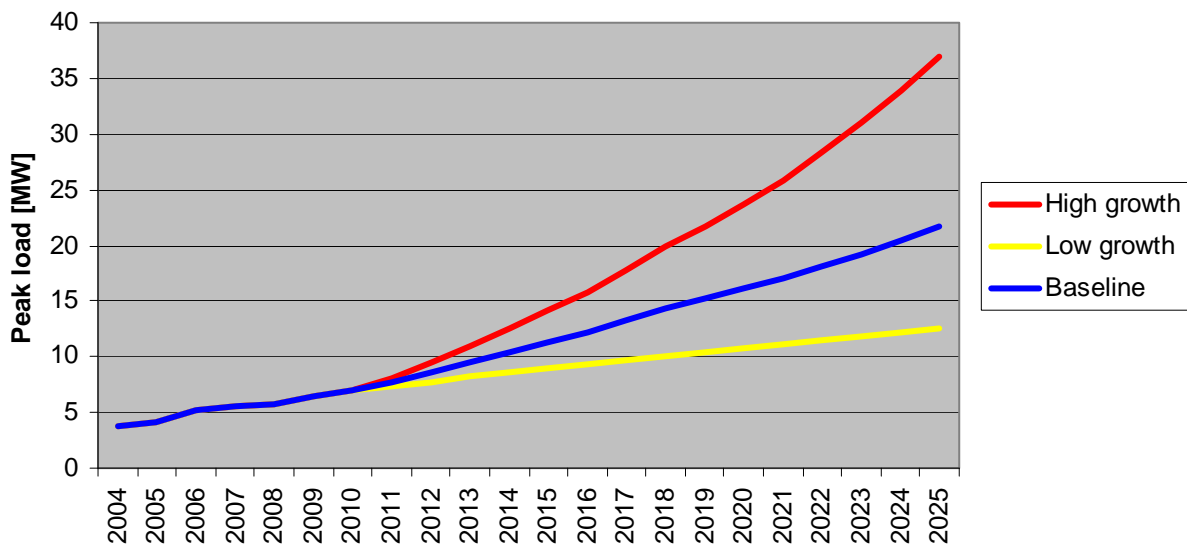
Figure 3-6   Agreed scenarios for demand growth – peak load for 15 years in MW

This forecast comprises the development of two main grids, Waikabubak and Waingapu, including the isolated grids that will be connected to the main grid in due course. The development of the current 'isolated grids' that are not foreseen to be interconnected is not part of this demand forecast.

The base forecast shows a triple consumption in 2025 compared to 2010. This is in line with the growth in the years between 2008 and 2010.

4   DEVELOPMENT OF SUPPLY

In the following, the development of the electricity supply forecast is analyzed in more detail. The assessment of existing resources has been determined and potential options for new installed capacities have been evaluated in order to select options for an optimal generation portfolio.

As mentioned, there are two major supply systems in Sumba. One is the Waingapu system which covers the town of Waingapu including most of the coast area of eastern Sumba. The other system is the Waikabubak system which interconnects the towns of Waikabubak, Waitabula and Waibokul. The systems are shown on the map of figure Figure 4-1.

Figure 4-1   Electricity distribution systems in Sumba

Both main grids are supplied by diesel power plants each containing several diesel engines of 200-800 kW. Besides these two main systems there are a number of local networks with small diesel plants containing diesel engines of 20-50 kW. These distributed diesel stations with mini grid will be connected to the main grids in due time. In the Waitabula grid there is also a PLN hydro power plant, Lokomboro, with 800 kW generating capacity.

4.1   Development of existing generating units

An overview of the existing electricity generating capacity is shown in Table 4-1 and Table 4-2 showing the available capacity for the Waingapu and the Waikabubak system.

Table 4-1 Generating units in the Waingapu distribution system

Unit	Maximum capacity [kW]	Year of commissioning
SWD DRO 216	220	1978
YANMAR 6MLHTS	220	1982
DEUTZ BA6M	180	1987
DEUTZ BA6M	120	1987
SWD DRO 216	220	1976
SWD DRO 216	200	1976
CATERPILLAR ACCER N32	550	2008
VOLVO PENTA TAD	220	2004
MTU 12V 2000G	450	2002
VOLVO PENTA TAD	220	2004
MAN 2842	420	2004
MTU 18V 2000G	430	2005
MTU V12 1600 G 20S	430	2010
MTU V12 1600 G 20S	430	2010
MTU V12 1600 G 20S	430	2010
MTU V12 1600 G 20S	430	2010
MTU V12 1600 G 20S	430	2010
Total PLTD	**5,600**	

Table 4-2 Generating units in the Waikabubak distribution system

Unit	Maximum capacity [kW]	Year of commissioning
YANMAR	220	1982
YANMAR	220	1982
DEUTZ	200	1987
SWD	200	1976
DEUTZ MWM	300	1997
MTU	390	2003
MAN 2841	300	2005
MAN 2841	400	2001
MAN 2866	220	2008
KOMATSU	400	2009
KOMATSU	750	2009
Total PLTD	**3,830**	
ALSTOM	800	2000
CROSS FLOW H	15	1999
Total	**4,375**	

The existing capacity will decrease in the course of time due to retirement of units that have reached their technical or economic lifetime. According to the generation planning in the PLN RUPTL, there is no decommissioning in the coming 15 years. In practice however old machines normally are taken out of service due to technical problems or high cost (O&M or fuel). Already now capacity is being replaced by rental machines. In this planning an optimistic maximum age of 30 years has been assumed for diesel engines. In reality this maximum age will probably be lower which will lead to more investments. For the comparison of scenarios however this has little influence. Note that for hydro power plants no decommissioning year has been defined.

Figure 4-2 shows the assumed development of the existing generating capacity.
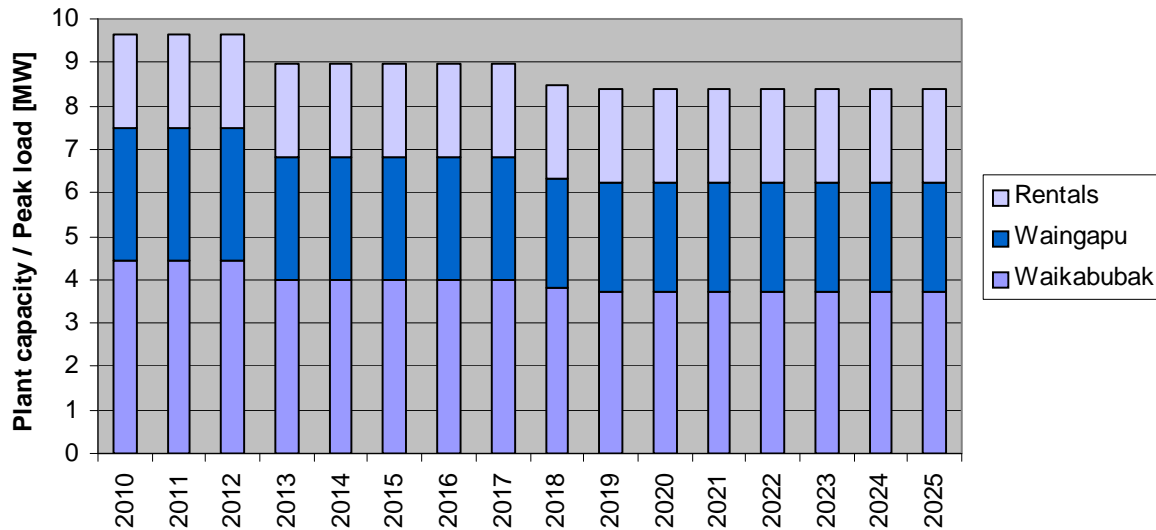
Figure 4-2   Assumed development of the existing generating capacity

4.2   Status of the existing plans for capacity extension

Besides the development of the existing generating capacity the existing initiatives for capacity extension have to be considered in the least cost plan. During the investigation the following plans came forward:

The installation of a 500 kW_{peak} photovoltaic solar installation in the Waikabubak network. Recently the Agency for the Assessment and Application of Technology (BPPT) was commissioned to design the installation of a 500 kW_{peak} solar PV system including a 1.5 MWh battery in the Waikabubak/Waitabula network. This new system will be tendered shortly and is considered part of the future supply. The systems is announced to be equipped with smart grid controls including automatic control of the diesel generators.

- Extension of the Lokomboro hydro station with two 800 kW turbines. The status of this plan is not clear. In this least cost plan the additional capacity is not considered a fixed part of the future generating capacity.

- A Korean initiative for a 10 kW wind farm. No recent developments have been found on this initiative. The additional capacity is not considered in this least cost plan.

- The distribution of 26,000 PV home systems for lighting purposes only. This is a concrete plan which will most probably be executed. The PV systems are meant for the remote non-grid areas and will therefore not influence the grid connected system.

- Extension of the diesel generating capacity of PLN with several rental diesels. This development is needed to ensure a reliable supply in the grids of Waingapu and Waikabubak. It fits very well in the least cost plan since all renewable generation capacity like hydro, wind and solar needs backup of dispatchable capacity like diesel engines.

Besides these initiatives for extension of generating capacity there are two other developments that influence the grid connected supply but from the demand side. First development to mention is the ongoing electrification in Sumba. PLN is steadily extending the network and is also connecting isolated small network to the main grids. Both actions increase the demand for the main networks. This development however has already been taken into account in the demand forecast of PLN. Another PLN plan is the interconnection of the Waingapu and Waikabubak systems with a 70 kV overhead line, probably around 2014. For the least cost plan, this interconnection is assumed to be realised indeed in 2014. The interconnection is very important for the renewable development.
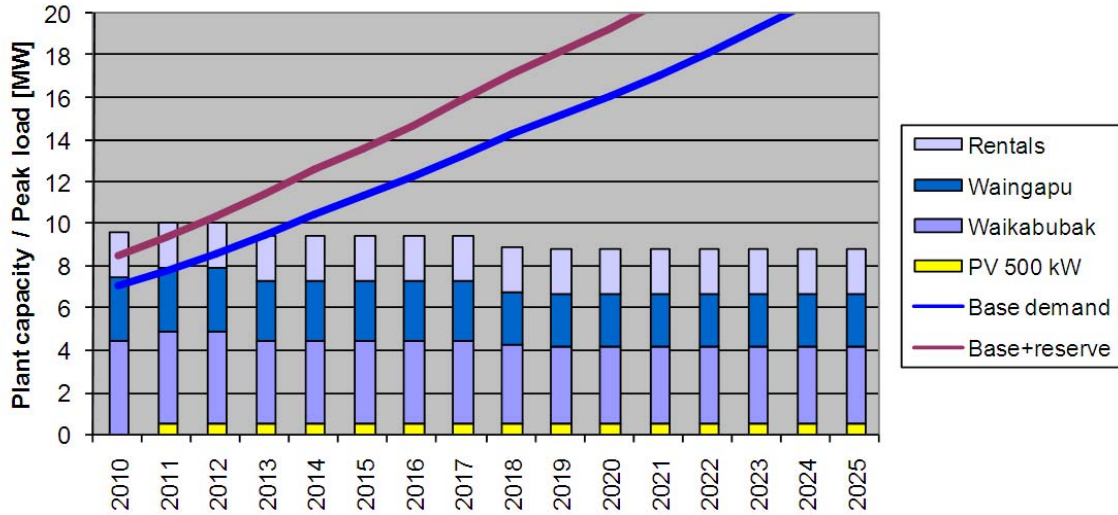
4.3   **Balance of supply and demand**

Based on the demand forecast and the development of the supply a balance of demand and supply has been made. The demand and supply balance gives an indication of the need for additional capacity. Not only the peak load must be met but additional capacity is required to compensate for maintenance and failures of generating units (15%-30% dependant on composition of the system).

For this balance the following preconditions apply:
- The balance is based on the interconnection of the two major systems, Waingapu and Waikabubak;
- A solar PV system of 500 kW_{peak} including short term battery storage is introduced this year (2011);
- In order to ensure a reliable electricity supply, 20% reserve generating capacity is considered necessary;

The future development of the demand and supply are mutually compared as shown in the next figure, Figure 4-3.

Figure 4-3   Balance of demand and supply for the interconnected system

Compared to the base load scenario of the demand forecast it looks like there is sufficient generating capacity to meet the demand until 2014. When taking 20% reserve capacity into account however extra generating capacity is already required next year (2012).

4.4   Possible alternative supply options between now and 2025

Having analyzed the future supply and demand balance, the relevant resources have to be designed. There are various technologies available to generate electricity including diesel engines, coal fired plants, gas fired combined cycle plants, solar, wind, hydro and other renewable sources. Since the aim is to develop a 100% renewable electricity supply in Sumba, only renewable options will be considered. Based on the Winrock report the following renewable sources are investigated:

- Hydro
- Wind
- Solar
- Biomass.

While in many areas in Indonesia geothermal energy is considered a good option for renewable energy, the circumstances in Sumba seem unfavourable. Another possible renewable resource could be blue energy. Blue energy uses the difference in salinity between sweet and salt water to generate electricity. The technique is promising but is expected to be commercially available only within 5 to 10 years.

The four mentioned renewable options are discussed in more detail below.

4.4.1   Wind energy

There is serious potential for wind energy in Sumba as can be seen on the wind energy map in Figure 4-4. This map is based on the wind database for Indonesia which has been set up by AWS Truepower, financed by the Dutch Agentschap NL.
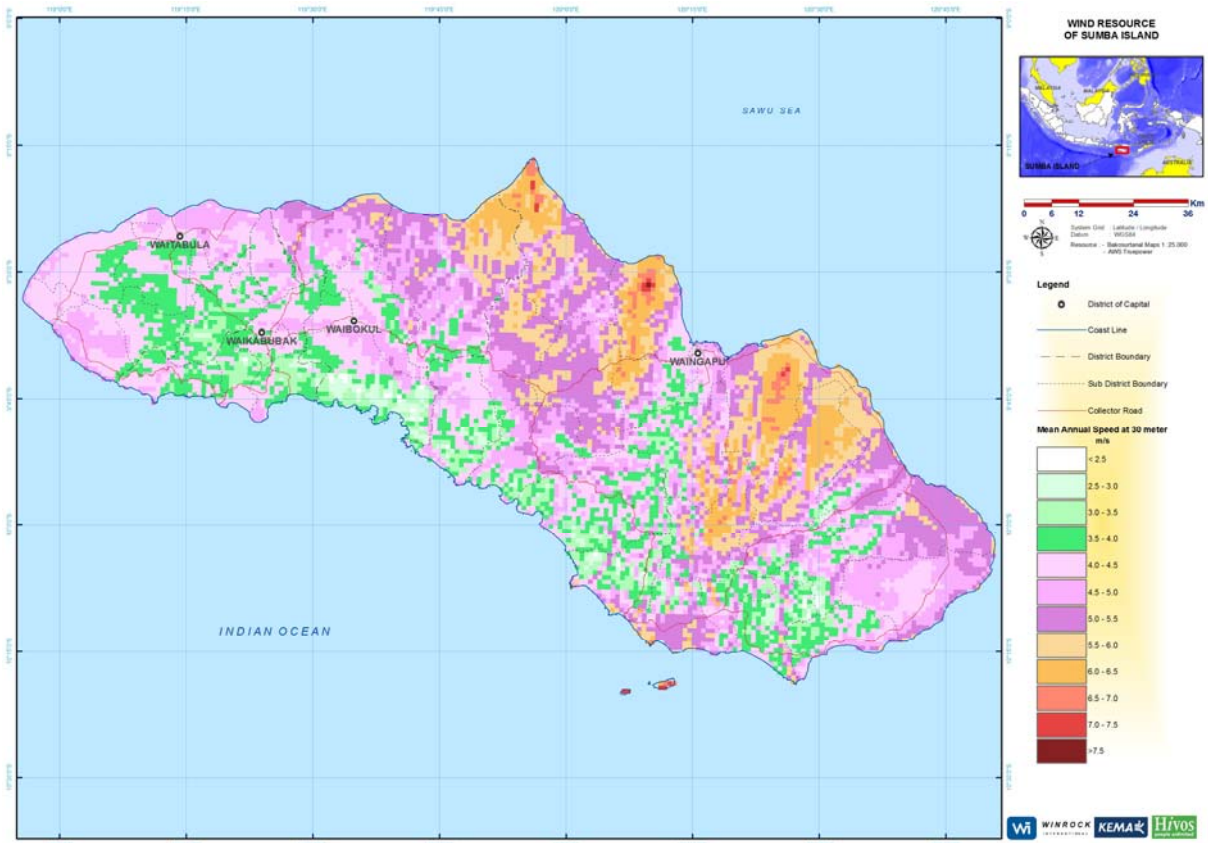

Figure 4-4   Wind energy map for Sumba

The darkest red spots represent areas with average annual wind speeds of more than 7.5 m/s which is normally considered a very good average wind speed for feasible exploitation of wind energy. Two promising location have been investigated during the field mission held in January 2011. The area explored for suitability and accessibility.

The monthly production and day patterns have been estimated using Homer software. Figure 4-5 shows the day pattern (hourly production) together with the electricity demand pattern.
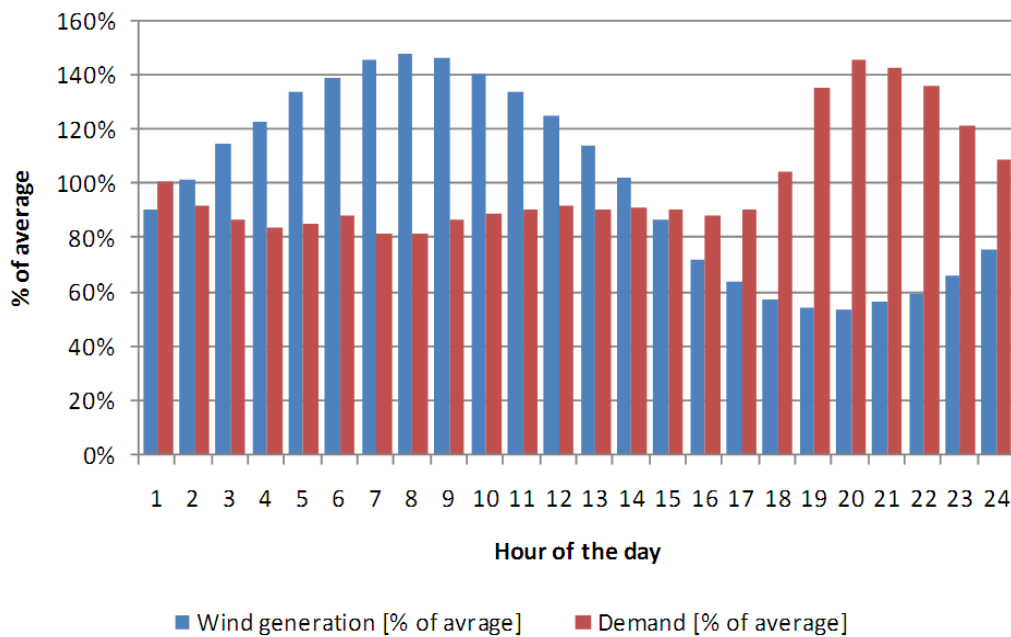
Figure 4-5   Indicative wind patterns and demand pattern – day patterns

Unfortunately, the day pattern of wind is almost the opposite of the day pattern of the demand. During the day with relatively low demand the wind contribution is the highest and during the evening when the demand is the highest, the wind is the lowest.
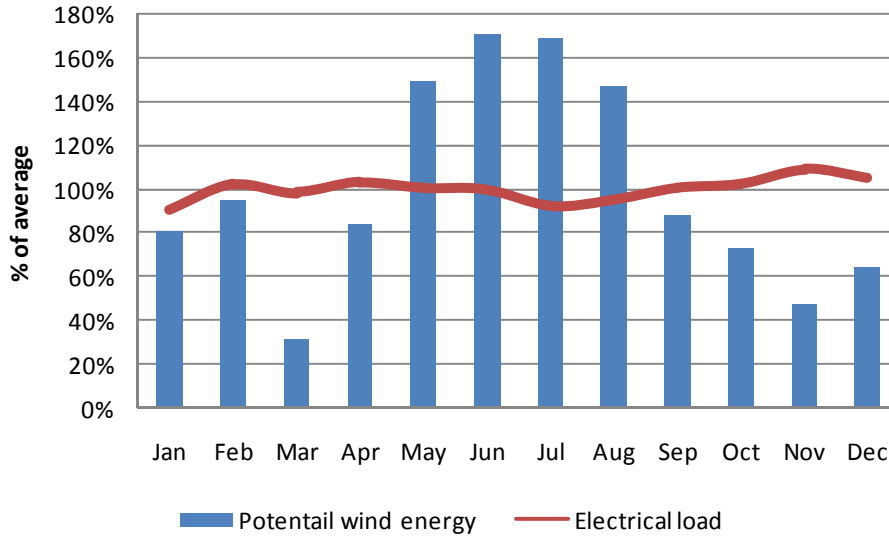
The monthly production and day patterns have been estimated using Homer software. Figure 4-5 shows the annual pattern (monthly production) together with the electricity demand pattern.

Figure 4-6   Indicative wind pattern and demand pattern – year patterns

The annual pattern of the demand is rather flat after correction for the annual growth. The wind yield however fluctuated considerable during the year. Especially in March and November there is little contribution of wind to be expected. The overall production factor is estimated to be about 30%.

The Homer software has standard assumptions of the diurnal wind distribution. Although these patterns look similar to the patterns from the AWS truepower database both sources are not based on actual measurements. Such measurements are required in order to improve the accuracy of the patterns and the production factor for further development of the wind option.

4.4.2   **Hydro energy**

For hydro both run off river and storage hydro are considered. For run off river hydro several possibilities have already been determined by PLN as shown on the map in Figure 4-7.
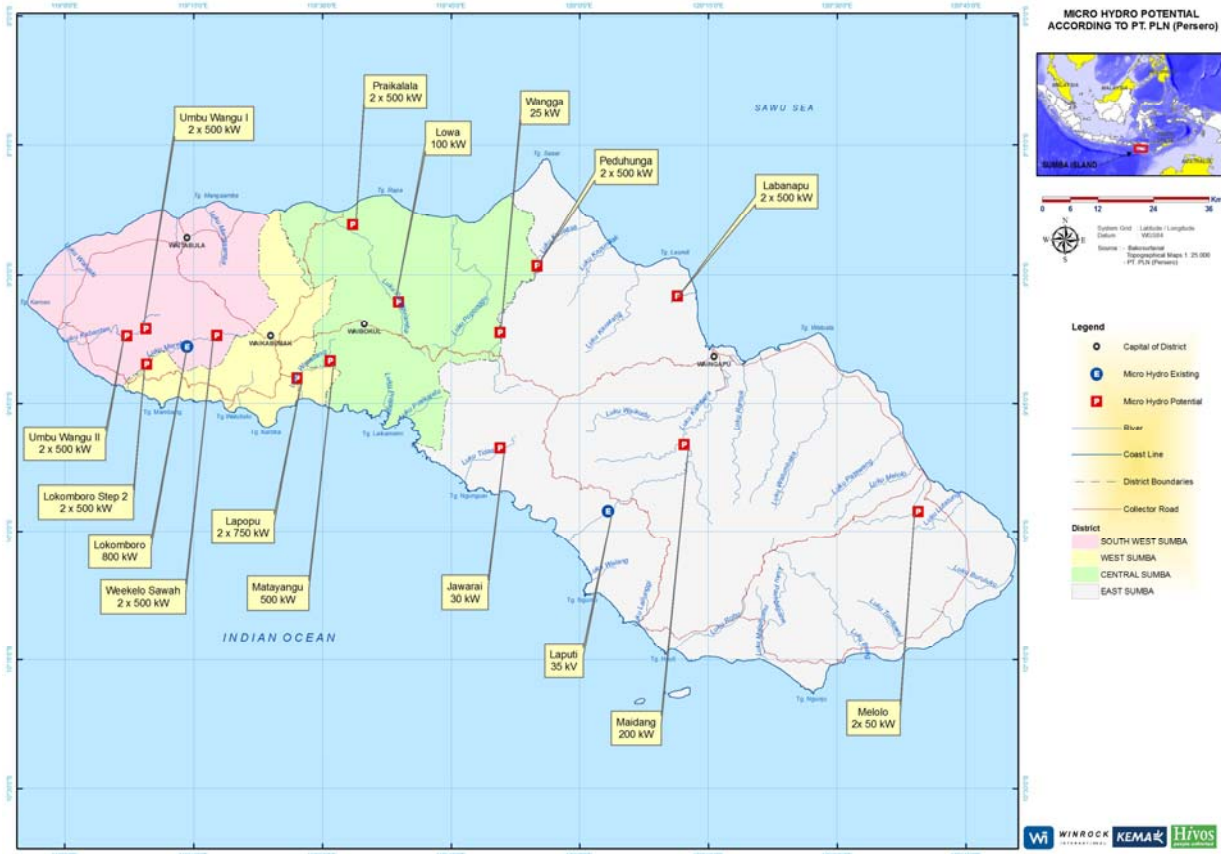
Figure 4-7   Possible hydro run off river power plants

Storage hydro

For storage hydro a dam has to be constructed which hold the water and to create an artificial lake. Such storage is very useful when integrating substantial amounts of intermittent renewable resources. As shown in the previous section the wind production during an average day is not synchronous with the demand pattern. If the capacity of the integrated wind capacity would increase, there could easily be too much wind during the day time and too little during the evening. Storage could solve this problem.

During the field mission a location has been sought for storage hydro in one of the main rivers in Sumba, the Kambaneru river. Based on GIS maps and visual survey two locations seem to be suitable to build a dam. Two options have been investigated further:

A. A hydro dam of 25.0 height and a storage capacity of roughly 400 MWh.

B. A hydro dam of 37.5 height and a storage capacity of roughly 700 MWh.

Based on these dams the generating capacity is optimized based on the flow of the river and the investment of hydro installations. Figure 4-8 shows the annual generation and the investment dependent on the generating capacity of the hydro station of the 37.5 meter dam.
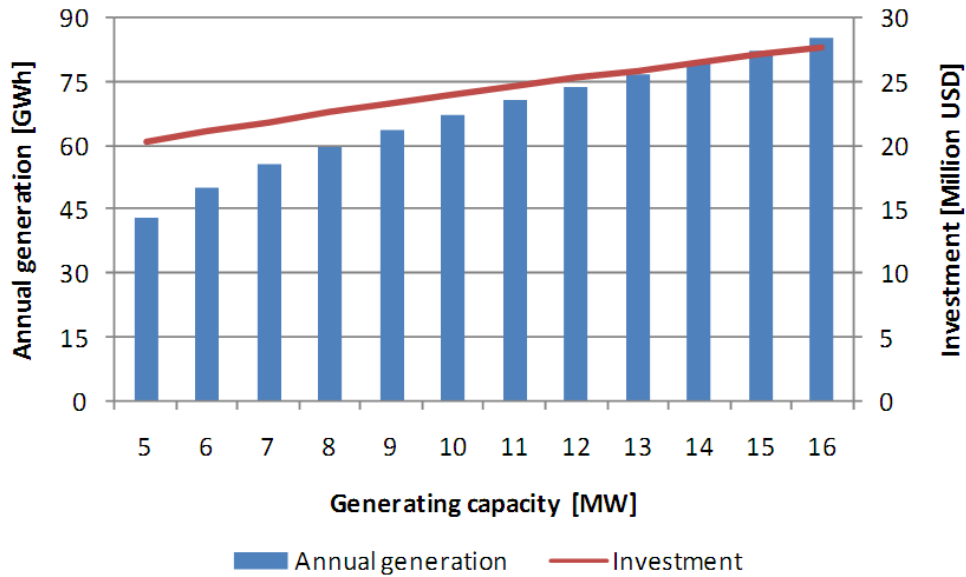
Figure 4-8   Annual generation and investment versus generating capacity of the 37.5 meter dam

Extra capacity is relatively cheap if the dam height is fixed. If for instance the capacity doubles from 5 MW to 10 MW, the investment increases with 18% but the output increases with 56%. From the calculations a 10 MW seems a good choice for the 37.5 meter dam.

Based on the flow of the Kambaneru river and the 10 MW capacity of the hydro installation the monthly generation is estimated. The results are shown in the next figure, Figure 4-9, together with the potential generation.
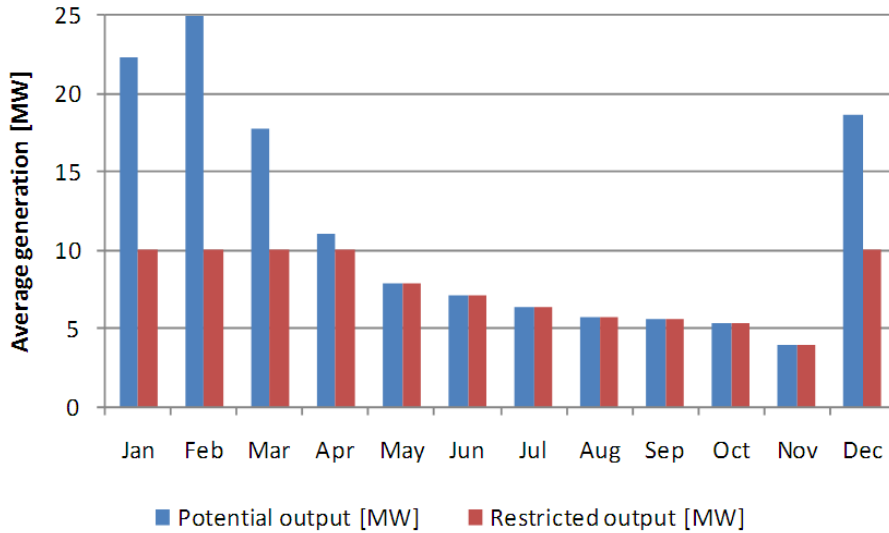
Figure 4-9   Potential output of a 37.5 meter dam and actual output at 10 MW

In the period from December to April the potential output is larger than 10 MW. The annual output of the hydro installation with a head of 37.5 meters and 10 MW generating capacity is 65 GWh. The estimated investment is 24 million USD.

The same exercise has been done for the 25 meter dam. Figure 4-10 shows the annual generation and the investment dependent on the generating capacity of the hydro station.

Figure 4-10   Annual generation and investment versus generating capacity of the 25 meter dam

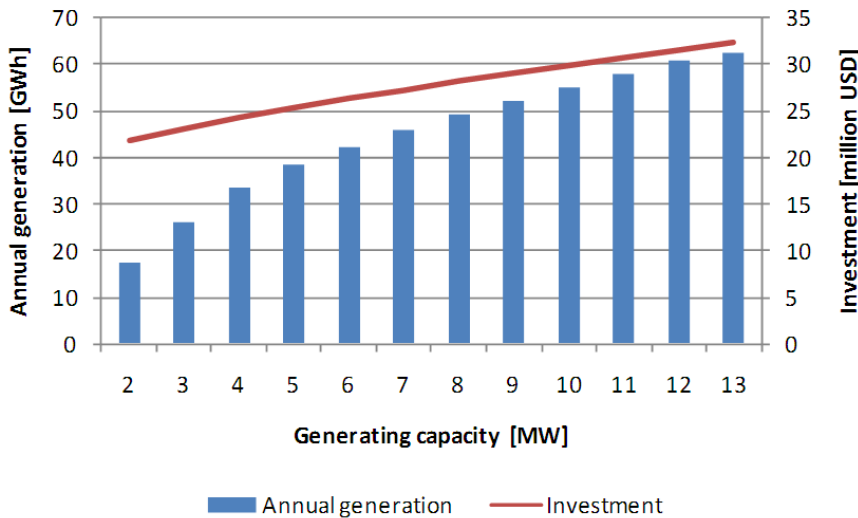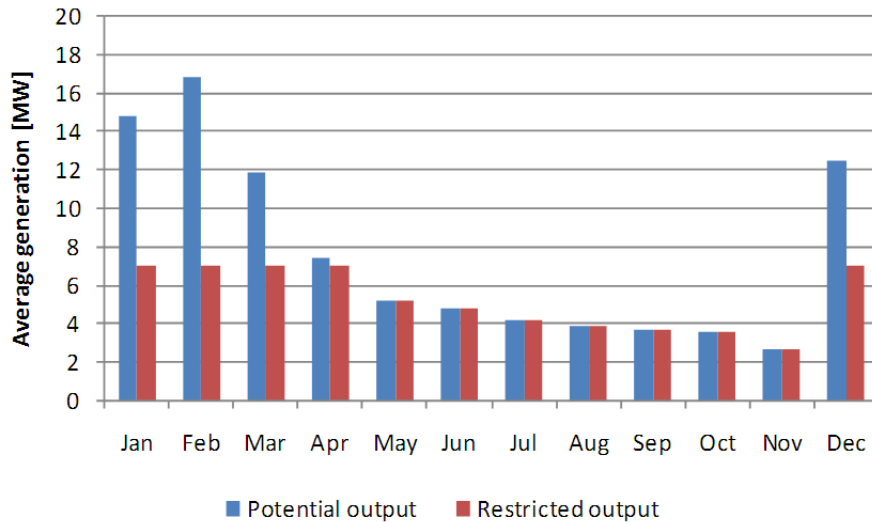From the calculations a 7 MW seems a good choice for the 25 meter dam. Based on the flow of the Kambaneru river and the 7 MW capacity of the hydro installation again the monthly generation is estimated. The results are shown in the next figure, Figure 4-11, together with the potential generation.

Figure 4-11   Potential output of a 25 meter dam and actual output at 7 MW

In the period from December to April the potential output is larger than 7 MW. The annual output of the hydro installation with a head of 37.5 meters and 10 MW generating capacity is 46 GWh. The estimated investment is 21 million USD.

Large hydro seems more attractive from the point of view of cost but the impact on the environment and society is larger. More land will be flooded and more people will have to move. For the 25 meter dam most probably no houses have to be moved. For the 37.5 meter dam some families will have to move .

During the field mission we briefly looked into the possibilities of pumped storage. With a pumped storage installation water can be pumped from a low altitude reservoir to a high altitude reservoir during periods with abundant renewable energy compared to the load. In times with a shortage this stored energy can be extracted from the high reservoir using a hydro turbine. Although there seem to be good possibilities in the vicinity of the Kambaneru river the cost of such a power plant would be substantial. For the time being it is assumed that a dam can be constructed for a reservoir hydro installation in the Kambaneru river and that this storage capacity will be used to save water when other renewable source (wind) are superfluous and to generate extra power in times of shortage.

In conclusion, the next two possible options for storage hydro will be used in the least cost investigation:

A. A hydro dam of 25.0 height giving a generating capacity of 7 MW and a storage capacity of roughly 400 MWh. For 7 MW this volume equals about 57 hours or about two and a half days;

B. A hydro dam of 37.5 height giving a generating capacity of 10 MW and a storage capacity of roughly 700 MWh. For 10 MW this volume equals about 70 hours or almost three days.

Run off river hydro

In order to determine the possible contribution of run off river hydro, generation data of Lokomboro hydro station and rainfall figures have been investigated. This leads to the following estimation of the average annual hydro pattern for Sumba based on a certain cut off capacity.
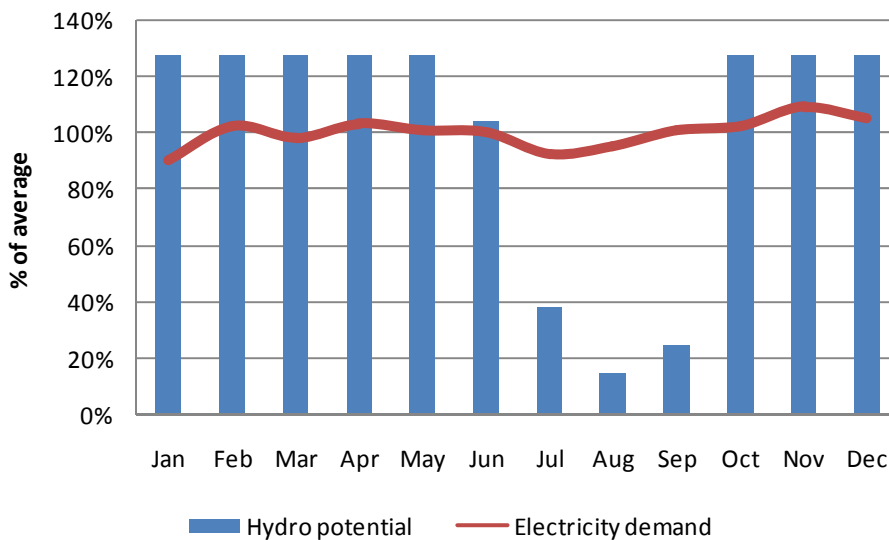
Figure 4-12   Indicative hydro pattern and demand pattern – year patterns

The hydro pattern is dependent on the location but the differences between the suitable locations are not very large. There is a clear dry period from June to October. Day patterns are assumed to be flat.

4.4.3   Solar energy

The potential for solar energy for Sumba looks reasonable based on the global potential shown in **Figure 4-13**.

Source: „Solar thermal power"; European Commission, Directorate General TREN.

Appropriate for Solar Thermal Power Plants:
excellent · good · reasonable · not appropriate
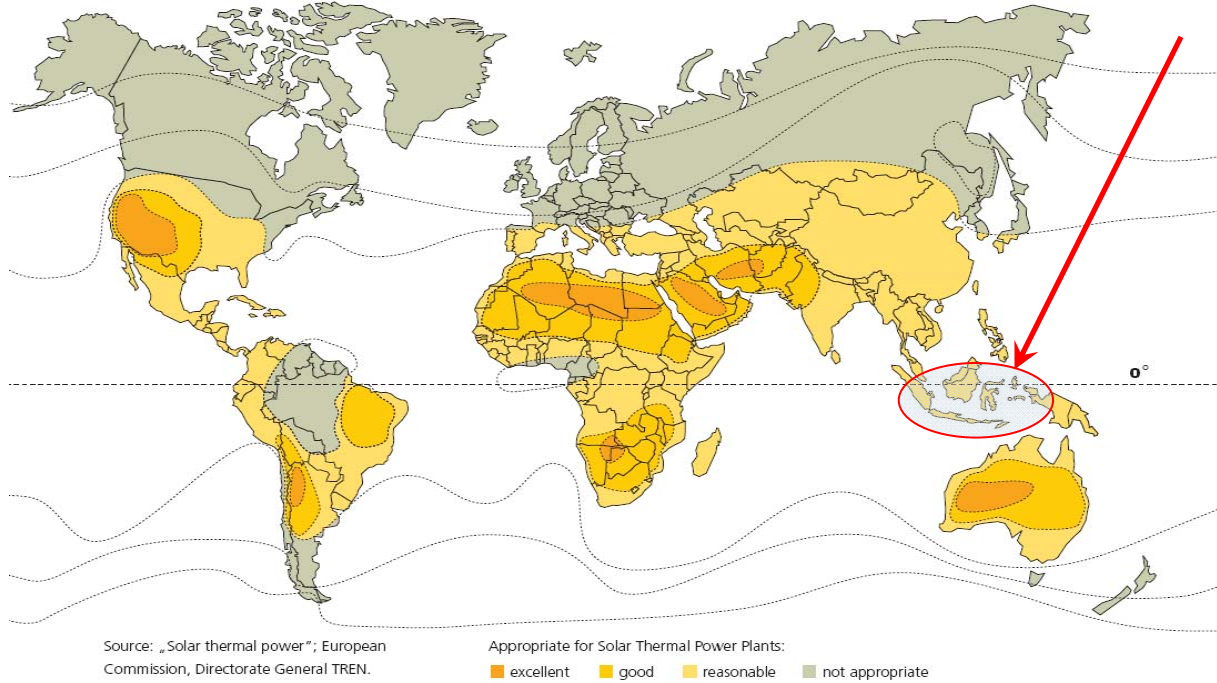
Figure 4-13 Overview on the worldwide solar thermal power potential - highlight on Sumba

The next figure reveals that the solar insolation is one of the best in Indonesia.
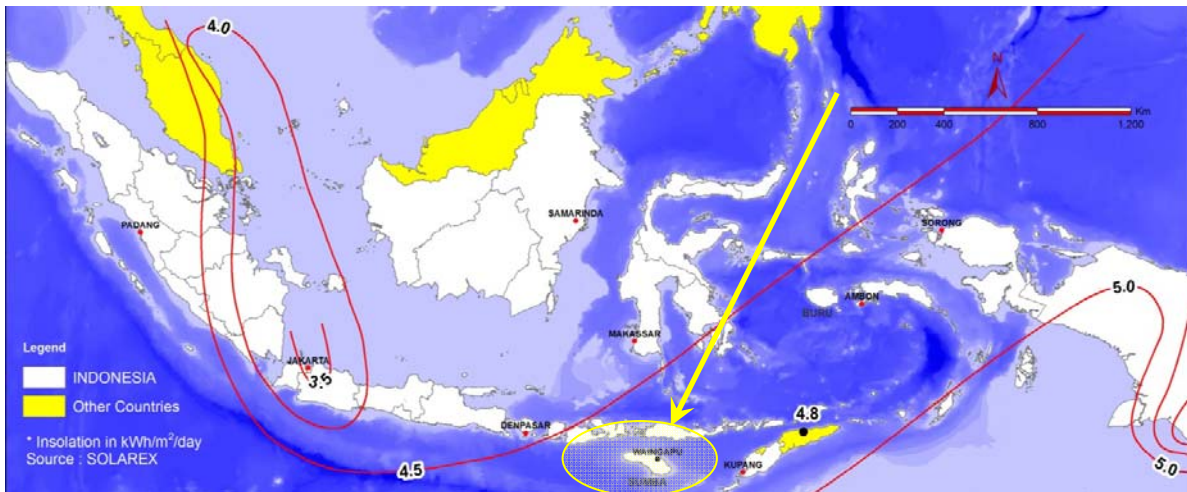
Figure 4-14 Insolation in Indonesia in kWh/m^2 with highlight on Sumba

At the present level of fuel prices (90-100 USD/bbl of crude oil), the cost of solar energy is still higher than large scale fossil electricity generation. However competition with small scale generation is much more promising due to the high prices of small scale production due to e.g. economy of scale and transport of diesel oil. If investment for solar energy drop as is expected and oil prices continue to be high, this option will become competitive in the near future.

Figure 4-15 shows the expected development of concentrated solar power (CSP) in the coming decades.
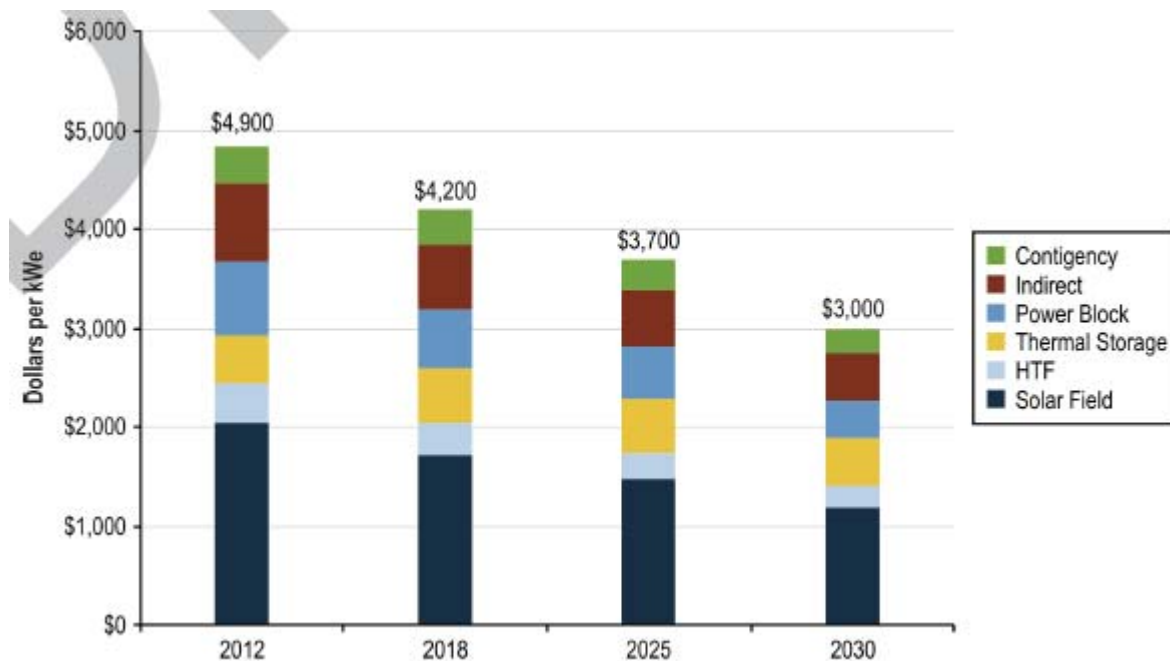
Source: Solar Vision Study, U.S. Department of Energy (DOE) Solar Energy Technologies Program, draft version of May 2010.

Figure 4-15   Expected investment drop for CSP in the coming decades

This investment is based on large installations of in the order of magnitude of 100 MW. For Sumba an installation of 5 MW would probably suit the supply system for electricity. In the least cost investment study an investment of 6000 USD/kW has been used. The assumed solar technique could be either thermal CSP or PV. The final choice depends on the best option by the time a decision needs to be taken.

The generation pattern of solar energy is, like the wind pattern, not favourable for the demand pattern in Sumba as can be seen from Figure 4-16. The demand is low when the sun shines and the demand is high when it is dark.
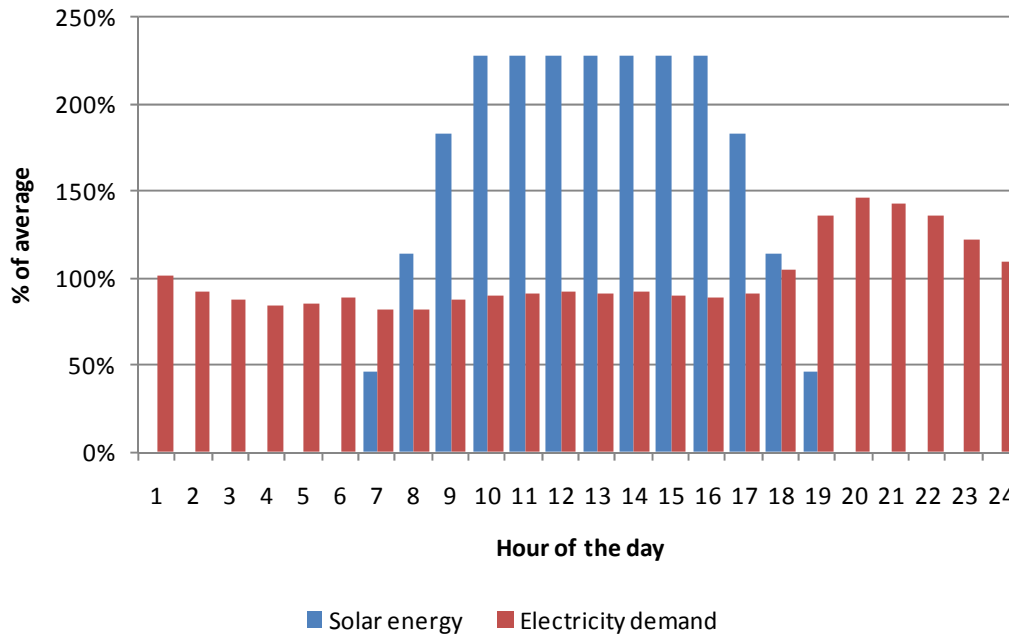
Figure 4-16   Indicative solar pattern and demand pattern – day patterns

The annual pattern is rather flat although the insolation in the wet season is a bit lower than the insolation in the dry season.

4.4.4   Bio energy

Biomass can be used in different ways. It can be burnt directly to produce heat for steam production which can be used in a steam turbine installation to generate electricity. Biomass can also be converted into biogas or biofuel. Both the biogas and the biofuel option including the potential in Sumba have been investigated in the Winrock report. The biogas is recommended for remote areas rather than for the grid connected supply. For the latter the biofuel is more suitable. This fuel can be used for the existing diesel engines instead of the diesel oil.

The potential for biofuel seems large enough to generate all required electricity in the coming decades. The viability however also depends on the cost of this biofuel. The idea to grow Jatropha for the production of biofuel (Sumba seemed to have good potential for Jatropha) has encountered some negative stories about yield and cost recently. More research in the potential of Jatropha is needed for a final conclusion on this crop as biofuel source at Sumba.

Palm oil may be an alternative. The yield of palm oil is about 3.7 ton per ha which is 4.5 to 7 time the yield of rape oil, soy bean oil or sunflower oil. Production of palm oil would mean work for many people. Figure 4-17 shows the historical price of palm oil on the world market. Palm oil is considered the cheapest vegetable oil even if it is produced in a 100% sustainable way (10-15% more expensive than non-sustainable)[2]. Yield has increased by 38% from 1976 to 2010 and further potential growth is expected. However, palm oil needs 'flat & wet' areas to be grown commercially which are difficult to find on Sumba. It would grow in the higher and central area of Sumba but harvesting might prove difficult
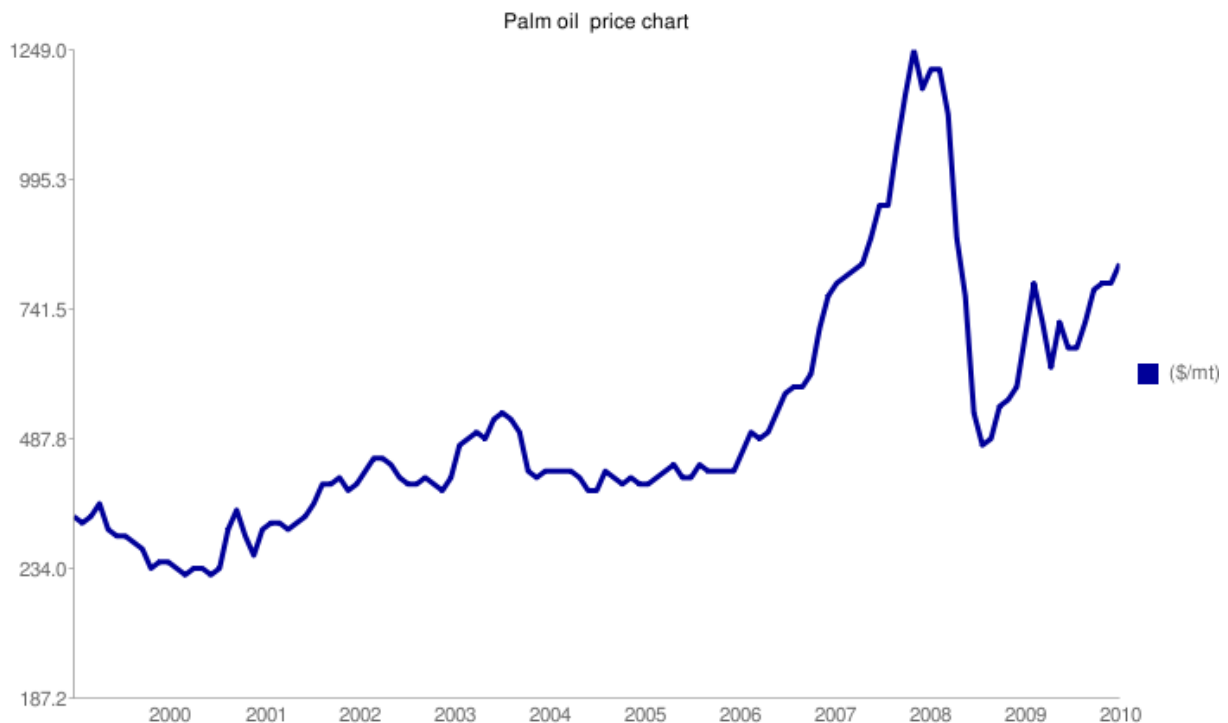
Figure 4-17   Historic price of palm oil on the world market

A level of 700 USD/ton is comparable with LFO (Light Fuel Oil) prices at a crude oil price of 100 USD/bbl. LFO is about 25% more expensive than crude oil and gives a price of 19 USD/GJ. This price is without cost of transport. Prices of palm oil have risen in 2010 and reached again levels of more than 1200 USD/ton due to shortages on the world market. If produced on Sumba the cost of palm oil could probably be lower than that and cost of transportation can be low. For the least cost investment the price of biofuel is assumed to be equal to the price of diesel oil.

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[2] Interview with Frans Claassen, director of the "productschap" margarine, vetten and oils, Trouw of 31 January 2011

In the future biofuel from algae may be a good alternative for palm oil of Jatropha.

4.5   Selection of resources

The following observations were made based on the previous sections regarding the different renewable resources.

- Wind
  - There are several locations with good conditions
  - The potential capacity is much larger than peak load.
- Hydro
  - There are several locations with good conditions
  - Potential capacity 20-30 MW
  - There seems to be good possibilities for storage hydro (dam).
- Solar
  - Circumstances for solar energy are reasonable regarding insolation
  - Expensive but new developments could make solar cost effective in due time
  - Potential electricity generation is superfluous.
- Biofuel
  - Potential for biofuel is large enough for electricity generation in the coming decades
  - Cost of biofuel is uncertain.
- Geothermal
  - Conditions in Sumba seem not suitable according to ESDM
  - Relatively small size for geothermal.

Following the investigation in the previous four sections, in this section a comparison is made to choose the best options for a 100% renewable electricity supply in Sumba. This comparison of options is based on:

- Investment
- O&M cost
- Expected generation
- Social impact
- Risks.

Fuel prices are an important input for the least cost calculations. They highly influence the cost comparison of possible investment projects. Since there are no liquid forward markets for the fuels at such time horizons, we must rely on forecasted prices.

4.5.1 **Fuels**

For the 100% renewable development of the electricity supply of Sumba in fact no fossil fuel is used. The prices of fossil fuel therefore seem less relevant. However, in order to compare the renewable options with the business as usual (BAU) scenario the prices of diesel oil (light fuel oil or LFO) are required.

For the biofuel option the cost of biodiesel must be known in order to calculate the generating cost of the diesel generators based on biodiesel. As mentioned in section 4.4.4 these cost are uncertain, therefore the price of LFO is used as a proxy for the biodiesel price.

For the selection of resources, three fuel price scenarios have been defined. Considering the variance in changes in oil prices a large bandwidth has been taken between the fuel price scenarios.

4.5.2 **World price crude oil forecasts**

For the investigation into the world price forecasts for crude oil the oil price forecast from the Annual Energy Outlook 2010 (AEO2010) and the early release of the AEO 2011 were used. The oil price forecasts are summarized in Table 4-3.

Table 4-3   Base Crude Oil price forecasts in real 2009 USD per barrel

Forecast ($/bbl)	2008	2009	2025	2035
Low-sulfur crude oil AEO2011	100.5	61.7	117.5	125.0
Low sulfur crude oil AEO2010	100.5	61.7	115.1	133.2
Crude oil AEO2011	93.4	59.0	107.5	114.1
Crude oil AEO2010	93.4	59.0	104.5	121.4

Figure 4-18, shows the reference oil price forecast of AEO2011 for low-sulfur crude oil together with the high and low oil price scenarios.
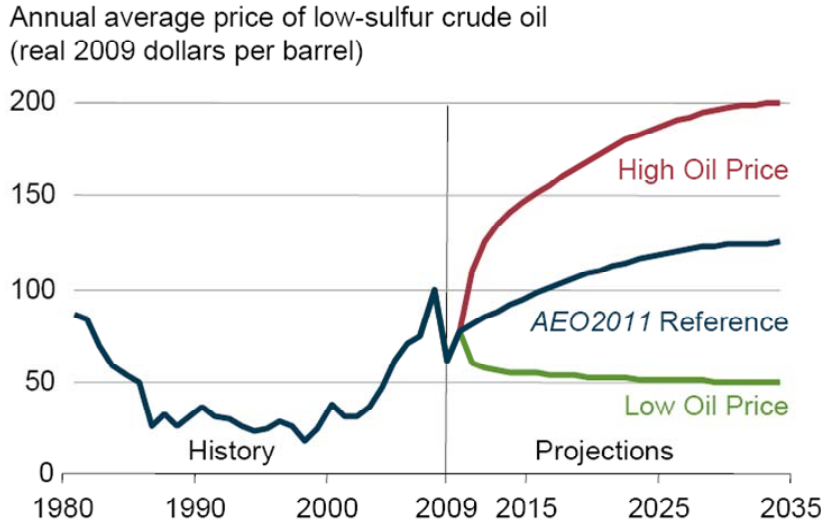
Source: AEO2011 Early release

Figure 4-18   Oil price scenarios Early Release of AEO2011

Based on this information KEMA and HIVOS agreed to use a base development scenario of 100 USD per barrel as a flat rate (real USD) for the total period from 2011 to 2025. The low fuel price scenario is based on 50 USD/bbl and the high fuel price scenario is based on 150 USD/bbl. The fuel for the diesel engines is light fuel oil which is historically about 25% more expensive than crude oil. The proposed scenarios for crude oil and light fuel oil are shown in Table 4-4.

Table 4-4   Proposed scenarios of oil prices in real USD

	Crude oil	Light fuel oil
Base fuel price scenario	100 USD/bbl	125 USD/bbl
Low fuel price scenario	50 USD/bbl	63 USD/bbl
High fuel price scenario	150 USD/bbl	188 USD/bbl

4.5.3   Economic comparison of generation options

The selection process of the options for generation portfolios is based on so-called "screening curves". This approach implies the comparison of on the one side the capacity utilization of two or more technologies and on the other side the annual generation cost utilization hours. Table 4-5 gives an overview on the parameter assumptions applied to the different generation options using typical sizes for the different technologies.

Table 4-5   Overview on assumptions applied to the different generation options

Option (typical size)	Capacity [kW]	Investment [USD/kW]	Life time [Years]	Fixed O&M [USD/kWa]	Variable O&M [USD/MWh]	Efficiency or production [%]
Wind energy	500	2,000	25	35	12	32%
Hydro	1000	2,000	40	38		75%
Hydro	7000	3,000	40	38		75%
Hydro	10000	2,400	40	38		77%
Solar energy PV	500	6,000	25	20	1	35%
Solar energy SEGS	5000	6,000	25	75	3	35%
Biomass	2000	6,000	25	400	1	24%
Diesel plants	500	1200	25	25	20	35%

The selection process aims to provide an indicative ranking of the existing supply options and is based on several performance indicators (e.g. average unit cost and utilization) per unit. This approach helps to quickly determine the feasibility of a certain investment based on which future generating configurations (scenarios) can be composed.

The following figures below show the results of several "screening analysis" for the purposes of the pre-selection process. The analysis focuses on the influence of fuel prices and studies hereby the impact of the carbon allowances price.
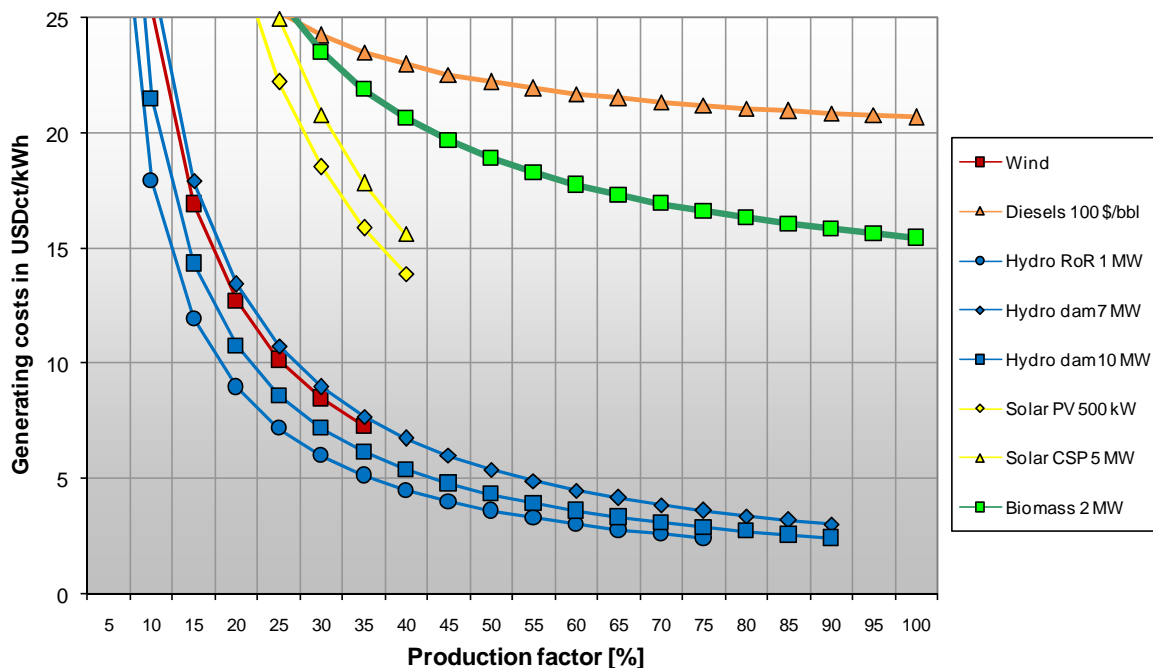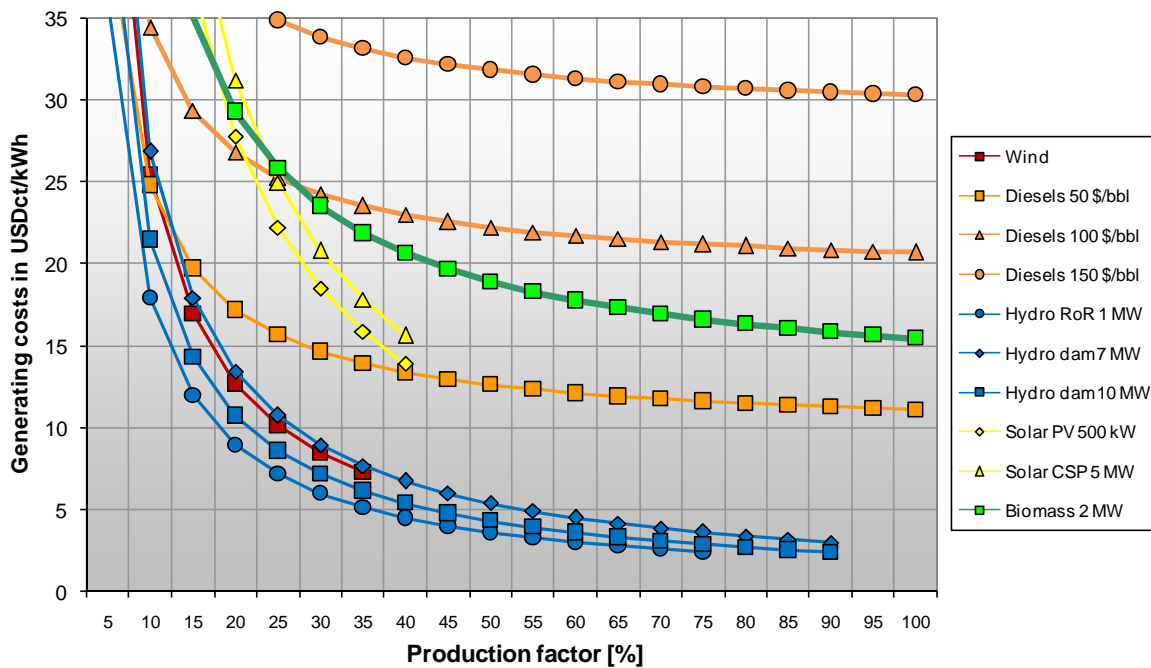

Figure 4-19   Cost comparison generation options: Crude oil price is 100 USD/bbl

At the present price level of fossil fuel (crude oil prices of about 100 USD/bbl) renewable options are by far the cheaper options for an island like Sumba. Even solar, at the assumed investment cost, shows lower generating cost than the diesel units. Hydro and wind are much cheaper than diesel generation Hydro is the cheapest option at the assumed investment cost. It should be noted that the cost of diesel oil is assumed to be equal to world market prices without any subsidies. The costs of electricity generation based on biodiesel is assumed to be equal to the cost of diesel generation based on fossil fuel since the price of biodiesel is assumed equal to the price of fossil fuel (LFO or light fuel oil).

In the comparison no value for CO_2 has been incorporated. Adding the price of carbon emissions makes the diesel option on fossil fuel even more expensive.

The comparison has also been made for the low and high fuel prices being 50 USD and 150 USD per barrel of crude oil. The results are shown in Figure 4-20.

Figure 4-20   Cost comparison generation options for different crude oil prices

At a first glance it becomes obvious that the comparisons show a high dependency on fuel price assumption. However even at low fuel prices hydro generation is very favourable. Compared to the diesel generation also wind is always cheaper. The compatibility solar depends on the price for diesel oil.

The selection of viable options serve for further investigation and inclusion in the modelling approach (see Chapter 5.2) in order to get the optimal generation plan, which should be of course feasible and minimize the construction and operation costs for the grid connected electricity supply in Sumba during the modelling period.

5 PRODUCTION PLANNING

This chapter focuses on the analysis of the different options for power generation and heat production. Based on the results of the analysis, conclusions are drawn concerning the cost-effectiveness and sustainability of the assessed configurations. This approach gives important insights into the process of choosing the overall portfolio for electricity and heat production in the upcoming years.

5.1 Definition of production configuration

The balance of supply and demand indicates a shortage of capacity already in 2012. This shortage needs to be overcome by the extension of generating capacity. In Chapter 4 the development of supply has been discussed. Options for additional generating capacity have been defined and a pre-selection of options has been made. Based on that, the optimum future supply will be determined as shown in the following sections.

From the investigation the following observations were made:
- It is not possible to compose a 100% renewable electricity supply based on 100% wind or 100% hydro without back up and/or storage
- 100% biofuel will be more expensive than a combination with hydro and/or wind
- Solar options are still too expensive but maybe feasible in the (near) future.

The first observation is illustrated in the next figure where the duration curve of the forecasted load in 2015 is plotted together with the annual contribution of the planned solar system, the existing hydro and the possible hydro dam of 7 MW.
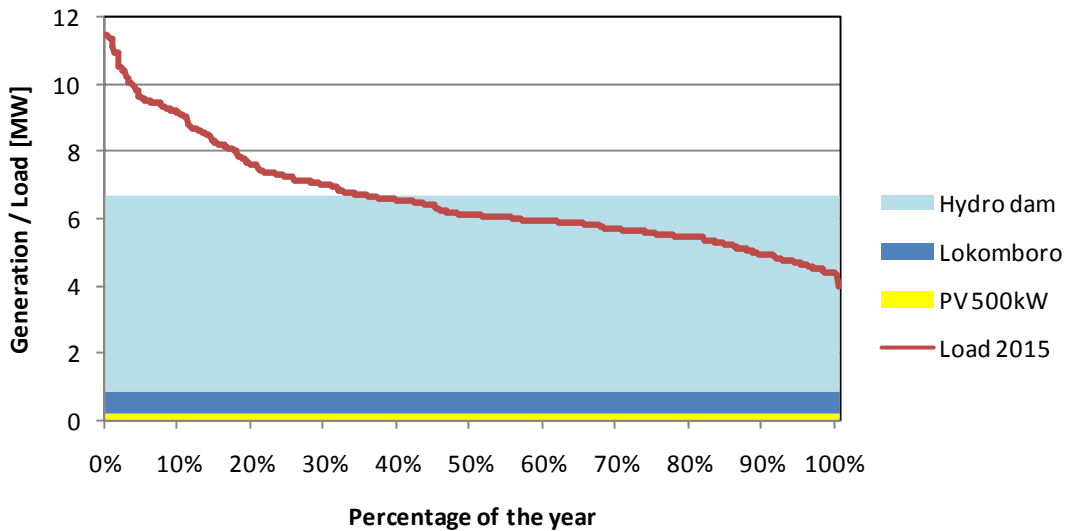
Figure 5-1   Load duration curve of 2015 with generation of hydro and solar

The figure shows that during 30% of the time the load is higher than the generation. Adding extra hydro or wind capacity would be too expensive since the remaining load is to low to compensate for the investment. This 30% can better be supplied with biodiesel using the existing diesel generators.

Based on the observations scenarios have been defined with combinations of hydro, wind and biodiesel for the 100% renewable supply. The following general ideas are used for the scenarios:

- Low investment scenario:
  – Limited hydro / wind and existing diesels on biofuel
  – This limits the investment but will keep variable cost maybe high
- Low variable cost scenario
  – Maximum hydro and wind with hydro storage and minimum biofuel
  – This minimizes the variable cost but has larger investment
- Business as usual with diesels using diesel oil
  – 100% of the generation based on diesel oil
  – This minimizes investment but gives high variable costs

5.2 Optimization of the production configuration

The selection of viable options as explained in Chapter 4 serve as input for the modelling approach in order to get the optimal generation plan and thus capacity investments for 2025, which should be feasible and minimize the construction and operation costs for the electricity supply system during the modelling period. The optimization determines the optimal size, location and timing of new investments. The optimal size will be determined based on availability, economy of scale and the balance of supply and demand (reliability). The construction timing will be mainly determined by the demand and supply development and the required level of reliability.

In the following part of the report, section 5.2.1 presents the optimization model, section 5.2.2 the modelling assumption, and section 5.2.3 finally discusses the simulation results.

5.2.1 Optimization model

For the optimization of the future electricity generation an Excel model has been made. This tool simulates the supply and demand balance on an hourly based and calculates the contribution of each resource. Energy storage is also part of the model. The model performs economic calculations based on the investment, operation and maintenance and fuel cost.
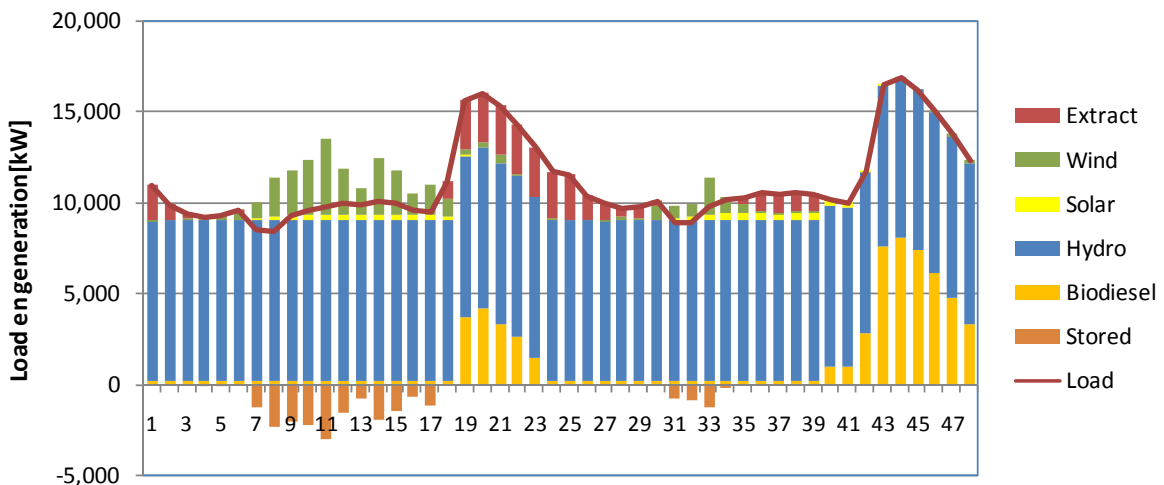

Figure 5-2   Example output of the model for two days

The figure shows that during the fist day the wind energy cannot be absorbed by the load since there is sufficient hydro to meet the load. This wind energy is virtually stored in the hydro reservoir by reducing the hydro output and feeding the wind into the grid. From hours 19 to 28 the hydro inflow is not enough to meet the load and extra water is extracted. From hours 19 to 23 there still is a shortage so biodiesel is added to meet the load. The water level in the lake needs to be kept at a certain minimum to get sufficient head for the turbines. Once this level is reached no extra extraction is allowed. This can be observed during the second day from hour 40 and further. Only biofuel is used then to supplement the hydro.

5.2.2   Model assumptions

Demand
As demand forecast for 2025 the modelling approach has referred to the demand forecast presented in section 3.2.

Supply
The development of installed capacities is based on the existing capacity and the scenarios for decommissioning schedules and extensions plans (see Chapter 4).

With respect to technical and economic data, the same figures have been used as applied in the selection of options (see Table 4-5). For the simulations also the following assumptions have been taken:
- Real prices are used
- The basis for the fuel price scenarios is the crude oil price
- Price for biofuel is set to equal to the price of diesel oil.
- For crude oil a base scenario of 100 USD/bbl flat rate until 2025 is used. The assumed prices of the high and low scenarios are 150 USD/bbl and 50 USD/bbl
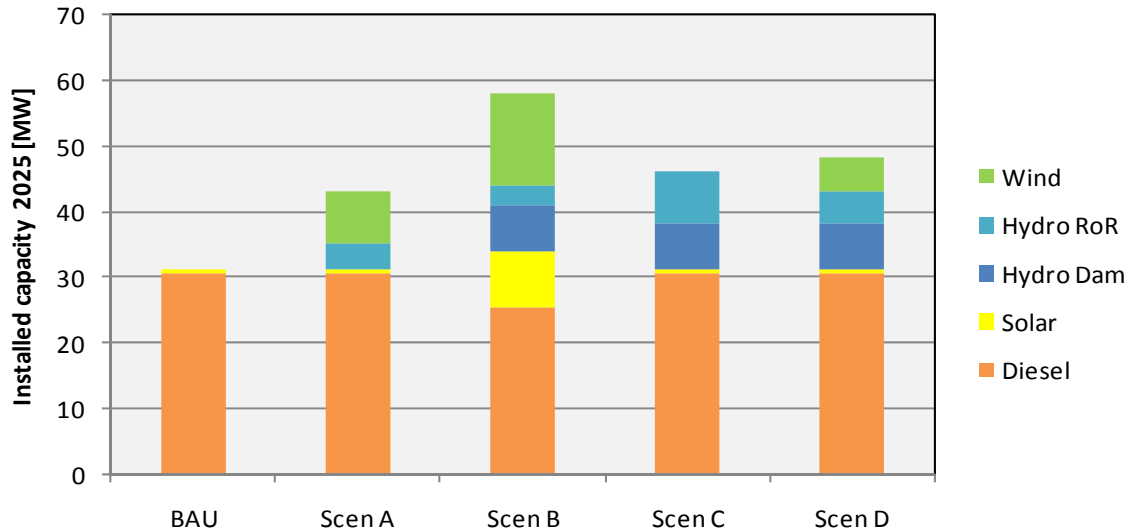- No price for CO_2 or Carbon Credits are assumed.

Simulation Scenarios
Four 100% renewable scenarios and one business as usual scenario have been investigated and mutually compared as described further in the next section.

5.2.3   **Simulation results**

Figure 5-3 shows the composition of the five scenarios that were investigated.


Figure 5-3: Composition of new generating capacity - base demand scenario

In all scenarios there is about 30 MW of diesel generating units except for scenario B. This capacity is required to ensure a reliable generation also in times of lack of hydro, wind or solar. In scenario B the capacity of diesel generation is a bit less due to the contribution of solar energy which is more reliable than wind energy. Even on cloudy days there is still a contribution of solar energy. In the business as usual scenario the diesel generators are the only source for the electricity except for the announced 500 kW_{peak} solar installation. The other scenarios have additional wind and/or hydro:

- Scenario A: Scenario without storage which limits the sensible amount of wind and hydro. Adding more wind or hydro would dramatically increase the required curtailment of renewable energy since the system cannot absorb all generated electricity
- Scenario B: This scenario contains maximizes the contribution of renewable energy with much hydro, wind and solar.
- Scenario C: This scenario contains a larger hydro storage and maximizes the amount of additional run off river hydro.
- Scenario D: This scenario also contains a larger hydro storage and adds both wind and hydro.

All five scenarios have been modeled in Excel and simulations have been made to calculate the contribution of the various resources. The average contribution has been plotted in Figure 5-4 below.
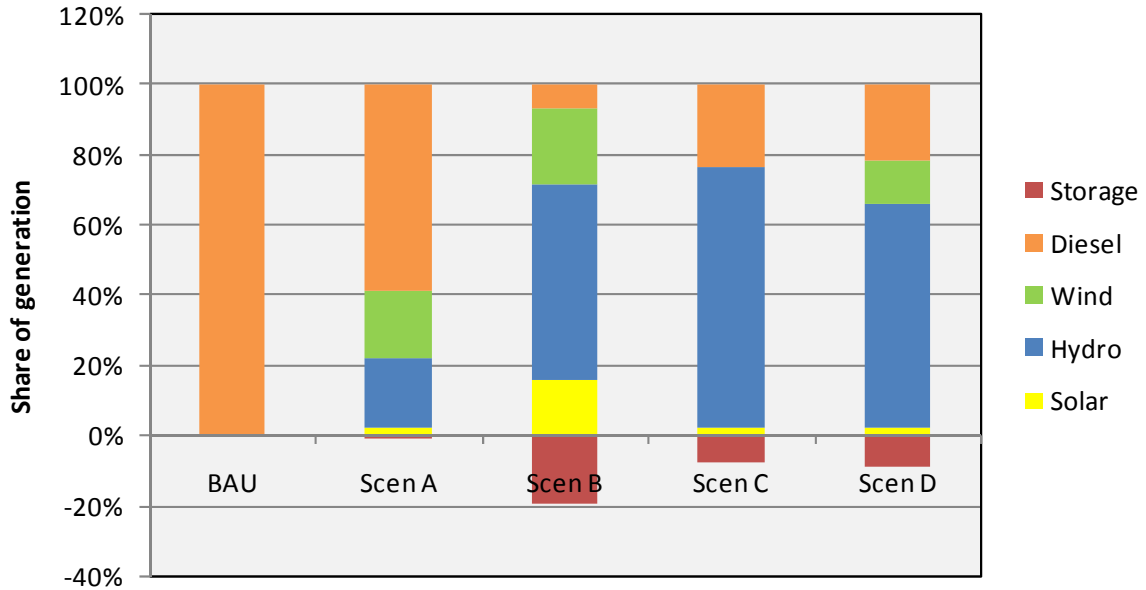
**Figure 5-4   Average contribution of resources in the overall generation**

The above shown results are based on the base scenarios for fuel prices and demand development. At higher fuel prices the share of diesel generation could be somewhat lower at the cost of larger investments in wind or hydro but the differences are relatively small. At higher or lower demand the share of the different resources will remain comparable to those in Figure 5-4. This will require more or les investment in all resources.

6 ECONOMY

The investments of the optimum plan and the cost price of electricity are discussed in the next sections.
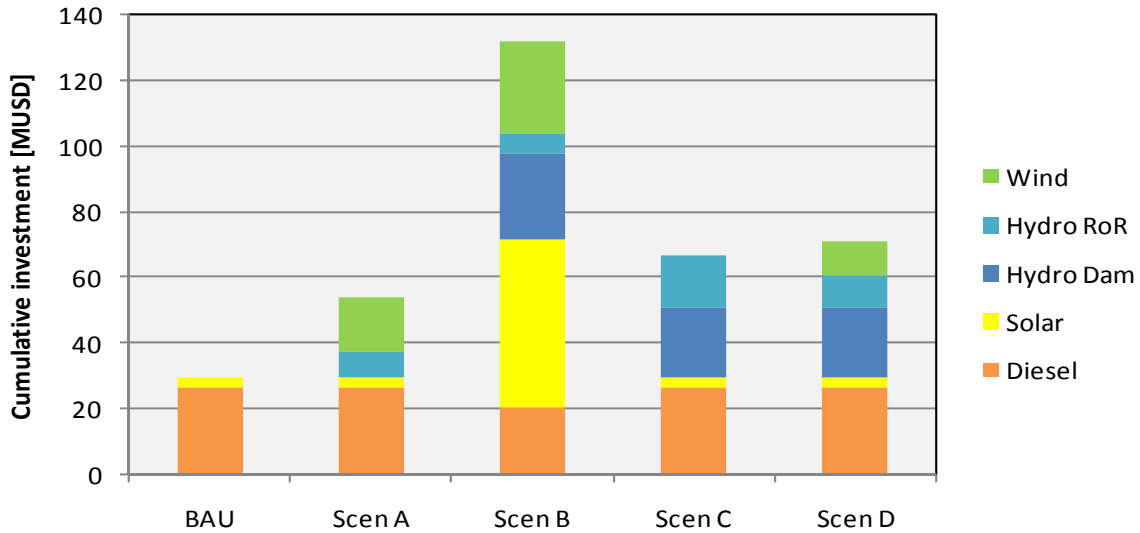
6.1 Investments

This section gives a rough estimate of the required investment of the expansion plan. The cumulative investments of the base scenario of the least cost plan are shown in the figure below.
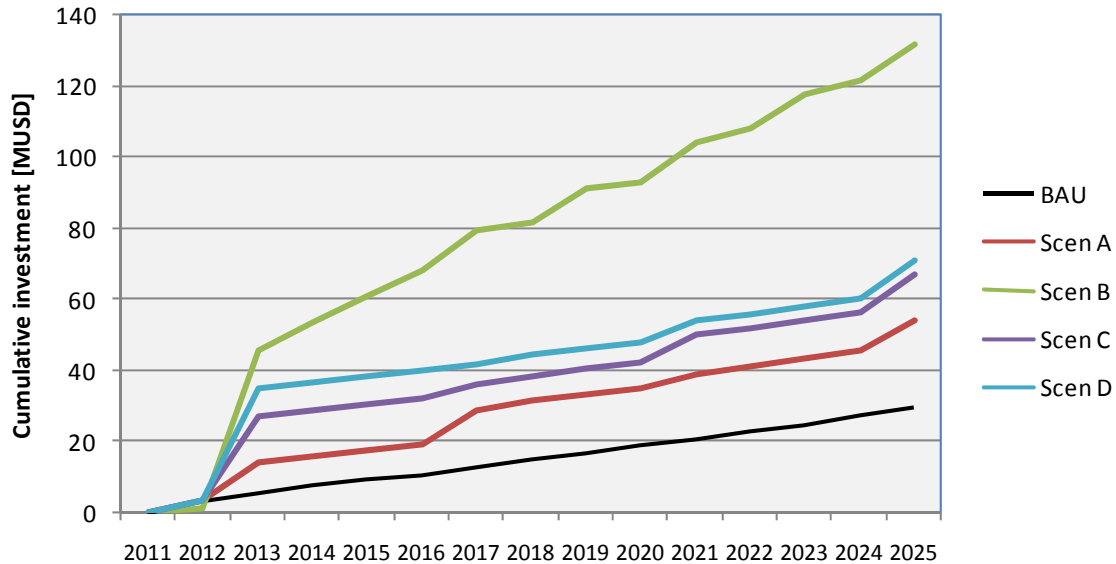
Figure 6-1   Estimate of investments for the least cost solution for five scenarios

The investment of the renewable scenarios are all much higher than the investment in the business as usual scenario with only diesel generators running on diesel oil. Scenario B with maximum hydro, wind and solar has about double the investment of scenarios C and D with more moderate wind and solar contributions.

Figure 6-2 shows the breakdown of investments for the least cost solution for five scenarios.

**Figure 6-2   Break down of investments for the least cost solution for five scenarios**

It appears that a considerable part of the total investment is for additional diesel generation capacity. In all scenarios this investment is necessary to maintain a reliable supply in times when hydro, wind and solar are not generating. As mentioned, the investment in scenario B is much higher than all other scenarios. This is mainly due to the large amount of wind and solar capacity. The investment in new back-up diesel generators is about 25% less than in the other scenarios.

For sensitivity scenarios the investment is more or less different. The scenario with the large spread between the fuel price needs 3% extra investment due to extra wind. The scenario with the small spread between the fuel price needs 10% less investment due to the absence of wind capacity. The low load scenario requires 12% less and the high load scenario 30% more investment.

6.2   Generation cost prices

Besides the least cost solution, the optimisation model also gives the cost prices of the energy market based on this least cost solution. These prices are based on the marginal cost of electricity generation and transmission.

As mentioned before no cost for CO_2 emission or Carbon Credits have been taken into account. Giving a value to the emeission reduction would increase the benefit of the renewable scenarios compared to the business as usual scenario.
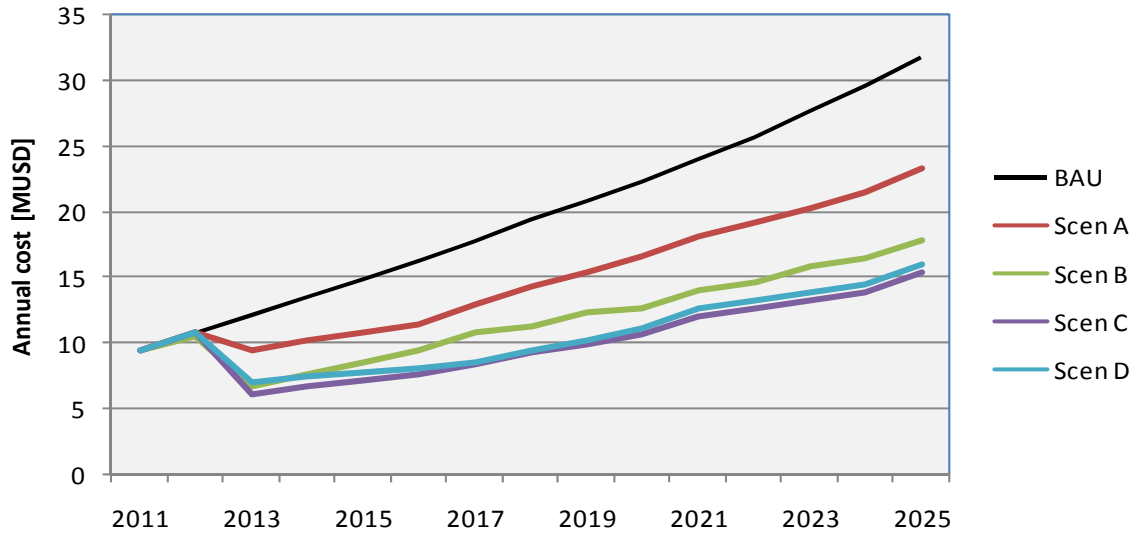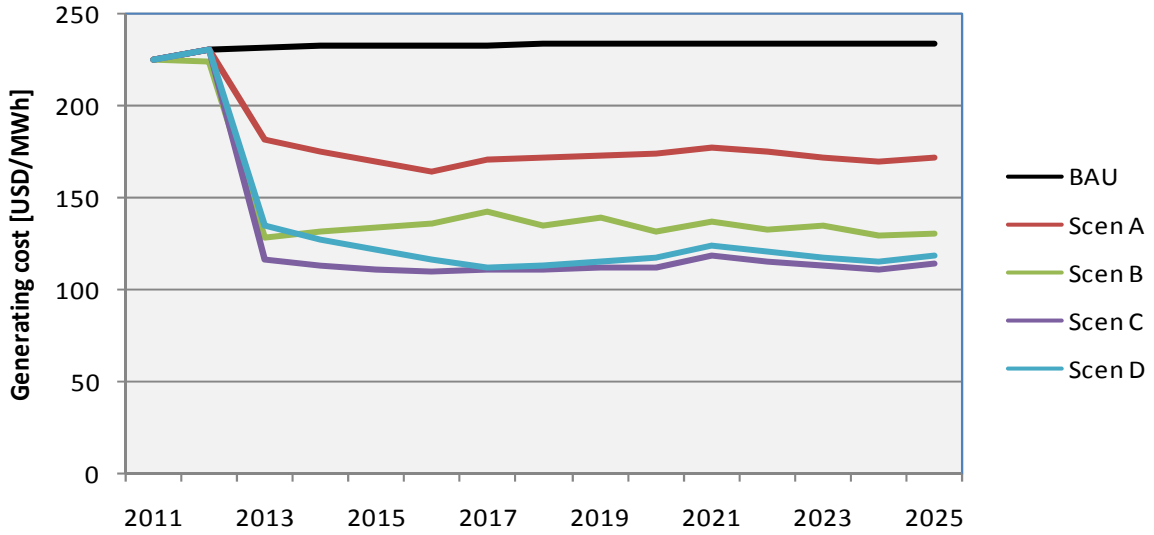

Figure 6-3   Annual cost of electricity supply for five scenarios

The generation cost of all renewable scenarios are much lower than in the Business As Usual scenario. Even scenario B with very high investment shows lower cost as a result of minimising the amount of expensive diesel oil. Since electricity is subsidised in Indonesia this implies that by introducing renewable energy the subsidies could be reduced considerably. A choice for the most beneficial scenarios could roughly save between 6 and 16 million USD per year.

6.3   **Generation cost prices**

Besides the least cost solution, the optimisation model also gives the cost prices of the energy market based on this least cost solution. These prices are based on the marginal cost of electricity generation and transmission.

Figure 6-4   Average annual cost price of electricity supply for five scenarios

The figure shows a sharp decrease of cost prices from 2013 on due to the introduction of renewable energy. After 2013 the cost prices are pretty stable.

The simulation results show electricity prices that stay in the range of 110-170 USD/MWh for the four renewable scenarios and about 235 USD/MWh for the BAU scenario.

7 CONCLUSIONS AND RECOMMENDATIONS

Main assumptions for the least cost plan

The main assumptions for the base scenario are:

- A demand growth of
  - 12% from 2011-2014
  - 9% from 2015-2018
  - 7% from 2019-2025
- Interconnection of the Waikabubak and Waingapu system in 2014
- Decommissioning of existing diesel engines will take place after 30 years lifetime
- A 500 kW$_{peak}$ solar PV system will be installed in 2012 in the Waikabubak system including a 1.5 MWh battery.

Main findings

The selection of renewable resources showed good possibilities and potential for wind, hydro, solar and biofuel. The economic comparison of the options revealed that hydro based electricity generation most probably is the cheapest from of generation on Sumba. Further investigation is required for technical and economic feasibility since this conclusion is made based on indicative research. Wind energy is a competitive options based on the used assumptions. Solar energy may be a good option in the near future when investment cost have decreased according to expectations. The fourth option, biofuel, is needed for peak and backup when the other resources are less or not available.

Four scenarios and the business as usual scenario have been optimized and mutually compared. Scenario C with a storage hydro option of 7 MW with extra run off river hydro is the best choice in terms of economics closely followed by scenario D also with a 7 MW storage hydro but supplemented with 5 MW wind energy. Both scenarios limit the amount of biofuel to 20-25%. Scenario B stretches the use of hydro, wind and solar. This minimises the amount of required biodiesel to about 6%. Although the investment for this scenario is by far the highest, the overall generation costs are only 10-15% higher than for scenarios C and D. Without storage hydro the share of biofuel would be about 60% (scenario A). This scenario is about 40% more expensive than scenarios C and D. The business as usual scenario based on 100% biodiesel is twice as expensive as the cheapest scenario, scenario C.

Recommendations

As a first step it is recommended to investigate the attitude of the local government and population towards a storage hydro installation. If a dam is acceptable and can be constructed in the Kambaneru river scenarios B, C and D are possible and the amount of biodiesel can be limited. If a larger dam in the Kambaneru river is not acceptable it is recommended to investigate a smaller storage either in the Kambaneru river or another river. A storage volume for 12-24 hours would also help to reduce the curtailment of renewable energy and to limit the amount of expensive biofuel.

It is recommended to closely follow the demand development. If the demand grows faster than the base scenario, the lack of generating capacity will become more serious.

For the following subjects, further research is recommended:

1. Investigation into the most suitable location for storage hydro and in depth hydro feasibility assessment that encompasses site selection optimization
2. Measurement of wind speed and fluctuations and long term wind resource prediction to determine the financial viability of the wind park
3. Determination of the optimum size of hydro and storage based on the outcome of 1 and 3.
4. Elaboration on the possibilities and cost of biofuel
5. Investigation into the value of CO_2 emission reduction
6. Investigations into the operation and stability of the preferred integrated solution.