Least Cost Rural Electrification Solutions

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M.sc. Programme: Sustainable Energy Planning and Management

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Preface

This masters thesis was written during the third semester of the M.Sc. programme *Sustainable Energy Planning and Management* at the Department of Development and Planning at Aalborg University, Denmark. It intends to fulfil the requirements for attainment of the mentioned above academic degree and was conducted during the period 01.04.2013 to 08.08.2013, under the supervision of Frede Hvelplund.

The report is divided into nine chapters, a bibliography and annex.

The Chicago method has been used to reference all sources in this report. The references are written using the authors surname followed by the year of the reference, e.g. (Obama 2007).

I would like to thank my supervisor, Frede Hvelplund, for her assistance and patience throughout this research process and all interviewees who lent me their valuable time and particular expertise.

Clemens Hussong

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Acronyms and Abbreviations

C_{grid}	Grid line investment cost
C_t	Distribution transformer investment cost
LCC_{alt}	Life cycle cost of the alternative
LCC_{gen}	Life cycle cost of the grid generated electricity
LCC_{grid}	Life cycle cost of the electricity grid
t_{gen}	Electricity generation cost
$\delta_{t\&d}$	Transmission and distribution losses
€	Euro
EDL	Economical Distance Limit
EIA	Environmental Impact Assessment
Excl.	Excluding
Genset	Generator setting
GiZ	Gesellschaft für international Zusammenarbeit
GW	Giga-Watt
h	houre
h	Annual operation hours
i	Discount rate
IEA	International Energy Agency
Inv.	Investment
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
KfW	Kreditanstalt für Wiederaufbau
Km	Kilometre
KV	Kilo-Volt
kVA	Kilo-Volt-Ampere
kW	Kilo-Watt
kWh	Kilo-Watt-hour
L	Load demand
LCC	Life Cycle Cost
LCOE	Levelised Cost of Electricity
LPC	Levelised Production Cost
MNT	Mongolian Tugrik
MW	Mega-Watt
MWh	Mega-Watt-hour
n	Project lifetime
No.	Number
NPV	Net present value
O&M	Operation and Maintenance
OECD	Organisation for Economic Cooperation and Development
PV	Photovoltaik
S.W.O.T.	Strengths, Weaknesses, Opportunities, Threats
SHS	Solar Home System

SME	Small and Medium Enterprise
TSO	Transmission System Operator
U.S. $	U.S. Dollar
UN	United Nations
W	Watt
WB	World Bank
Wp	Watt peak
β	O&M cost as fraction of investment cost

Executive Summary

Sufficient access to electricity is not given for around 1,3 billion people. The development world faces the challenge to change that in order to drive economic development and improve livelihood of those people. 84% of those are living in rural areas. Therefore rural electrification is one of the big challenges in our days. In order to design successful rural electrification projects, they have to be efficient and the amount of power has to be sufficient.

Until now the decisions to realise a certain electrification project are made by decision maker based on an inexplicable decision making process. Often lobbyists and political forces are of a major influence. This thesis develops a pre-assessment methodology, to be applied in order to reach transparent as well as informed decisions. Therefore it adopts a very general view on rural electrification, circumventing specific local incidents. This approach might be questionable since it is shown throughout this thesis that the specific local conditions are of major influence to the success of rural electrification projects. But it enables decision makers to gain a quick first insight towards favourable possible projects. Before being governed by lobbyists and political forces. Later on feasibility studies have to incorporate details, which cannot be part of a pre-assessment.

Furthermore environmental and social costs of rural electrification measures are incorporated since it is shown throughout this thesis that they are of major influence regarding the overall or “real” costs of such projects and on the way towards sustainable development.

In order to develop a pre-assessment methodology, the economical as well as environmental and social costs, including foreseeable impacts and possible future effects of certain generation technologies, distribution schemes and tariff systems are analysed. Economic considerations are simplified and qualitative information is taken into account.

The developed methodology is reviewed carefully and it is shown, that successful rural electrification is only possible in regard to local conditions. Nevertheless the pre-assessment methodology as developed provides a tool for informed and therefore more profound decisions.

1. Introduction

Access to modern energy services like electricity or clean cooking facilities is nearly natural for everybody living in the developed world. Not so for 1,3 billion people, who do not have access to electricity and for 2,7 billion people, who do not have access to clean cooking facilities. 95% of those people live in Sub-Saharan Africa or in Asia. And 84% live in rural areas. This lack of accessible energy hinders economic and social development (IEA 2011).

Not only institutions like the IEA (International Energy Agency) or the World Bank (WB) are highlighting the importance of fulfilling the energy needs of the rural poor, also Wladimir Iljitsch Lenin acknowledged the importance of rural electrification already in 1920, when he wrote “Communism is Soviet power plus the electrification of the whole country, since industry cannot be developed without electrification” (Lenin 1965). Therefore today, rural electrification programs and projects are on-going all over the world (Hussong 2013). They are supporting economic development and promoting livelihood security by enabling productive use of electricity. Furthermore they improve the living conditions of the rural poor. (M. S. Nouni 2008)

1.1 Problem Formulation

In order to enable electricity access for the rural poor population in development countries, a vast amount of technologies and systematic approaches can be used. While the decision, which of those should be used in an electrification project is mostly based on economics also myriad other factors are of major influence. Those might reach from political pressure of different parties like donor organisations to resources available on sight. Often this results in a situation, where rural electrification projects are not chosen in regard to their costs but much more due to other factors. This leads to inefficient individual projects, both with regard to business- and macro economy. Because projects are not necessarily realised, where the lowest cost are to be anticipated. Hence decision makers in development countries should ask, where to do rural electrification the cheapest instead of where to do a specific project the cheapest. This does not necessarily mean, that the least economic cost are to be expected within a certain project, but much more that the least over all cost are to be found. Hence, the most positive influence can be exerted by causing the smallest economic, environmental and social cost.

When international donor organisations and development cooperation consultancies come in place, often the decision to do a rural electrification project has already been made by national decision makers or institutions. In order to find out what to do where, it is necessary for decision makers to be aware of all governing factors and how they are influencing the overall costs of rural electrification measures to come up with the least cost solution. Therefore this Thesis is analysing those factors and the linkages between them. It aims to provide assistance, finding the least cost solution for rural electrification actions. Incorporating not only economic cost, but also environmental and social cost of certain generation, distribution and tariff systems.

In order to serve this purpose, a pre-assessment methodology is needed, which provides the possibility of a quick and easy first analysis of possible rural electrification projects, without carrying along the high cost and efforts of a pre-feasibility- or feasibility study. Therefore this thesis tries to develop such an methodology which could be incorporated in the decision making or project developing process, as shown in Figure 1, before the high cost of any feasibility study arise.

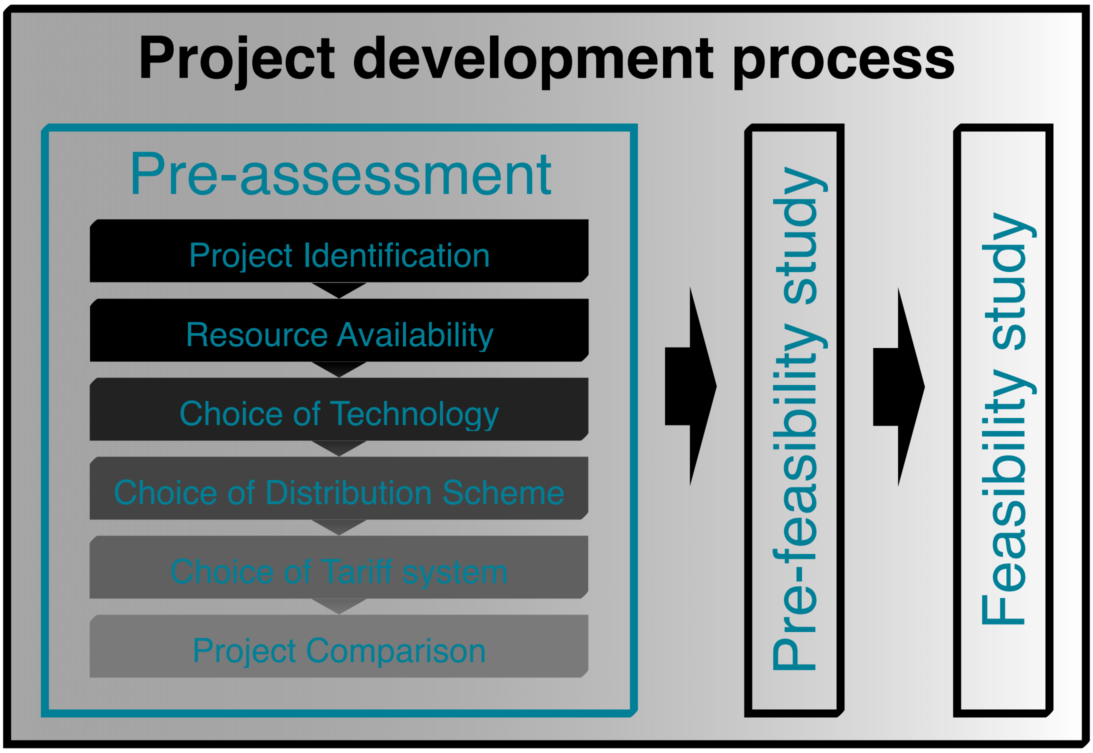

Figure 1: Project development process including possible Pre-assessment methodology

Since rural electrification projects are complex, and their success is dependent on several factors, which are on the technical side mostly dependent on the projects location and at the same time dependent on social structures and individual given circumstances. Developing a universal pre-assessment methodology, which can be applied in different regions, countries or continents, regardless of religion, social structures and educational background of the population is therefore a difficult task, which this thesis tries to fulfil, resulting in a product, which can actually be applied in the real world, outside of scientific studies and simulations. If this is even possible is not known at the beginning of the work and will be discussed later on in this thesis.

1.2 Research Question

In order to fulfil the targets as mentioned in the Problem Formulation, this project aims to answer the following research question:

How to find the least real cost rural electrification solution?

As mentioned before it is not known, if a universal methodology can be developed to find the least real cost rural electrification solution. But as a first step to answer this question, it is necessary to analyse not only quantitative but also qualitative information, coming from different projects all over the world.

Furthermore the sub-question of *how different factors influence the real cost of rural electrification solutions* arises.

1.3 Research Methodology

In order to answer the main research question, first of all extensive literature research is necessary. During this phase of the thesis information from scientific journals and papers as well as internal reports of several consultancy firms working in the sector of rural electrification and governmental organisations like the Gesellschaft für international Zusammenarbeit (GiZ) or Kreditanstallt für Wiederaufbau (KfW) is reviewed. Most of this information is accessible online.

If case studies where used as a source of information, they were reviewed with a special focus on different premises and local economic, environmental and social circumstances.

Scientific publications are peer reviewed and therefore offer reliable and accurate information. All other sources have to be considered as biased and therefore analysed carefully. Furthermore information based on experiences of earlier work by the author is considered.

Due to the nature of the development sector, available information is often not representing the whole situation in development countries. In order to gather critical information, several informal interviews with former colleagues and experts in the field of rural electrification where conducted during the study.

The gathered information then lead to the following methodology, answering the main research question;

Several factors are of major influence for the real cost of rural electrification projects. In general those factors can be divided in three categories whereby ownership models and financing schemes are withhold from these categories, since they are considered subject to a later status of project development due to their need for more detailed information and their minor influence on the cost of a specific project:

- Technical types of generation
- Distribution schemes
- Tariff systems

Those categories interact with each other as shown in Figure 2. Available resources and load density are input parameters determining which generation technology or distribution scheme respectively can be used. Whilst the choice of a certain tariff system influences the cost directly but also the demand, which again influences the overall cost accordingly to the generation technology used. Additionally the used distribution scheme is producing costs itself.

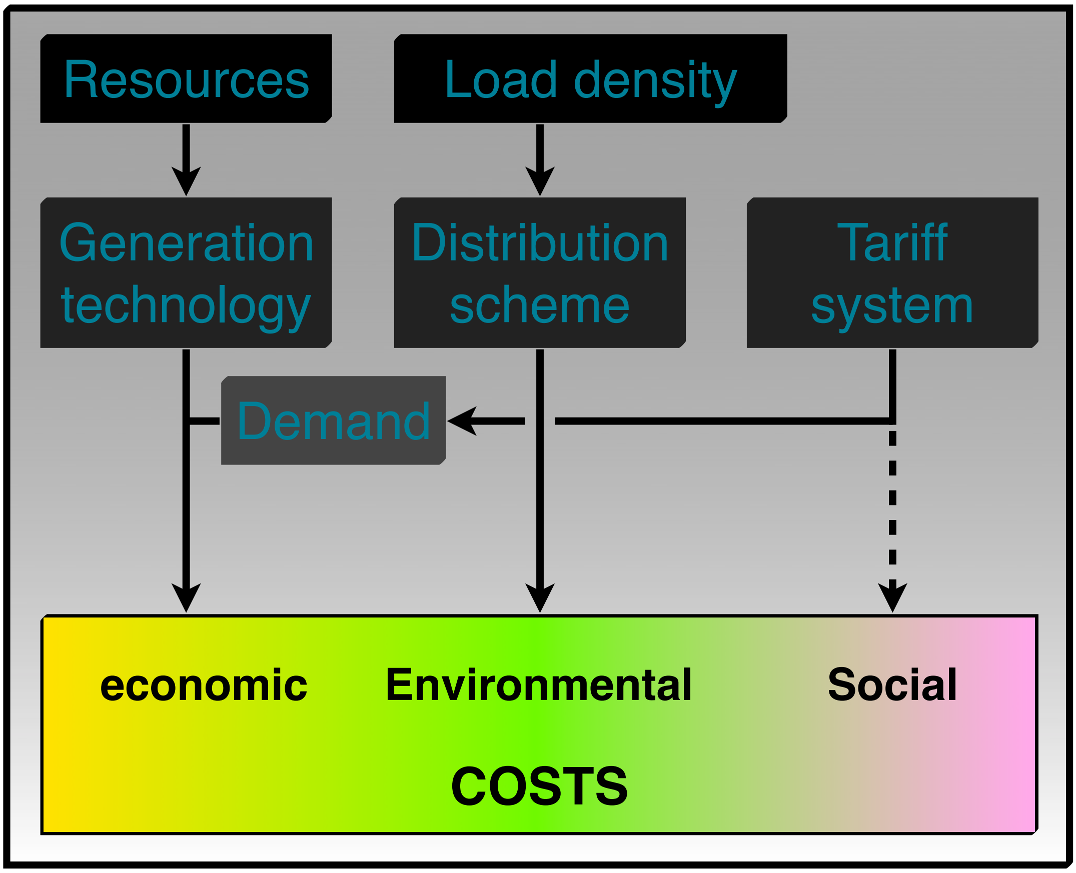

Figure 2: Cost development process

In order to find the least cost rural electrification solution those interactions have to be considered. To do so, this thesis is first of all defining certain terms if necessary, including economic environmental and social costs and benefits. Therefore qualitative as well as quantitative information is dissected.

In a next step a brief overview of different types of Generation is provided within section 2 of this thesis. The most common systems are introduced. Their Strengths and weaknesses as well as opportunities and threats are shown within brief generalized S.W.O.T analyses in the context of the research question of this thesis.

The same approach is used to analyse the most common distribution schemes and tariff systems within rural electrification within sections 3 and 4 of this thesis. The possible effects of combining certain generation technologies with those are described in section 5.

Based on these analyses a pre-assessment method is developed to rank possible rural electrification projects regarding to their approximately real cost to provide assistance in the decision making process and to give direction towards the most likely least cost scenarios, leading to successful and favourable projects. It is also providing possible targets and hints for and towards pre-feasibility studies. This method is then applied, in a sort of simulative setting, to a fictional area, within section 7, in order to test its feasibility as well as applicability.

The methodology applied throughout the whole thesis as well as assumptions made and critical information used is discussed in section 8. Including the question, if it is possible to develop a generalised and at the same time useful pre-assessment methodology

Finally a conclusion is reached, incorporating information gathered and knowledge gained throughout the description as well as analytical and simulating part of the thesis. Furthermore a checklist is developed to provide concrete assistance within the decision making process of rural electrification projects.

The research methodology as it is implemented is summarised in Figure 3 for a better understanding.

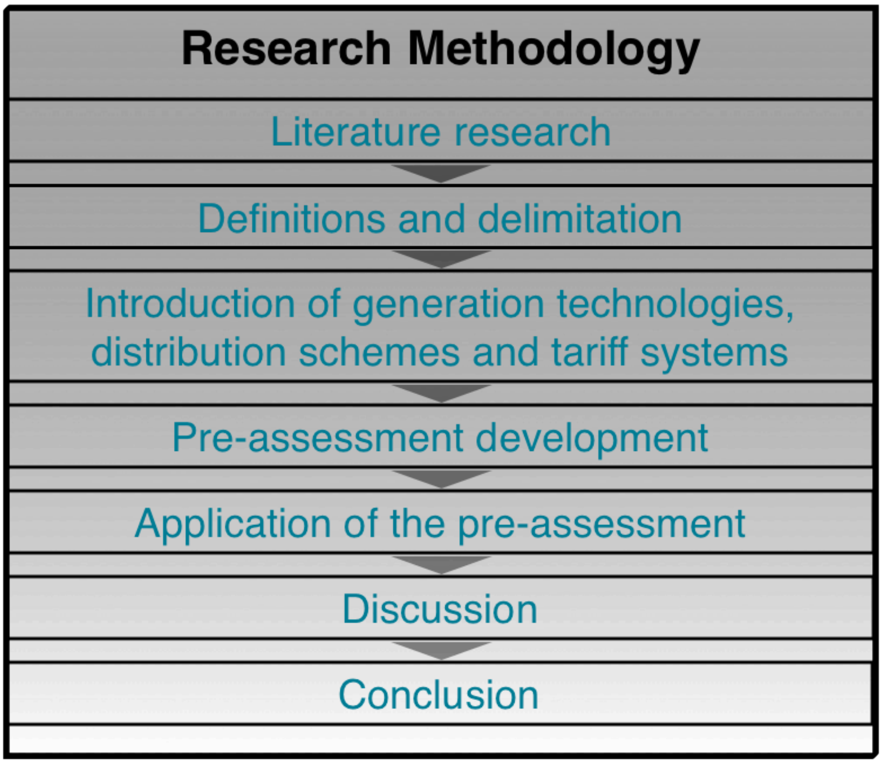

Figure 3: Summary of the research methodology

1.4 Delimitation and Definitions

The following sections delimit this thesis and provide definitions, where necessary, since the use of some terms might lead to misunderstandings and therefore to confusion. If no common definition is to be found in literature, the author defines terms himself in order to prevent any misconception.

1.4.1 Delimitation

This thesis only deals with the electrification of rural areas in development countries. It does therefore not necessarily apply to emerging economies e.g. China.

Furthermore this thesis is providing general information, applicable in most cases. In rare exceptional cases some of the assumptions made by the author in order to reach this general output might not be applicable and therefore misleading. This is mostly valid for very extraordinary local conditions. The thesis is referring to such cases wherever necessary. In order to develop a general pre-assessment methodology, this thesis is limited to non-location-specific information. Further investigations have to concentrate on specific data and local preconditions. In this regard this thesis also delimits any data related to demand or production curves including the production cost of electricity. Those costs have to be identified on the feasibility study level, when thorough investigations are conducted.

All cost data and monetary figures are recalculated to Euros, using an exchange rate of 1$ = 0,7624€ from the 30th of April 2013 (Exchange-Rates.org mbH Media .Inc 2013). Whenever useful figures are rounded.

Larger-scale storage technologies are not considered to be part of this thesis. This is due to the fact, that battery storages are quite costly. In any case, where electricity storage would be needed the storage can be considered as an additional source of generation and therefore easily implemented into the pre-assessment technology as a hybrid installation. When doing so it has to be kept in mind, that the energy stored within the storage has to be generated as well. The exemplary calculation in Box 1 shows, that very high cost can be expected in such a case.

Exemplary storage calculation

Table 1: Lead acid battery storage input data

Typical investment cost	50-150 €/kWh
Typical life span	200-1000 cycles
Typical depth of discharge	75%
Typical efficiency	75%

If a load of 100 kW is expected to be demanded outside the availability of renewable energy sources e.g. solar PV installations this load has to be available for several hours. It is assumed, that this timespan is limited to 6 hours (19:00 to 01:00). This means, that a total load of at least 600 kWh has to be available from the storage facility. In addition discharge depth and efficiency has to be in cooperated, resulting in a storage capacity of at least 937,5 kWh. This work has to be produced during daytime wen sunshine is available within a timespan of for example another 6 hours. Resulting in the need for additional generation capacity of 156,25 kW. Therefore the investment cost for the generation technology alone would increase by 156%. Additionally a storage facility like this would generate investment cost of 93.750€. In total the Investment cost of this project would be around 734.000€ instead of 410.000€ for the solar technology alone. Since the storage would be needed every day it would exceed its lifetime most probably within 3 years therefore reinvestments of 337.930€ would be necessary within the lifetime of the solar installation. Additionally O&M cost would arise. This simple example without the pretension to be complete or precise already shows, that battery storage technologies are still very expensive. Additionally the system as introduced in this example would only be able to supply the given demand as a band for 12h a day.

Box 1: Exemplary storage calculation (Divya and Østergaard 2009) and (IEA 2010)

1.4.2 Definitions

The following definitions have been applied throughout this thesis:

Sustainability: The term of sustainability is hard to be defined, because true sustainability in its narrowest definition would mean, that nothing ever gets consumed or moved from one place to the other. Human existence under these conditions is hardly imaginable. Therefore this thesis follows the most used definition of sustainable development as the Brundtland Commission defined it in 1987: Sustainable development is: *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Brundtland Comission 1987)

S.W.O.T. Analysis: The term S.W.O.T. Analysis is used throughout this thesis to describe an analysis of Strengths, Weaknesses, Opportunities and Threats, of a certain technology or act. This analysis is derived by the economical S.W.O.T. analysis but should not be mistaken as such. Anyways, an internal analysis, showing strengths and weaknesses is implemented as well as an external analysis showing opportunities and threats. The author chooses this kind of analysis, because a simple view on "pro's and con's" might not be able to grasp the complexity of most of the topics analysed.

Electrification: In order to define the term of electrification, the definition provided in earlier work of the author is given as follows: "*No uniform definition of the term electrification can be found in literature. The International Energy Agency (IEA) defines access to electricity for households as a reliable source* *of electricity satisfying a demand of at least 250 kWh per year* (OECD/IEA 2011). *It has to be mentioned, that this demand is rather low and households, which got recently connected to the electricity grid in development countries intend to develop average demands of around 800 kWh per year after a short time already* (OECD/IEA 2011). *Therefore this project defines electrification as follows: "Electrification is the act of taking measures to provide reliable and sufficient electricity access." This explicitly includes the use of more energy intense devices like a small refrigerator, or a sealing fan and may result in an electricity demand around the mentioned 800 kWh per year."* (Hussong 2013)

Levelised Production Cost (LPC):
The LPC or also called levelised cost of electricity (LCOE) are defined by (IRENA 2012) as follows: *"The LCOE of a given technology is the ratio of lifetime costs to lifetime electricity generation, both of which are discounted back to a common year, using a discount rate, that reflects the average cost of capital."* This thesis follows the given definition and therefore refers to the total cost per unit of work (€/MWh or €/kWh) as the LPC.

Large- and small-scale installations:
Throughout the thesis the terms large- and small-scale installations are used several times. For the sake of clarification the author defines them as follows:
Small-scale installations are generation facilities with an installed capacity of up to 1 MW, while large-scale installations are those with higher capacities.

Non-technical losses:
Besides the usual losses of a power system or electricity grid, which accrue due to inefficiencies and electrical resistance of cabling, so-called non-technical losses are to be found. Those are significantly higher in development countries (up to 50%). The term refers to every form of electricity theft from tempering with meters through illegal connections up to just ignoring not paid bills. (Navani, Sharma and Sapra 2012)

1.4.2.1 Costs and Benefits
This chapter introduces different costs and benefits associated with rural electrification measures. As this thesis aims to help decision maker finding the least cost solution, different types of costs and benefits have to be incorporated. The combination of those costs and benefits can then be called "real costs" since not only economic expenditures are included, but also environmental and social ones.

In order to understand the emergence of these costs as well as different influences on them it is important to understand cost development as a process as displayed in section 1.3.

Economic costs:
All monetary costs that arise during actions taken or decisions made can be considered as economic costs (including opportunity costs). The economic

costs of rural electrification measures, like most other construction projects, are driven by investment as well as operation and maintenance costs. Economic costs are not including externalities such as environmental or social costs.

Anyhow externalities are real and environmental as well as social effects can be observed within every rural electrification project. Hence this thesis incorporates those costs as they are described in the following sections.

Environmental costs:
The OECD defines environmental costs as *"costs connected with the actual or potential deterioration of natural assets due to economic activities"* (UN 1997). Those costs are usually accounted for using environmental impact assessments (EIA's). In order to do so a vast amount of variables has to be clarified. Hence those assessments are complicated for remote locations in development countries. Therefore this thesis incorporates environmental costs and benefits for different types of generation, systematic approaches and tariff systems as they can be suspected in a more general matter as qualitative information.

Social cost:
The social effects of rural electrification measures are not negligible. Most of those effects are positive and aimed for. But some of them are negative and can therefore be considered as social costs. Different types of generation, distribution or tariff systems have different social effects when applied. The most common effects are energy poverty, low cost awareness and low identification with the product or power plant (IEA 2010). Whilst energy poverty is a direct social impact of certain measures, low cost awareness and low identification are results of those and lead to higher energy demands and rejection of projects.

Furthermore possibilities for economic growth are influenced by social costs. Some measures might support the development of local SME's or generate employment within the power generation and distribution sector, while others won't.

2. Types of Generation

In order to decide on different generation technologies to be used within a rural electrification project and their environmental and social cost, it is necessary to be aware of foreseeable as well as possible effects and events in regard to their implementation. Hence, the following sections are providing a short overview of the most common generation types used in rural electrification projects, including a very brief analysis of each generation type including their strengths and weaknesses (internal / foreseeable events) as well as opportunities and threats (external / possible effects). First, conventional power generation is dealt with in section 2.1, followed by renewable sources of electricity in section 2.2. Nuclear power plants are not considered as a source of electricity throughout this thesis since most development countries do not have sufficient access to nuclear technology.

Some of the following arguments might appear in contradicting sections of the analyses. This is due the Fact, that those arguments might be valid in both sections, depending on factors like plant size or maturity of the installation. Additionally one has to have in mind, that the analyses, within the sections below, are generalised. Therefore a specific S.W.O.T. analysis for one generation technology at a specific location might find different results.

The Investment cost of each generation technology are given as ranges in €/kW. Information about the availability of each generation technology is provided within the analyses and has to be regarded.

2.1 Conventional Power Generation

In total, around 89% of the worldwide electricity consumption is generated by conventional and nuclear power sources (U.S. energy information administration 2013). In addition the most used generation types in rural electrification are conventional diesel Generators or grid electricity.

2.1.1 Diesel Generators

Diesel Gensets are available from household sizes (about 3 kW) to an industrial scale and capacities up to several MW. Small installations are available in every country and fairly cheap due to mass production. All diesel engines can use regular diesel fuel and biofuels. Due to the restricted access to biofuels this thesis concentrates on diesel fuel driven installations.

Cost box:

Investment cost	880 - 1040	€/kW
O&M cost excl. fuel	1-2	% of inv. / year
Life time	20.000	hours
Fuel cost	0,26	€/kWh

Box 2: Diesel generators cost box; Derived from (Breeze 2005); (Hussong 2013); (PerfectFuel.ca 2013); (World Bank 2013); (KPMG 2010)

The efficiency of diesel generators ranges from 30% for smaller ones, to 48% for large installations (Breeze 2005).

Table 2: S.W.O.T. Analysis of Diesel Gensets

Strengths	• Always available power production including both, base and peak load • Simple and well known technology • Local generation therefore high local acceptance • High employment possibilities
Weaknesses	• High fuel cost • High emissions for generation • High reinvestment cost
Opportunities	• Enables economic development through secure 100% supply of demand, capacities are easily increased • Low investment cost • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses
Threats	• High fuel cost • High dependency on fuel deliveries • Fuel could be “vanishing” due to subsidiary possibilities of use (Fuel theft)

2.1.2 Grid Electricity

Large-scale conventional power plants are used to power electricity grids all over the world. They are either based on natural resources like coal and natural gas or large-scale hydro power. In addition, a number of different technologies is available for either one of those power plant types. Hence it is quite complicated to determine the impact of grid electricity since it is dependent on the types of power plants within the energy system. Therefore the environmental and social costs of electricity generated within an electricity grid are specific to each power system.

Cost box:

Investment cost (transmission line)	5.844	€/km
Investment cost (Distribution transformer)	520	€/piece (63 kVA)
O&M cost	1	% of inv. / year
Life time	20	years
Generation cost	0,03	€/kWh
Transmission losses	20	%

Box 3: Grid electricity cost box; Derived from (Sadhan Mahapatra 2012)

Table 3: S.W.O.T. Analysis of Grid electricity

Strengths	• Always available power production including both, base and peak load • Central power generation and grid management • Very low reinvestment cost
Weaknesses	• Emissions unclear • Central power generation therefore low local acceptance • Complex technology • low employment possibilities
Opportunities	• Enables economic development through secure 100% supply of demand • Low investment cost
Threats	• Load shedding if grid extension is to fast (grid is to weak) • High transmission losses due to long power lines • Weak identification with the product by the rural population. Therefore bad ratio of payment and an increased rate of non-technical losses

2.2 Renewable Power Generation

Renewable energy sources such as solar photovoltaic, wind power, hydropower or biomass installations enable access to electricity in remote areas where a connection point to the national electricity grid is far away and infrastructure is weak. Therefore they are indispensible in rural electrification projects. Furthermore they offer in general an environmentally friendly and more sustainable way of electrification, than conventional power sources. Although only around 11% of the world-wide electricity consumption is generated by renewable sources (U.S. energy information administration 2013), they incorporate large potentials specially in small capacity settings. In addition, the utilisation of some renewable energy sources is well known and the technology used to do so is fairly simple in comparison to some conventional power sources.

Again it is important, to keep in mind, that the external effects presented in the following analyses are not all necessarily becoming effective. In addition the individual context and circumstances within a rural electrification project will influence those effects.

2.2.1 Solar Photovoltaic

Solar Photovoltaic installations are widely used throughout rural electrification projects (Drenkard 2013). A huge variety of projects is implemented. They reach from individual small-scale solar installations to bigger ones, powering mini grids or feeding into national electricity grids.

Cost box:

Investment cost	3.100 – 4.700	€/kW
O&M cost	1	% of inv. / year
Life time	20	years
Fuel cost	0	€/kWh

Box 4: Solar Photovoltaic cost box; Derived from (IEA 2010)

Table 4: S.W.O.T. Analysis of Solar PV Installations

Strengths	• No fuel cost • Low demand for maintenance
Weaknesses	• Electricity is only available during daytime but not at peak hours • High investment cost (even higher including storage technologies) • Low employment possibilities • Rather small capacities
Opportunities	• No emissions for generation • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses
Threats	• Risk of weather • Power production is unpredictable

2.2.2 Wind Power

Along with hydropower, humans are utilising wind as a source of power since thousands of years now. In our days wind power installations reach from very simple constructions to cutting edge technology like offshore wind farms.

Cost box:

Investment cost	1.000 – 1.900	€/kW
O&M cost	4 -10	% of inv. / year
Life time	20	years
Fuel cost	0	€/kWh

Box 5: Wind Power cost box; Derived from (IEA 2009)

Table 5: S.W.O.T. Analysis of Wind Power Installations

Strengths	• No fuel cost • Simple technology (for very small capacities) • Employment possibilities • No emissions for generation
Weaknesses	• Very complex technology (for larger installations) • High Investment cost
Opportunities	• Low investment cost • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses
Threats	• Risk of weather

2.2.3 Hydropower

Mankind uses hydropower since several thousand years. The technology is very mature and can be simplified resulting in lower efficiencies but also lower need for maintenance. Hydropower installations are available in nearly every capacity. From small individual installations up to several GW installed capacity.

Cost box:

Investment cost	760 – 7.620	€/kW
O&M cost	2 - 3	% of inv. / year
Life time	50	years
Fuel cost	0	€/kWh

Box 6: Hydro power cost box; Derived from (IRENA 2012)

Table 6: S.W.O.T. Analysis of Hydropower Installations

Strengths	• No fuel demand • Always available power production including both, base and peak load • High employment possibilities • No emissions for generation
Weaknesses	• High investment cost • High environmental interference
Opportunities	• Enables economic development through secure 100% supply of demand • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses
Threats	• Risk of weather • Nearly no possibility to increase capacity

2.2.4 Biomass

Biomass is the oldest energy carrier. Traditionally biomass in the form of wood or cow dung is used in a simple stove or open fire installation. This still applies for many regions in the world. In order to produce electricity, different technologies are applied. Either biomass is burned, to power a steam engine, or it is gassed to be used in gas driven engines. Biomass installations are typically of smaller scale than hydro or wind power installations.

Cost box:

Investment cost	1.830 – 7.470	€/kW
O&M cost excl. fuel	3 – 6,5	% of inv. / year
Life time	20	years
Fuel cost	0,027	€/kWh

Box 7: Biomass cost box; Derived from (IEA 2012) and (Sadhan Mahapatra 2012)

Small biogas plants are very simple installations and widely used to supply primary energy (mostly for lighting, heating and cooking) in rural areas of developing countries like China and India (Deublein und Steinhauser 2011). Larger, industrial installations, which can be found in western countries, Especially in Germany and Denmark are much more complex installations focusing on generating renewable energy to be fed in the national electricity or natural gas grid. (GTZ 2010)

Table 7: S.W.O.T. Analysis of Biomass Installations

Strengths	• Always available power production including both, base and peak load • Simple technology (for very small capacities) • High employment possibilities
Weaknesses	• High fuel demand • Not free of emissions
Opportunities	• Enables economic development through secure 100% supply of demand • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses • Capacities are easily increased
Threats	• Competition to food products (Subsidiary use of farmland) • Competition to traditional sources heating and cooking energy. • Possible environmental impact due to growing of energy plants or deforestation

2.3 Conclusive Summary

The cost data presented during the introduction of different types of power generation will later on serve as an input within the pre-assessment methodology. Furthermore it is important to evaluate those generation technologies concerning their possible environmental and social but also economical effects in order to reach a statement regarding their influence on the real cost within a rural electrification project. As shown, those effects can be of very different natures resulting in different impacts on possible projects. Nevertheless in contrast to the presented generalised S.W.O.T. analyses, which can only provide shallow intelligence, a project specific analysis has to be performed later on in the project development process. The qualitative information given within the analyses also serves as an input for the pre-assessment methodology.

3. Distribution Schemes

A number of different distribution schemes are used to electrify rural areas of development countries. They greatly differ from each other in terms of project size, feasibility, effort and therefore complexity. Hence their environmental and social impacts vary. The most common scheme is expansion of the national or larger regional distribution grids (Nouni, Mullick and Kandpal 2007). But also mini grid installations gain importance in developing countries. While individual generation serves mostly to cover the minimal electricity demands of the rural poor, living in areas with low population density. The following sections are describing and analysing those three most used distributions schemes due to their influence on the over all real cost of rural electrification measures. Those effects are mostly realised by raised environmental or social costs as shown below.

3.1 Grid Expansion

The expansion of existing national or large-scale regional grids is by far the most used method to supply rural areas with electricity. The following table briefly analyses advantages and disadvantages of this distribution scheme.

Table 8: S.W.O.T. Analysis of Grid Expansion

Strengths	• Full supervision of generation. • Access to grid electricity
Weaknesses	• High investment cost compared to other distribution schemes • Increased environmental impact due to heavy construction measures • High transmission losses • Medium O&M costs
Opportunities	• Reliable and unlimited power supply therefore economic development is enabled • Enables local employment
Threats	• Danger of low supply • Possibly high non-technical losses

3.2 Mini Grids

Mini grid installations are used to electrify rural population density centres such as small cities or towns, villages or even small clusters of houses. They combine advantages of grid installations and local generation as shown below.

Table 9: S.W.O.T. Analysis of Mini Grid installations

Strengths	• Medium investment cost. • Low environmental impact.
Weaknesses	• High O&M costs
Opportunities	• Enables local employment • Strong identification with the product by the rural population. Therefore better ratio of payment and an decreased rate of non-technical losses
Threats	• Possible non-technical losses

3.3 Individual Generation

Several different systems are currently at use throughout the electrification sector to distribute individual generation installations. Each of those approaches has different strengths, weaknesses, opportunities and threats. Anyways, all the different systems have one similarity. The generation of electricity takes place fully decentralized at the point of consumption through small generation units. Other than that, the type of generation is varying as well as the distribution model for those small-scale generation systems. In Bangladesh for example Solar Home Systems are sold to the consumers, while they are rented out in other programs. In some projects, individual generation units are neither rented nor sold to the customer but only supplied by an electricity distribution company, which also collects a tariff from the customers. Some of those approaches allow traditional metering and tariff models others do not. If the system is for example sold to the customer no tariff system will be in place to charge the consumed electricity. (Drenkard 2013)

Because in depth analysis of all possibilities for distribution of individual generation systems would exceed the boundaries of this thesis, the term refers to the most common solution, where the system is sold to the consumer.

Table 10: S.W.O.T. Analysis of individual generation installations

Strengths	• Very high investment cost • No environmental impact due to the absence of grid construction measures • Very high O&M cost
Weaknesses	• Highly inefficient
Opportunities	• Highly enables local employment • Strong identification with the product by the rural population.
Threats	• Hinders the development of sufficient and efficient power supply • Access threshold

3.4 Conclusive Summary

The Strengths, weaknesses, opportunities and threats of different distribution schemes are presented during generalised S.W.O.T. analyses along with a short introduction to the most common distribution schemes. This is necessary in order to enable decision makers to make an informed choice, incorporating possible effects. Hence this qualitative information serves as an input for the pre-assessment methodology. It is shown, that effects to be expected, as well as possible impacts differ greatly for the different distribution schemes.

4. Tariff Systems

Throughout the world different tariff structures are used to charge rural consumers for the electrification services received. These tariff systems reach from nation wide schemes to regional payment conditions. Often depending on the distribution scheme and national electrification policies. In the following sections, the most important hence most used tariff systems are introduced and briefly analysed. This is done due to the fact, that besides costs, which are produced by the tariff system itself, they also have an impact on the demand for electricity. Not only are tariff systems influencing the amount of consumed energy, but they are also able to serve as a regulative tool to flatten out demand curves and therefore reduce the needed capacities for peak load production, which may influence the over all cost to a great deal.

4.1 Life-line Tariffs

Representative for a vast amount of possible multi-tariff systems, using different electricity prices in dependency of the time of consumption or the amount consumed this thesis incorporates the life-line tariff as described below.

Life-line tariffs serve as a cross subsidy scheme to support poorer consumers and to ensure energy access for the rural poor. Hence the richer consumers (with higher consumptions) are paying a higher price per kWh to subsidise the consumers with lower energy needs (Rolland and Glania 2011).

Often life-lines are available for every consumer to ensure equal treatment. When a certain amount of electricity is consumed, a considerable higher rate is charged either for the whole amount or only for the amount of electricity above the life-line. (Integration Umwelt & Energie 2010)

As every tariff system life-lines incorporate different benefits and difficulties as shown in the following brief analysis:

Table 11: S.W.O.T. Analysis of Life-line Tariffs

Strengths	• Opportunity to cross subsidise, hence allows access to electricity for poor people
Weaknesses	• Complex tariff system, hence lower cost awareness
Opportunities	• Enables economic growth through energy availability and cheap access cost. • Possible full cost coverage.
Threats	• Possible higher electricity demands due to low cost.

The following example shows a life-line tariff designed for a mini grid installation, powered by a Hydropower station and a Diesel genset in rural Mongolia:

Promotion of Renewable Energy Sources (Mongolia):

The following example shows the tariff structure of an isolated mini grid installation in rural Mongolia. Generation of electricity is realised through a hybrid installation of a 375 kW small hydropower installation in combination with 1,1 MW's capacity by diesel gensets. Due to the income structure of the local population it was decided to follow the consultants recommendation to introduce a life-line tariff as shown in Figure 4. This example is based on (Integration Umwelt & Energie 2010).

The LPC of the hybrid installation was calculated to be located somewhere between 162,00 and 470,00 MNT per kWh, depending on the subsidy on diesel fuel, which was available during the time of research. (1MNT = 0,00051€)

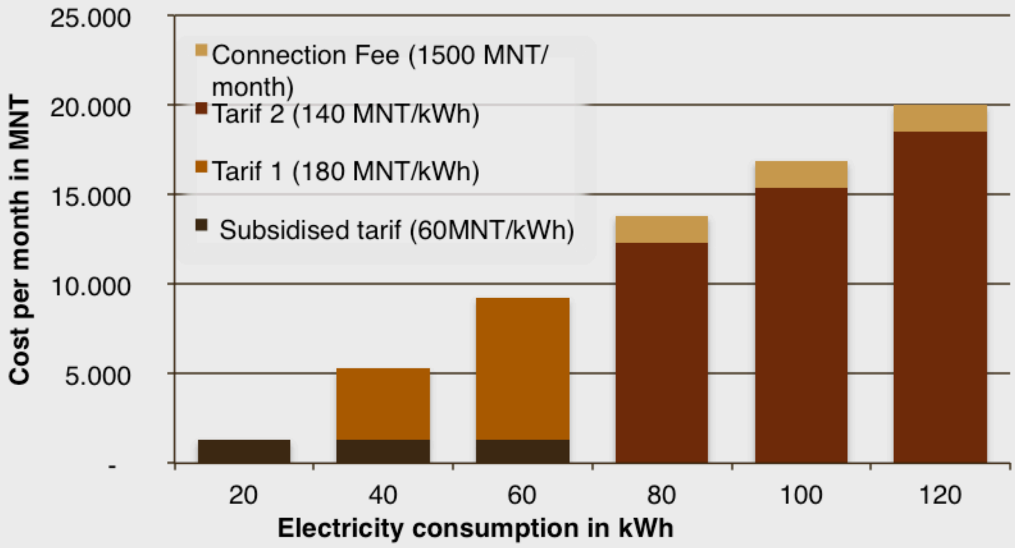

Figure 4: Life-line tariff design in rural Mongolia (Tosontsengel) as proposed by rural electrification experts

Figure 4 shows that until the consumer reaches a consumption above 20 kWh, the LPC are not reached. Furthermore it can be seen that the subsidised tariff is available for all consumers with demands lower than 80 kWh per month. If more than 20 kWh are demanded the consumers are obligated to pay Tariff 1 for every additional kWh. This changes once the barrier of 80 kWh is reached. In order to support SME's it was decided to introduce a connection fee of 1500 MNT and reduce the kWh price in return to 140 MNT within Tariff 2.

Box 8: Example of a life line tariff system (Integration Umwelt & Energie 2010)

4.2 Flat Rates

A flat rate is by definition a package price, paid for the unlimited usage of a good. Flat rates are most common for example in telecommunication tariffs (Gabler Wirtschaftslexikon 2013).

Within the field of rural electrification flat rates were often used as a tariff system for very small loads in order to save metering costs. Those installations usually aim on covering the very basic need of illumination. Since those loads are not in line with the definition of rural electrification as given in section 1.4.2, they are not considered throughout this thesis.

The fact, that the price paid by the customer is not related to the actual usage in any way, leads to several issues shown in the following brief analysis.

Table 12: S.W.O.T. Analysis of Flat Rate Tariffs

Strengths	• Billing is simple and cheap. Meters are not needed.
Weaknesses	• Consumption is enforced due to the shrinking cost per next kWh. Therefore electricity demands are likely to be very high. (No cost awareness)
Opportunities	Not applicable
Threats	• Uncertain cost coverage. • Possible access threshold due to high monthly rates in order to cover generation cost for high demands. This might lead to energy poverty. • Might lead to high non-technical losses due to illegal shared connections.

4.3 One Price per kWh

The one price per kWh tariff describes a simple billing system. Every consumer is obligated to pay the same price per kWh. The one price per kWh tariff is briefly analysed in the table below.

Table 13: S.W.O.T. Analysis of Flat Rate Tariffs

Strengths	• Simple billing system. • Full cost awareness.
Weaknesses	• No support for SME's. • No possibility for load curve management
Opportunities	• Enables economic development • Lower demands due to high electricity prices.
Threats	• Possible access threshold. • Possible energy poverty due to high cost.

4.4 Conclusive Summary

The Strengths, weaknesses, opportunities and threats of different tariff systems are presented during generalised S.W.O.T. analyses along with a short introduction to the most common systems. This is necessary in order to enable decision makers to make an informed choice, incorporating possible effects. Hence this qualitative information serves as an input for the pre-assessment methodology. It is shown, that effects to be expected as well as possible impacts differ greatly for the different tariff systems.

5. Influences of Different Generation Types, Distribution Schemes and Tariff Systems

The following section shows effects of combining different types of generation, with different distribution schemes and tariff systems as they are described above. This is done in order to provide an overview about positive and negative impacts of combining those. These impacts should be considered within the pre-assessment besides the effects of individual technologies or distribution schemes as well as tariff systems. Most of the information gathered in this section of this thesis is not based on classical scientific research but much more on the experiences made by the author during several internships and prior assignments in the field of rural electrification, as well as informal interviews and discussions with experts in this field.

5.1 Combinations of Different Generation Types with Distribution- and Tariff Systems

This section analyses the effects of different distribution and tariff systems on the types of generation as they were introduced above. Therefore it only comprises effects, which are typical for the exact combination of one generation type with one distribution scheme or one tariff system. The effects of combining distribution schemes with tariff systems are described in section 5.2.

In order to fulfil this task the section is arranged into six subsections representing the different types of generation as presented above. Displaying the compiled information in this way is chosen, because a choice about distribution scheme or tariff system is usually available to decision makers, whilst choosing the right generation type is mostly dependent on given resources.

5.1.1 Diesel

Grid expansion:

Diesel fuel can be considered as a premium energy carrier. Hence it is expensive as a fuel and therefore inappropriate to power national scale electricity grids.

Mini grid:

In a mini grid Diesel gensets can be run as backup units for more unreliable sources of electricity like most of the renewable generation types but as the only utility providing electricity, the high fuel cost are not appropriate if other resources are available. In addition high emissions are to be expected with bigger diesel installations, which might be a problem especially in the centre of small towns or villages.

Individual generation:

While the investment cost for small Diesel gensets are rather low and therefore convenient for individual installations, high fuel cost are driving the production cost. But since the consumer, as he also is the owner of his own gen-

erator, has full cost awareness he might try to keep down the cost of electricity by saving energy and therefore emissions.
In addition Small individual diesel generators are less efficient and less reliable (Diesel service and supply Inc. 2013) in comparison to bigger installations, while emitting a lot of noise and exhaust gases.

Life line:

The particular high fuel cost of diesel generator settings is cross-subsidised using a life line tariff system. This might lead to a very low awareness of cost with the small-scale consumers. Therefore they might consume a bigger amount of electricity, only because they are not aware of the cost they might cause. This effect has an especially strong environmental impact if Diesel gensets are used for electricity generation due to their high emissions.

Flat rate:

A flat rate tariff might either not reflect the high fuel cost generated by a Diesel genset or the flat rate itself might be quite expensive while doing so. This might also lead to energy poverty, when the rural poor are not able to pay the high flat rate. In addition the tariff is driven up by the high consumption, which can usually be observed when flat rate tariffs are in place for an unlimited electricity source, since no cost awareness is available and even worse: "electricity is paid for anyways".

One Price:

The high fuel cost of diesel gensets are in place for every consumer to the same amount. This might lead to energy poverty, if fuel cost drive the electricity prices into areas, where it is not affordable or comes with to many sacrifices for the rural poor. But this also might lead to lower demands, since every consumer is aware of the cost he is generating. High cost for the next kWh will therefore lead to lower consumption and, using a high emissions diesel genset, also to lower emissions.

5.1.2 Grid Electricity

Grid expansion:

The only way to supply rural areas with electricity from the national power grid is to expand it. This leads to higher investment cost since not only the investment cost of the power plants but also those of the grid have to be covered. Furthermore it increases complexity. A Large-Scale Conventional Power plant (LSCP) installation itself is rather complex and running those needs a lot of well educated personal. If a fairly big electricity grid is added, the system complexity increases al lot. In addition the already quite high O&M cost of LSCP installations are increased through the also not negligible O&M cost of the electricity grid.

Nevertheless, running LSCP installations in a stable and well-maintained grid is one of the most efficient ways of supplying electricity.

Mini grid:
Grid electricity is not applicable for Mini grids.

Individual generation:
Grid electricity is not applicable for individual generation.

Life line:
The fuel and transmission cost of electricity generated within national power grids is cross-subsidised using a life line tariff system. This might lead to a very low awareness of cost with the small-scale consumers. Therefore they might consume a bigger amount of electricity, only because they are not aware of the cost they might cause. This effect has an especially strong environmental impact if the energy system contains a lot of high emissions generation facilities.

Flat rate:
A flat rate tariff might either not reflect the cost generated by an power system or the flat rate itself might be quite expensive while doing so. This might also lead to energy poverty, when the rural poor are not able to pay the high flat rate price. In addition the tariff is driven up by the high consumption, which can usually be observed when flat rate tariffs are in place for an unlimited electricity source, since no cost awareness is available and even worse: “electricity is paid for anyways”.

One Price:
The high fuel and transmission cost of the power grid installations are in place for every consumer to the same amount. This might lead to energy poverty, if cost drive the electricity prices into areas, where it is not affordable or comes with to many sacrifices for the rural poor. But this also might lead to lower demands, since every consumer is aware of the cost he is generating. High cost for the next kWh will therefore lead to lower consumption and, especially if a lot of high-emissions-power plants are within the energy system, also to much lower emissions.

5.1.3 Photovoltaic

Grid expansion:
Only large-scale PV installations can sufficiently be integrated in national electricity grids. The environmental impact of those installations is nearly restricted to the land used to construct them on.

Mini grid:
The maintenance demand for PV systems is rather low. Therefore the effect of higher O&M costs of mini grid installations is reduced. But this also results in smaller local employment opportunities.

Individual generation:
As described above PV installations are one of the most common generation types for individual generation of electricity. But individual set ups including a

battery storage, charge controller and PV panel (Solar Home System (SHS)) are much more inefficient than bigger installations. The direct environmental impact of this inefficiency is rather low since no emissions accrue during the production but (Drenkard 2013) shows, that proper handling and recycling of lead acid batteries used for storages might become an environmental issue. In addition the weather risk is shifted to the consumer, which leads to a lower security of supply. Furthermore the amount of electricity produced with a usual 45 Wp PV panel within a SHS is way below the needed amount to fulfil the definition of rural electrification as stated in section 1.4.2.

Life line:
Low cost awareness of small-scale consumers has a lower impact than it has with fuel intense types of generation since variable O&M costs of PV installations are rather low. This also leads to a lower environmental impact of the higher electricity consumption, which might come with low cost awareness.

Flat rate:
The environmental impact of higher energy demands due to flat rate tariffs is of course lower than it would be using fuel intense generation technologies. But the maximum amount of electricity generated by a PV installation is limited by the size of the installation and the actual output is highly dependent on the amount of solar irradiation. Therefore it is necessary to cover higher demands generated by a flat rate system with bigger PV installations, resulting in even higher investment cost.

One Price:
In contrast to fuel intense generation types, the effect of one price tariff systems leading to lower consumptions due to high prices for the rural poor is not necessarily resulting in lower emissions. Since no emissions are added during the production of electricity. Furthermore nearly no variable cost accrues. Therefore the price of electricity is easy to foresee and very stable throughout the lifetime of the installation. Nevertheless might a one price tariff system lead to energy poverty since investment cost of PV installations are rather high which may lead to quite high electricity prices.

5.1.4 Wind power

Grid expansion:
Only larger-scale wind power installations can sufficiently be integrated in national electricity grids. The environmental impact of those installations is nearly restricted to the construction phase.

Mini grid:
Larger wind power installations require a high amount of O&M work. Therefore they might generate local employment but also add up on the already higher O&M cost of mini grid installations. Furthermore, larger Wind power installations are emitting noise and shadow flicker, which can be quite disturbing if erected in a populated area close to a town or village.

Individual generation:
Individual wind power set-ups including a battery storage, charge controller and small wind turbine are much more inefficient than bigger installations. The direct environmental impact of this inefficiency is rather low since no emissions accrue during the production but (Drenkard 2013) shows, that proper handling and recycling of lead acid batteries used for storages might become an environmental issue. In addition the weather risk is shifted to the consumer, which leads to a lower security of supply.

Life line:
Low cost awareness of small-scale consumers has a lower impact than it has with fuel intense types of generation, hence a lower environmental impact of the higher electricity consumption, which might come with low cost awareness.

Flat rate:
The environmental impact of higher energy demands due to flat rate tariffs is of course lower than it would be using fuel intense generation technologies. But the maximum amount of electricity generated by a wind power installation is limited by the size of the installation and the actual output is highly dependent on the amount of wind available. Therefore it is necessary to cover higher demands generated by a flat rate system with bigger wind power installations, resulting in higher investment cost.

One price:
In contrast to fuel intense generation types, the effect of one price tariff systems leading to lower consumptions due to high prices for the rural poor is not necessarily resulting in lower emissions. Since no emissions are added during the production of electricity. Furthermore nearly no variable cost accrues. Therefore the price of electricity is easy to foresee and very stable throughout the lifetime of the installation.

5.1.5 Hydro power

Grid expansion:
Also smaller and medium-size hydro power installations can sufficiently be integrated in national electricity grids. The environmental impact of those installations is bigger than with most other renewable energy sources. This is especially important considering large- scale installations.

Mini grid:
Hydro power installations are able to supply a steady amount of electricity. Additionally they can be regulated easily. This makes them a favourable solution for mini grid installations. Furthermore it has to be mentioned, that local employment can be generated within the power plant. But, small-scale hydro power installations might block rivers for shipping as well as fish migration.

Individual generation:
Individual hydro power set-ups including a battery storage, charge controller and small hydro turbine are much more inefficient than bigger installations. The direct environmental impact of this inefficiency is rather low since no emissions accrue during the production but (Drenkard 2013) shows, that proper handling and recycling of lead acid batteries used for storages might become an environmental issue. In addition the weather risk is shifted to the consumer, which leads to a lower security of supply.

Furthermore, a sufficient water source in form of a creek or river has to be nearby the house of the consumer. Since such so called pico-hydro power installations are usually only using a small fragment of the water available, the dependency on weather is reduced significantly.

Life line:
Low cost awareness of small-scale consumers has a lower impact than it has with fuel intense types of generation since O&M costs of hydro power installations are rather low in comparison. This also leads to a lower environmental impact of the higher electricity consumption, which might come with low cost awareness.

Flat rate:
The environmental impact of higher energy demands due to flat rate tariffs is of course lower than it would be using fuel intense generation technologies. But the maximum amount of electricity generated by a hydro power installation is limited by the size of the installation and possible water storage reservoirs. Furthermore the actual output is in most cases dependent on weather. Therefore it is necessary to cover higher demands generated by a flat rate system with bigger hydro power installations, resulting in even higher investment cost. This is especially relevant due to the anyways-high investment cost of hydropower installations.

One price:
In contrast to fuel intense generation types, the effect of one price tariff systems leading to lower consumptions due to high prices for the rural poor is not necessarily resulting in lower emissions. Since no emissions are added during the production of electricity. Furthermore nearly no variable cost accrues. Therefore the price of electricity is easy to foresee and very stable throughout the lifetime of the installation. Nevertheless might a one price tariff system lead to energy poverty since investment cost of hydro power installations are rather high which may lead to quite high electricity prices.

5.1.6 Biomass

Grid expansion:
Also small and medium sized biomass installations can be integrated into large electricity grids. Since most installations produce biogas, to be used for the generation of electricity, which is easily storable, they can even serve demand peaks. Larger installations are often very complex, using a wet fermen-

tation process. In addition they consume a large amount of biomass as fuel. This might lead to negative effects in agriculture and deforestation. Or even substitution of food products for energy reasons.

Mini grid:
Biomass installations have a high demand of maintenance. This correlates with the high maintenance demand of mini grid settings in general, leading to even higher maintenance cost. But they are also able to generate local employment and value added throughout the local gathering of fuel. This also results in a very high identification with the power plant, hence a lower amount of non-technical electricity losses and higher acceptance. Nevertheless this might lead to environmental impacts as described above.

Individual generation:
Biomass installations are hardly applicable in individual generation solutions due to their complexity and emission of smell.

Life line:
The fuel cost of Biomass installations is cross-subsidised using a life line tariff system. This might lead to a very low awareness of cost with the small-scale consumers. Anyhow the impact of potential higher consumption due to low cost awareness is lowered because of the small amount of added emissions during the production of electricity. In contrast are those installations often powered by biomass gathered within a community this might raise cost awareness.

Flat rate:
A flat rate tariff might either not reflect the fuel cost generated by a Biomass installation or the flat rate itself might be quite expensive while doing so. This might also lead to energy poverty, when the rural poor are not able to pay the high flat rate. In addition the fuel consumption and therefore the tariff is driven up by the high consumption, which can usually be observed when flat rate tariffs are in place for an unlimited electricity source, since no cost awareness is available and even worse: “electricity is paid for anyways”.

One Price:
The fuel cost of Biomass installations are in place for every consumer to the same amount. This might lead to energy poverty, if fuel cost drives the electricity prices into areas, where it is not affordable or comes with to many sacrifices for the rural poor. But this also might lead to lower demands, since every consumer is aware of the cost he is generating. High cost for the next kWh will therefore lead to lower consumption and lower fuel consumption, which is critical if the biomass used to generate electricity is limited.

5.2 Combination of Different Tariff Systems and Distribution Schemes

No special effects of combining different tariff systems and distribution schemes can be found. All impacts can be seen as a direct result of applying the selected tariff system or distribution scheme itself as they are described above. Hence no correlation between tariff systems and distribution schemes can be noticed. The effects of combining different generation types with either a tariff system or distribution scheme are described above in section 5.1.

5.3 Conclusive Summary

It is shown, that combining different generation technologies with distribution schemes and tariff systems results in complex three-dimensional problems. Often the effects of a certain combination cannot be foreseen. This section of the report cannot claim to be complete or precise but it gives a hint towards possible effects and correlations of those combinations. Hence it is used as input of qualitative information throughout the pre-assessment methodology.

6. Choice Analysis

In order to make a choice, where in a country or region the least real cost for rural electrification can be found, hence where the first investments should be made, it is necessary to decide on a certain project and therefore also location out of several alternatives. This section analyses how such a decision can be reached by going through every step of the following pre-assessment methodology. The single steps are shown in Figure 5 and elaborated on below.

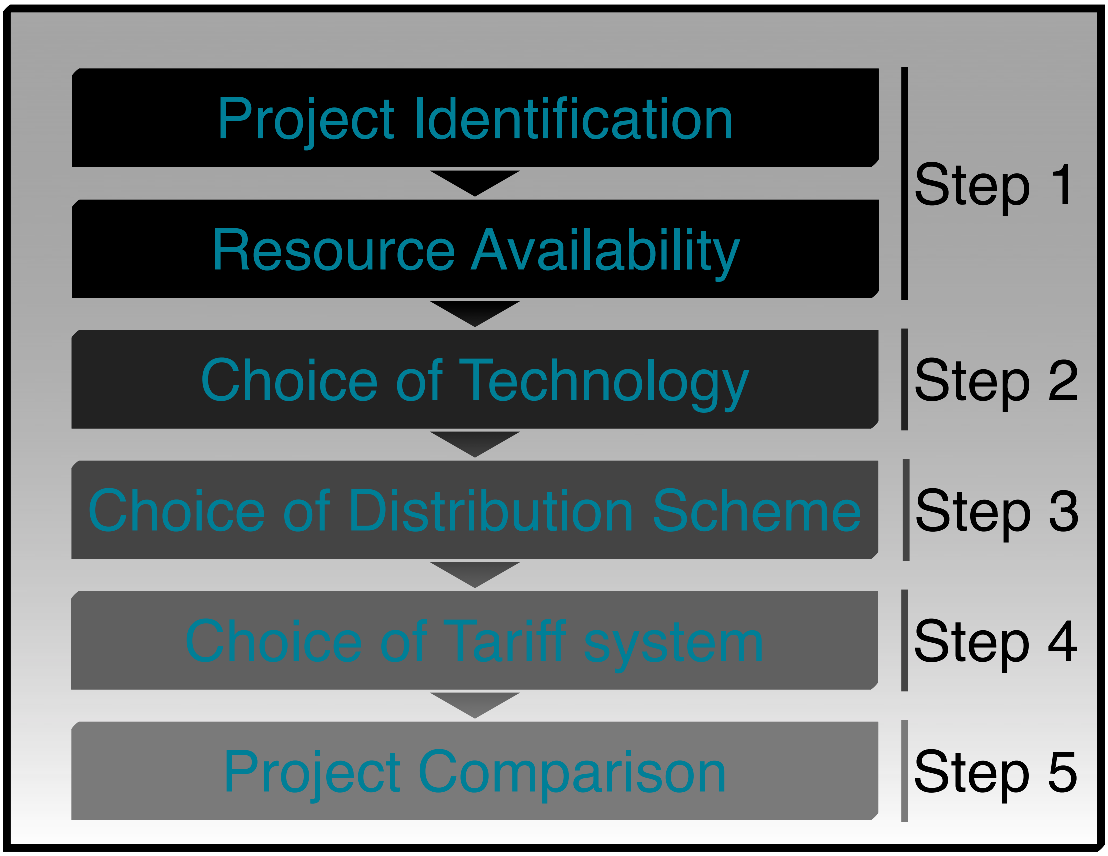

Figure 5: Steps of the decision making process

6.1 Identifying Possible Projects and Resource Availability

First of all possible rural electrification projects have to be identified. To do so several approaches can be used. A in depth analysis of different project identification methods would exceed the boundaries of this thesis but for a better understanding at least some are generically introduced. Subsequently the availability of natural resources has to be considered. It is important, that at this point of the process no possibilities are left out. In order to find the most useful and therefore least cost solution all possible choices should be available.

6.1.1 Project Identification

One of the most favourable identification methods would be an impact-oriented view, hence searching for locations, which would benefit the most from rural electrification measures. Those areas are usually bigger villages, village clusters or towns, which have no access to reliable electricity. Nevertheless some electrical infrastructure might be available because of the existence of an unreliable supply for some parts of town by diesel generators. In this scenario SME's are often already in place and willing to invest into electrically powered machinery once the power supply is stable and sufficient.

Another method would be to look for the economically most favourable location. This often correlates with the impact oriented approach, since in those locations more added value can be expected. But it also means to look at locations, where natural resources are easily accessible and therefore available for power generation.

6.1.2 Resource Availability

In a second step possible methods of power generation should be considered for the chosen locations. Again it is vital to stay open for all possibilities without factoring out certain technologies. Determining the availability of resources is one of the most difficult and at the same time most important steps in developing a successful electrification project.

Some generation technologies require more specific data than others. For example is it crucial to have precise water flow data reaching back a long period of time in order to sufficiently determine the availability of water resources for power generation. This is also valid for biomass installations. A careful analysis of available biomass resources is necessary to make sure that enough biomass is available as fuel to supply the installation and to cover the electricity demand in the area. Nevertheless a rough assessment should be sufficient at this point of the choosing process. Since further feasibility studies will be carried out later on.

6.2 Choice of Technology

Choosing the right generation technology for a rural electrification project is crucial. In most cases the specific conditions predetermine which technology could be used to generate electricity. On top of geographical factors, economic as well as environmental and social factors are influencing the choice of technology.

In order to economically compare different technologies roughly, without visiting each site and compile very costly pre-feasibility studies, this thesis simplifies the most important economic factors. Additionally the grid accessibility plays an important role. It determines if grid electricity is a possible source of electricity.

6.2.1 Grid Accessibility[1]

In order to find out if access to the power grid is available it has to be made sure, that the power grid is able to supply the additional demands which come with new grid connections. Every Transmission System Operator (TSO) has access to load curves, load factors and similar data, which should be reviewed before considering grid expansion as a possible distribution scheme.

In addition the distance to the next grid access point is vital. In order to calculate the so-called Economical Distance Limit (EDL) a brake even analysis between the life cycle cost of the grid and the life cycle cost of alternatives to grid expansion has to be performed as presented below. The outcome of this calculation is the distance until a grid expansion is economically feasible. All input parameters are explained in box 9 below.

$$EDL \times (LCC_{grid} + LCC_{gen}) - LCC_{alt} = 0$$

Consequently:

$$EDL = \frac{LCC_{alt} - LCC_{gen}}{LCC_{grid}}$$

Where:

$$LCC_{gen} = t_{gen} \times L \times h \times \left(\frac{1}{1 - \delta_{t\&d}}\right) \times \left(\frac{(1+i)^n - 1}{i \times (1+i)^n}\right)$$

and

$$LCC_{grid} = C_{grid} + C_t + \left(C_{grid} + C_t\right) \times \beta \times \left(\frac{(1+i)^n - 1}{i \times (1+i)^n}\right)$$

Input parameters:

LCC_{alt}	Life cycle cost of the alternative
LCC_{grid}	Life cycle cost of the electricity grid
LCC_{gen}	Life cycle cost of the grid generated electricity
L	Load demand
h	Annual operation hours
n	Project lifetime
t_{gen}	Electricity generation cost
$\delta_{t\&d}$	Transmission and distribution losses
C_{grid}	Grid line investment cost
C_t	Distribution transformer investment cost
β	O&M cost as fraction of investment cost
i	Discount rate

Box 9: EDL calculation input parameters (Sadhan Mahapatra 2012)

[1] This section is mainly based on (Sadhan Mahapatra 2012)

The accessibility or over all feasibility of a power grid connection is not only dependent on technical or neo-classical economical factors but also a question of the real cost of electricity generated within the power system (grid generated electricity) Therefore it is, later on in the decision making process, necessary to look into the mix of generation as well as environmental and social costs related to the specific generation structure. For more information on this topic please see section 2.1.2.

6.2.2 Investment Cost

The investment cost of each generation technology as it is presented in section 2 is used to derive uniform investment costs for each of those technologies, since mostly investment ranges can be found in literature. This process is explained in Table 14. It is important that even though some information on itemisation of those ranges is available in literature, estimations regarding uniform investment cost are still difficult and based on a well educated guess by the author. In a next step those assumed investment costs are used to compile a replacement plan for each technology to cover a lifespan of 50 years. Furthermore those investments for replacement are discounted using a discount rate of 20%, which is usual for development countries. This is shown in Table 15.

Table 14: Assumed investment cost per kW installed generation capacity. Derived from: (Breeze 2005); (Hussong 2013); (PerfectFuel.ca 2013); (World Bank 2013); (KPMG 2010); (Sadhan Mahapatra 2012); (IEA 2009); (IEA 2010); (IEA 2012); (IRENA 2012)

Technology	Given range in €/kW	Assumed inv. Cost in €/kW	Explanation
Diesel	880 – 1.040	1.000	Smaller installations are to be found on the upper range.
PV	3.100 – 4.700	4.000	Smaller installations are to be found on the upper range.
Wind	1.000 – 1.900	1.450	Smaller installations often use a less mature technology therefore the average value is assumed
Hydro	760 – 7.620	7.000	Smaller installations are to be found on the upper range.
Biomass	1.830 – 7.470	4.650	Smaller installations often use a less mature technology therefore the average value is assumed

Table 15: Replacement plan and investment cost calculation per kW-installed capacity (The full calculations can be found in the annex)

Replacement plan and investment cost calculation					
	Diesel	**PV**	**Wind**	**Hydro**	**Biomass**
Assumed inv. cost	1000	4000	1450	7000	4650
Replacement after no. Of years	3	20	20	50	20
Discounted inv. cost	2.373 €	4.107 €	1.489 €	7.000 €	4.774 €
1	1000	4000	1450	7000	4650
2	0	0	0	0	0
3	0	0	0	0	0
4	1000	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	1000	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	1000	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	1000	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	1000	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	1000	0	0	0	0
20	0	0	0	0	0
21	0	4000	1450	0	4650
⋮	⋮	⋮	⋮	⋮	⋮
50	0	0	0	0	0

Finally the discounted investment cost as presented in Table 15 are subject to a much simplified rating system, where the generation of electricity using a diesel generator setting is used as a benchmark. This is done due to the fact, that the investment- as well as the O&M cost for diesel gensets can be considered as uniform nearly throughout the whole development world due to international fuel prices. Since a diesel engine is the easiest and most available solution with internationally uniform costs it would be the natural first choice for off-grid electrification measures. Therefore the question to be asked is: How do other generation technologies perform in comparison to diesel gensets?

To answer this question a rating system, scaling from -3 to +3 is introduced, where the diesel generator sets the Benchmark with a rating of 0. And the scale of -3 to +3 is representing very high-, much higher-, higher-, lower-, much lower- and very low investment cost. The following Table 16 shows this rating as the author carries it out:

Table 16: Investment cost rating

Generation technology	Rating	Explanation
Diesel	0	Serves as benchmark
PV	-2	Higher investment cost
Wind	1	A bit lower investment cost
Hydro	-3	Very high investment cost
Biomass	-2	Higher investment cost

The investment cost for electricity generated by the electricity grid differs dependent on distance to the next grid connection point since the only possible distribution scheme is grid connection. Therefore a short calculation has to be done for each case. Nevertheless it can be said, that in general investment cost are rather high.

6.2.3 O&M Cost

The O&M cost of different generation technologies as presented in section 2, are used to calculate the actual discounted O&M cost for the assumed lifespan of 50 years. For this reason fuel cost data for diesel fuel (PerfectFuel.ca 2013) and Biomass (Sadhan Mahapatra 2012) was incorporated. The outcome of this calculation including the O&M cost without fuel cost is presented in the following Table 17, which is also showing the rating undertaken by the author in order to simplify the comparison of different generation technologies. It has to be mentioned, that similar to the investment cost, the diesel generator serves as a benchmark.

Because the high cost of diesel fuel is having a big impact on the O&M cost, the benchmark is set at very high O&M cost. In order to differentiate between the renewable generation technologies, it is necessary to keep up the scale of one to three, representing lower, much lower and very low O&M cost respectively. Even though the presented rating is not linear.

Table 17: O&M cost rating

Generation technology	O&M cost excl. fuel cost in €/kW	O&M cost incl. fuel cost	Rating
Diesel	100	11.191	0
PV	200	200	3
Wind	725	725	2
Hydro	1.050	1.050	2
Biomass	1.511	2.663	1

The O&M cost for electricity generated by the electricity grid differs dependent on distance to the next grid connection point since the only possible distribution scheme is the grid connection. Therefore a short calculation has to be done for each case. Nevertheless it can be said, that grid O&M cost are rather low.

6.3 Choice of Distribution Scheme

In order to be able to make a sound decision regarding the least cost rural electrification solution a distribution scheme has to be chosen. The main factors determining which of the introduced distribution schemes is applicable for an identified possible project are load density and distance to the next grid access point. For more information about grid accessibility please see section 6.2.1.

6.3.1 Load Density

Population density and electricity demand size and structure determine the load density of an area. If a region is barely populated and great distances are to be found between single consumers, which are having very low, household accessory sized, demands the load density is considered low, therefore a large amount of infrastructure (distribution grid) has to be build up. This hinders grid expansion as well as mini grid distribution schemes. Therefore an assessment of load density in possible projects is necessary. In most cases, this is already included in the step of project identification considering an impact-oriented approach has been used.

Furthermore detailed information regarding foreseeable impacts and possible effects of the chosen distribution scheme is available in section 3 of this thesis. It should be considered before choosing a distribution scheme for each possible project.

6.4 Choice of Tariff System

Choosing the right tariff system is critical in order to develop a successful rural electrification project. From the three, presented above (section 4), tariff system introductions it becomes clear, that the introduction of a flexible tariff supporting the rural poor as well as SME's and other industrial consumers is the only possible solution to ensure sustainable development. But also a tariff scheme, where every customer is paying the same price can be flexible regarding peak time prices.

Multi tariff meters enable utilities to charge different tariffs depending on the demand curve, reducing peak demands and therefore levelling out load curves. Hence the instalment of a multi tariff meter is state of the art. Nevertheless, cost awareness is an important topic and subsidies of any kind intend to reduce the awareness for caused cost. This also is the case with life line tariffs.

More detailed information about the effects of different tariff systems in combination with certain generation technologies can be found in section 5.

6.5 Project Comparison

After identifying different projects, checking the availability of resources and choosing possible generation technologies, distribution schemes and tariff systems for the selected locations, those projects need to be compared to each other. This step is necessary in order to find the least cost project. The comparison of those projects is happening on two different levels. Whilst comparing economic cost is a rather simple task, the comparison of environmental and social cost is more complicated.

6.5.1 Comparison of Economic Cost

Regarding investment as well as O&M cost of different possible rural electrification projects a rating, comparing different technologies, is applied during step 2 (Choice of Technology) of the pre-assessment methodology. This rating supplies clear indication of project overhead. It is not supposed to deliver monetary numbers as such. It much more serves to provide an economical overview, indicating if a possible project can be expected to be rather cheap or expensive.

6.5.2 Comparison of Environmental and Social Cost

Since no numbers, ratings or hard facts regarding the environmental and social costs of different rural electrification projects are available in most cases a comparison is only possible in a qualitative sense. Hence it is necessary to look into foreseeable impacts and possible effects of applying the chosen combinations of different generation technologies, distribution schemes and tariff systems as they are described in sections 2 to 5 of this thesis. Most decisions made in this regard are of political and macro-economic nature. But an overview of possible effects should already be provided in this step of the decision making process in order to grasp the real cost of possible projects. Hence a qualitative comparison should be conducted relating to the impacts and effects as they are presented earlier.

6.6 Conclusive Summary

While developing the pre-assessment methodology as introduced in this section, it becomes clear, that using such a general methodology cannot result in in depth analysis or precise information. But it may give the possibility to make an informed and therefore more objective decision where to implement which rural electrification measures in order to reach the most effective or least real cost solution. Furthermore this methodology includes externalities as qualitative information hence decision makers are encouraged to incorporate those cost into their thoughts. Additionally the generalised and simple approach of this methodology also leads to a very cheap and fast conductible pre-assessment, which might be able to point out the most likely least cost solution. It therefore provides a simple way indicating where to conduct further analyses like pre-feasibility- and feasibility studies.

7. Exemplary implementation

In order to show how the developed pre-assessment can be implemented this section provides an exemplary implementation of the assessment within a fictional region (Utopia) to cover as many different settings as possible. Nevertheless is a setting like this realistic, since for example several countries in Asia provide a vast amount of different natural resources. Other than that is this scenario based on observations made by the author throughout several field trips during internships and previous assignments.

The exemplary implementation is divided into two main sections, first introducing the fictional setting and implementing the actual pre-assessment methodology in a second step.

7.1 Introduction of Utopia

Utopia is located in eastern south Asia, providing a good solar potential all over the country and very wet water rich summer months. Steady and strong winds can be found on the coast. Most of the country is rather flat but a mountain range is located in the east of the country. The following Figure 6 shows a sketch map of Utopia including areas where hydro and wind resources can be found.

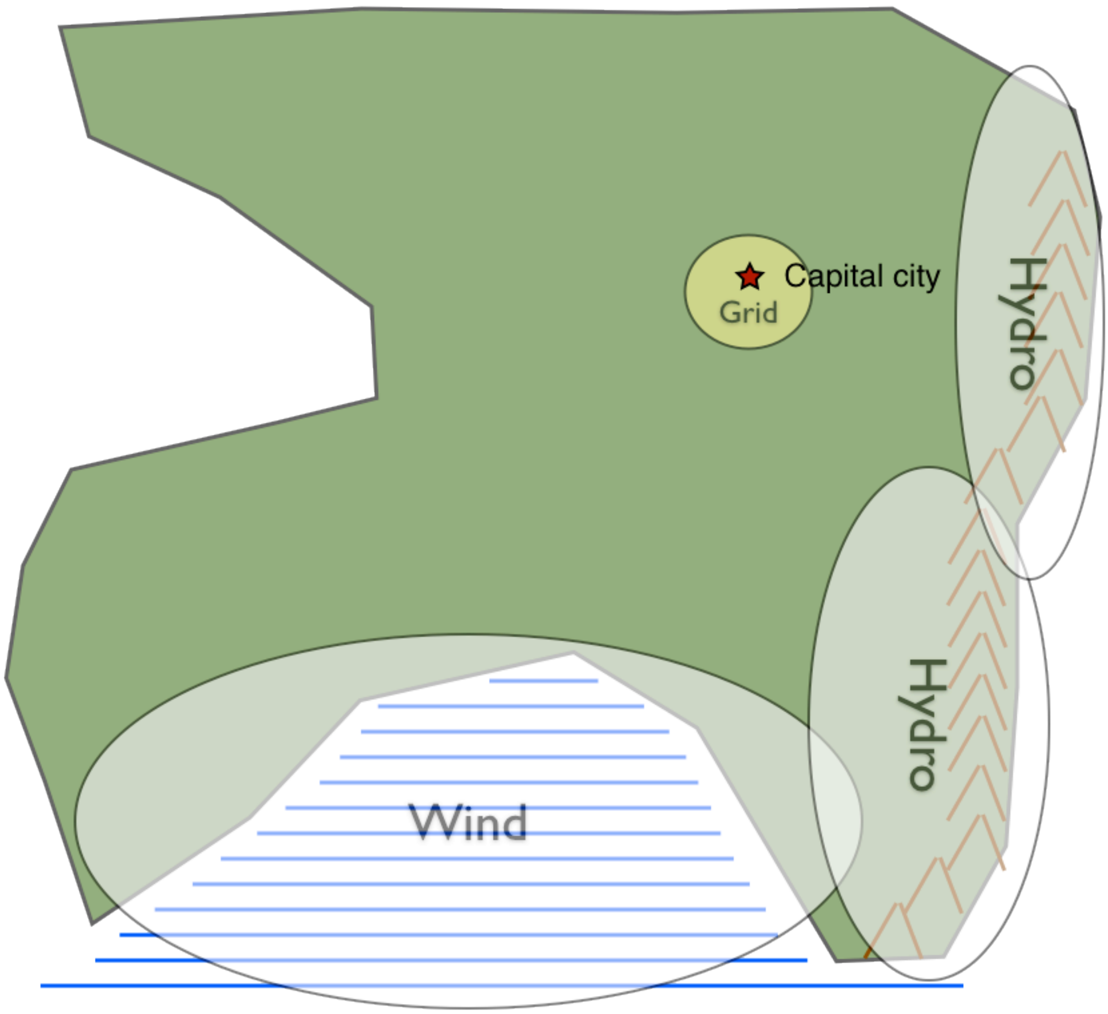

Figure 6: Sketch map of Utopia

Furthermore the capital of Utopia (Capital City) is indicated on the sketch map. The area around Capital City is developed by an electricity grid. Other than that no overhead power cabling is available. In addition it is assumed, that none of the rural population of Utopia has sufficient access to electricity.

7.2 Exemplary Pre-assessment

This section follows the five steps as they were introduced in section 6 of this thesis. Hence starting with the identification of possible projects and resource availability. Proceeding with choosing generation technologies, distribution schemes and tariff structures for the identified projects. Finally the different projects are compared in a last step.

7.2.1 Project Identification and Availability of Resources

In order to identify possible rural electrification projects some knowledge regarding possible impacts of electrification measures, availability of resources, population densities, average incomes and electrification rates is necessary. For most decision makers, obtaining that knowledge is not a complicated task but for the sake of simplicity presenting all this data is waived. Furthermore it is assumed, that all possible projects have a load demand of 100 kW, representing up to 300 households with a maximum demand of around 330 W each.

It is assumed, that a number of 5 different possible projects could be identified. The project locations are displayed in Figure 7 and shortly introduced below.

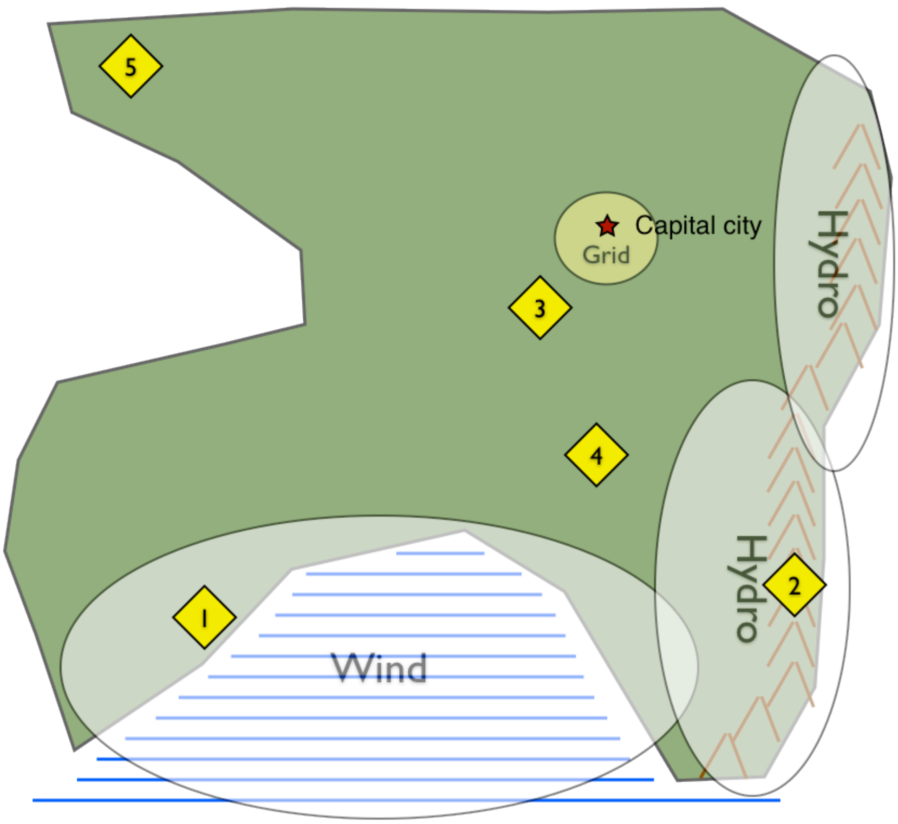

Figure 7: Possible project locations

Table 18: Possible rural electrification projects

	Distance to the next grid connection point [km]	Available resources	Load density
Project 1	192	Wind	Low
Project 2	140	Hydro	Low
Project 3	30	Solar	High
Project 4	60	Biomass	Medium
Project 5	175	Solar	High

Project 1: The first identified possible electrification project is located in the south west of Utopia close to shore. Therefore good and stable wind resources are available all year long. The distance to the next grid connection point is more than 190 km and a connection is therefore probably very costly and unlikely to happen in the near future. The load density in this area is low, since only a few small villages are spread out over a bigger area.

Project 2: The second project, which could be of interest, is located in the south east of Utopia, 140 km away from the next grid connection point. Only a small number of individual houses is spread across the area within the mountain range. Good water resources seem to be available in the area.

Project 3: The third possible project is located quite close to Capital City, in the centre of Utopia, only 30 km away from the next grid connection point. Therefore a possible grid connection could be economically feasible and should be investigated further. The population density is high since the project is located in a smaller town. Solar resources would be available for electricity generation.

Project 4: The fourth project is located South of Capital City, in a village cluster, providing medium load density. Furthermore the small-scale forestry industry in this location would provide residue usable as biomass. The distance to the next grid connection point is 60 km.

Project 5: Project number five is located in the north west of Utopia in a small town, 175 km away from the next grid connection point. Solar resources are available to generate electricity.

7.2.2 Choosing Generation Technologies

In order to choose possible generation technologies the available resources as indicated in section 6.1.2 have to be considered. Other than that diesel generators can provide a secure and stable supply with electricity. Furthermore it was mentioned earlier, that solar resources are available nearly everywhere in Utopia. Therefore they also should be considered as possible generation technologies. On top of that the accessibility of the power grid has to be checked.

First of all the EDL for each generation technology is calculated. The results of this calculation are displayed in Table 19. The full calculations can be found in the annex.

Table 19: EDL in km for different generation technologies with a 100kW load demand

	Diesel	Solar PV	Wind	Hydro	Biomass
EDL [km]	153,4	34,3	7,4	82,4	74,5

It can be seen, that the EDL for diesel based generation is quite high, resulting in the insight, that besides Projects 1 and 5 all the identified possible electrification projects are within the EDL of diesel generators.

In a second step the rating of investment- and O&M cost as introduced in section 6.2 is applied. The following Table 20 summarises the economical part of the process of choosing generation technologies for the five identified projects. It is elaborated on below.

Table 20: Summary of the economic factors for choosing generation technology

	Within EDL	Possible generation technologies	Inv. Cost rating	O&M cost rating	Remarks
Project 1	NO	Wind	1	2	Check for sufficient resources
		Diesel	0	0	
		Solar	-2	3	Check for sufficient resources
Project 2	Only for diesel	Hydro	-3	2	Check for sufficient resources
		Diesel	0	0	
		Solar	-2	3	Check for sufficient resources
Project 3	YES	Solar	-2	3	Check for sufficient resources
		Diesel	0	0	
		Grid electricity	0	2	
Project 4	Only for diesel	Biomass	-2	1	Check for sufficient resources
		Diesel	0	0	
		Solar	-2	3	Check for sufficient resources
Project 5	Only for diesel	Solar	-2	3	Check for sufficient resources
		Diesel	0	0	

Generating electricity by diesel gensets can be identified as the economically most expensive solution in all cases. It is therefore displayed in red. The economically most favourable solution on the other hand is displayed in green. While a possible third solution if available is displayed in yellow for representing medium economic cost compared to the alternatives.

In the last column of Table 20 remarks are added regarding each possible generation solution. They are suggesting to further investigate the availability of all renewable resources. This is due to the fact, that most of them are not able to supply a sufficient amount of power all year long. In this case backup power in the form of diesel generators, biomass installations or power storage is needed. This will influence the cost of each of those projects, also shifting the EDL of each project.

7.2.2.1 Actual Choice of Generation Technology

This section will consider the arguments of section 2 as well as the economical investigation of section 7.2.2 in order to conclude on a generation technology for each possible project. In most cases further investigations regarding demand situation and actual resources are recommended. Those are necessary to recalculate economic indicators as well as the EDL if generation technologies are combined.

Project 1: (Wind power) Since no access to the electricity grid is available even considering a diesel generator as the only generation technology in place, the choice is fairly simple. Wind power has the ability to deliver electricity also during peak times, when solar irradiation might not be sufficient anymore. Therefore Wind Power will be chosen as the primary generation technology. Further research might have to investigate the actual wind resources and demand situation in order to recalculate according to the needed power backup.

Project 2: (Hydropower) Since hydropower has the ability to generate a steady amount of electricity all year long, depending on water resources, those should be further investigated. It might be possible to generate a sufficient amount of electricity without the negative environmental impacts of a diesel genset. Which would be economically unattractive anyways, since Project 2 is located within the EDL if a diesel generator is used to full extend. In addition a further investigation of the hydro resources should also consider possible environmental impacts as they are described in section 2.2.3.

Even though a solar PV installation might be cheaper than a hydro based electrification project, the fact, that hydropower has a bigger availability than solar power serves as the main argument to pick hydropower as generation technology.

Project 3: (Grid electricity) The third project lies well in the EDL even if only solar resources are used to generate electricity. Therefore Grid electricity would be the first choice as generation technology. In this regard it should be further investigated what the economic and social impacts of the Utopian grid electricity are. This depends on the electricity mix of the Power system as described in section 2.1.2.

Project 4: (Solar PV / Biomass hybrid) Solar PV seems to be the economically most attractive generation technology for Project 4. Nevertheless as a stand-alone technology it is not feasible in most cases due to the fact, that it is not able to supply electricity at night-time. Therefore a hybrid installation considering the available biomass resources, which would probably still be economically more attractive than a diesel based solution, could be interesting. This combination might even lie outside it's EDL. In order to pursue this project, an assessment of the available biomass resources and demand situation has to be considered in order to recalculate EDL and gather information regarding the social and economical impacts of a possible biomass installation.

Project 5: (Solar PV / Diesel hybrid) Solar PV is not able to supply electricity during night times. Therefore it would be insufficient as a stand-alone installation. Further investigations should be considered, regarding the demand situation in order to recalculate the EDL and economic indicators for a possible hybrid installation using solar power and a diesel generator.

7.2.3 Choosing Distribution Schemes

Choosing the right distribution scheme for a possible project is crucial. In most cases a decision can be reached based on the load demand. Since the demand size for all the identified possible projects is assumed to be 100 kW the load density is determined by the population density as well as demand structure. The following Table 21 is based on the information given in section 7.1 as well as the description of each possible project in section 7.2.1 and the type of generation selected in section 7.2.2.

Table 21: Choosing possible distribution schemes

	Load density	Generation technology	Distribution scheme
Project 1	Low	Wind power	Individual generation
Project 2	Low	Hydropower	Individual generation
Project 3	High	Grid electricity	Grid expansion
Project 4	Medium	Solar PV / Biomass Hybrid	Mini Grid
Project 5	High	Solar PV / Diesel Hybrid	Mini grid

The choice of a distribution scheme is also related to the chosen generation technology. Furthermore the effects of combining generation technologies with certain distribution schemes are described in section 5. They will be further investigated in section 7.2.5.

7.2.4 Choosing Tariff Systems

The final step in defining possible projects is to choose a tariff system for each project. The chosen tariff systems are inserted into Table 21 resulting in the following Table 22. It is elaborated on below.

Table 22: Choosing possible tariff systems

	Load density	Generation technology	Distribution scheme	Tariff system
Project 1	Low	Wind power	Individual generation	Flat rate
Project 2	Low	Hydropower	Individual generation	Flat rate
Project 3	High	Grid electricity	Grid expansion	One price
Project 4	Medium	Solar PV / Biomass Hybrid	Mini Grid	Life line
Project 5	High	Solar PV / Diesel Hybrid	Mini grid	Life line

Since Projects 1 and 2 are based on individual generation usually a kind of flat rate tariff will be in place. In most cases the installations are sold to the customer as described in section 3.3. Therefore no real tariff system is applied but all electricity is already paid for, similar to a flat rate tariff. Nevertheless the cost awareness is higher since the customer himself does all investments.

Project 3 could benefit from a one price tariff since cost awareness is higher than it would be within a life line based system. In addition the rather low cost of grid generated electricity might enable even the rural poor to benefit from the project.

Projects 4 and 5 should apply a life line based system in order to cross-subsidise the higher cost of generation which comes with using fuels like biomass or diesel. This applies even more to Project 5 due to its higher fuel cost.

The effects of combining generation technologies with certain tariff systems are described in section 5. They will be further investigated in section 7.2.5 below.

7.2.5 Project Comparison

In order to compare the five identified projects to each other Table 23 summarises all the facts compiled during sections 7.2.1 to 7.2.4. Furthermore the environmental and social costs of those projects are discussed in below.

Table 23: Economic project comparison

	Generation technology	Distribution scheme	Tariff system	Generation Inv. Cost rating	Generation O&M cost rating
Project 1	Wind power	Individual generation	"Flat rate"	1	2
Project 2	Hydropower	Individual generation	"Flat rate"	-3	2
Project 3	Grid electricity	Grid expansion	One price	0	2
Project 4	Solar PV / Biomass Hybrid	Mini Grid	Life line	-2	2
Project 5	Solar PV / Diesel Hybrid	Mini grid	Life line	-1	1

Table 23 shows, that the economically most attractive solution would be Project 1 with the least investment cost and comparable O&M cost to the other projects regarding the generation technology. But effects of the chosen distribution scheme and tariff system have not been considered yet.

After the quick economical analysis and first insights derived from this the most favourable possible projects are subject to a first analysis of possible environmental and social effects, which might appear due to the electrification project. Therefore the effects described in sections 3 to 5 of the thesis are consulted.

Project 1: A distribution system based on unreliable renewable generation technologies such as wind power always bares an environmental risk in form of power storage. Batteries are needed not only to bridge low wind times but also to serve as a buffer in order to receive a steady current. This leads to the issue of battery recycling, which can be a complicated task as described by (Drenkard 2013). Additionally the risk of weather is shifted to the consumers. Since no real tariff system is in place but the installations are sold to the customers the most common effects of a flat rate tariff will not arise or have very low impact. Since no emissions are generated during power production the possibly higher demand, which is inducted by a flat rate tariff has no environmental impact. Furthermore individual generation installations always bare the risk of hindering the development of a more efficient and sufficient power supply. In addition the investment cost as well as O&M cost for those installations can be considered as very high. This might result in an access threshold.

Anyways further investigations have to show, if the wind resources are sufficient to power individual installations enabling them to generate electricity in a way that falls under the definition of rural electrification given in section 1.4.2 of this thesis, providing reliable and sufficient access to electricity.

Project 3: The next considerable project is project 3. A supply with grid electricity through grid expansion combined with a life line tariff not only offers rather low investment cost but also competitive O&M cost of generation. Although the management of an electricity grid is a complex task, project 3 offers the most efficient way of supplying the rural population with reliable and sufficient electricity, which is in most cases available for low cost. On the other hand the complex tariff system leads to a low cost awareness, which is supported by the central generation and therefore low identification with the product. This might lead to high non-technical losses and raised electricity demands.

In addition grid expansion always bares the risks of high transmission losses (in relation to the length of the connection) and load shedding, if the power supply of the grid is not strong enough to take on the additional demand of the expansion. Furthermore the environmental effects of grid generated electricity have to be investigated in further studies since they are dependent on the electricity mix within the grid.

Therefore it is essential to conduct further investigations in order to find out if the grid is stable enough to cover the additional demand and how the grid electricity is generated respectively what environmental and social cost are linked to this generation.

7.3 Conclusive Summary

Due to the effects described above it becomes very clear, that a definite decision which project is incorporating the least cost can not be reached in this stage of the decision making process. Therefore in a next step pre-feasibility studies have to be conducted. But the two projects which are most likely to represent the least cost rural electrification solution could be identified. Indicating details to concentrate the pre-feasibility studies on. Additionally the two identified projects are of very different nature, representing expansion of the electricity grid and individual generation additionally to the facts and possibilities presented in this analysis political influences might shift the decision makers towards one or the other possible project.

8. Discussion and Recommendations

This section discusses the methods used throughout this thesis as well as possible points of debate and recommendations for further studies. It therefore revises critically if a generalised view on cost influencing factors, as used in order to develop a universal pre-assessment methodology, is applicable. The section is split into two parts, firstly focusing on methods and points of debate and secondly giving recommending further investigations beyond the framework of this thesis.

8.1 Discussion of Methodology and Assumptions Made

Social cost: Incorporating social cost into project planning is always difficult. This is especially the case, if the project planning is done in a universal way as this thesis aims to do. On the pre-assessment level a calculation of, for example, the future employment possibilities would pretend a level of detail, which cannot be reached. Therefore the thesis tries to foresee the most common and most likely social effects of different generation technologies, distribution schemes and tariff systems as they are introduced shortly within the sections 2 to 5.

Types of generation: This thesis waives a fundamental description for the presented generation technologies. Only a short introduction is given including rough estimations on investment as well as O&M costs. Especially the presented investment cost data often ranges widely. This is mostly due to varying generation capacities (see hydropower) but also due to the fact, that a precise cost statement cannot be made due to the fact, that investment cost are influenced by several factors like location and available infrastructure. Furthermore the used cost data comes from several different sources. Those sources are not necessarily coherent in their assumptions. Therefore the reliability of such data is questionable. In addition some assumptions regarding investment cost where undertaken by the author in order to loose the wide data ranges. Those assumptions are mainly based on information regarding capacity sizes given in the sources or on a well educated guess by the author.

S.W.O.T. analyses: The S.W.O.T. methodology is used as an internal as well as external tool to analyse certain topics much more than as a “real” S.W.O.T. analysis in the traditional sense. It would not be sufficient to reduce the effects mentioned in those parts of the thesis as simple pros and cons. Therefore the S.W.O.T. scheme is used. It allows differing between internal Strengths and weaknesses and external opportunities and threats. Whereby the internal effects are considered as foreseeable impacts, and the external effects are considered as something that could happen with different probabilities. Most of these effects are obvious to the interested reader or could be derived during informal interviews with experts in the field of rural electrification and small-scale renewable energy installations. Others are based on experiences made by the author during several internships and earlier assignments including field trips. Nevertheless it is difficult to provide clear sources for those facts. Additionally they are not described in detail, which would be clarifying.

But a detailed description for every single presented effect would again exceed the boundaries of this thesis.

Distribution schemes: Regarding the introduced distribution schemes it has to be mentioned, that in certain cases the transition between an individual installation and a mini grid installation can be vague. Therefore it is assumed, that any installation with more than one meter using the same source of generation is considered a mini grid. This might not always be the case in reality. Furthermore the distribution of individual installations and the financing related to that is a big and interesting issue, which was not part of this thesis but might have a considerable impact on the success of such projects.

Tariff systems: Multi-tariff systems offer the possibility to influence the demand curve of customers by charging different prices per kWh dependent on the current demand of the whole grid. This might lower peak loads and supports the use of electricity during daytime, when most of the productive usage can be expected. The price difference between multi-tariff and single-tariff meters is negligible and therefore multi-tariff meters can be considered state of the art. In this relation the investigation of effects of multi tariff systems on rural electrification projects would be interesting. As en exemplary multi-tariff system this thesis introduces the life line-tariff, which can also be used utilising single-tariff meters and offers other advantages such as energy poverty avoidance. In order to thoroughly analyse the effects of different multi-tariff systems, demand curves and demand purposes have to be available. This cannot be expected to be the case on the pre-assessment level.

Effects of combining generation technologies with distribution schemes and tariff systems: The effects of combining the introduced generation technologies with different distribution schemes and tariff systems, as presented in section 5, are simply derived from the information given in sections 2 to 4. A more thorough investigation of those effects would come with a far greater effort regarding literature research, which would exceed the boundaries of this thesis. Anyhow the deduction of those effects follows logical paths.

Organisational structure: This thesis does not deal with the organisational structure of a possible rural electrification project although it might have an impact on its success. This is due to the fact, that possible financing and organisational schemes are mostly related to cultural as well as social and technical differences of specific project locations. The role of so-called independent power producers (IPP's) as well as cooperative owner models is an interesting topic, which could be subject to further investigations. It is even conceivable, that the presented pre-assessment methodology could be extended by a "choosing ownership model" step.

Project identification: The first step of the developed pre-assessment methodology is the identification of possible projects. The methodology as presented could only be able to identify the most favourable project of those, which are identified in the first place. Therefore this step is of major importance. Despite that, the thesis does not discuss the project identification thoroughly. This is because projects are identified in many different ways, the most feasible ways are shortly introduced in section 6.1.1 but a deeper investigation would exceed the boundaries of this thesis. On top of that it is often the case, that decision makers already have projects identified when a pre-assessment is carried out.

Resource availability: The availability of resources within the identified projects is only briefly checked throughout the developed pre-assessment methodology. This simplifies the process to a great amount but is also the point of origin for many uncertainties, which disparage the possible achievements of the pre-assessment. In order to classify the results produced by such a pre-assessment it is important to keep in mind, that it is only the first step in the process of project development and that pre-feasibility- and feasibility studies will follow, which will investigate the availability of resources as well as the demand structure, available infrastructure and much more, in detail.

Calculations and assumptions made: The following paragraphs discuss possible sources of confusion as well as distortion throughout the calculations made during sections 6 and 7 of the thesis.

All grid calculations are based on cost data regarding a 33 kV over-land power line. Usage of a different kind of cabling with higher capacity will result in higher cost. Additionally the range of a 33 kV power line is limited. In order to reach all the in section 7.2.1 identified possible projects higher capacity lines would have to be used. This would result in different EDL values, lower than stated. Additionally all calculations were executed assuming cost for three distribution transformers. If several access points to the grid should be available more than those three transformers would be needed. This would raise the investment cost.

Furthermore all calculations are conducted assuming an electricity demand of 100 kW for all the identified projects. This is of course unrealistic. And while applying the developed pre-assessment methodology each calculation has to be made with the corresponding demand to be expected in regard to the number of households within the area.

In regard to the O&M cost rating the usage of diesel generated electricity as a benchmark is discussable. Since diesel O&M cost are much higher than those of the next costly generation technology (Biomass) the rating can not be executed in a linear matter. This might lead to confusion and has to be taken in regard when comparing the O&M cost rating (Diesel O&M cost are about 4,2 times as high as Biomass O&M cost). Additionally the cost for diesel fuel assumed are a world wide average of 2012 and therefore not forwarded up to 2062. This could have an effect on the actual outcome of the calculation. But the high interest rate of 20% would eat up future cost anyways since it can be expected to be higher than the rate of price increase.

The cost of biomass as a fuel are uncertain and differ for every location. They are highly dependent on the opportunity cost of biomass hence the value of biomass in a different use.

All investment cost data is given in € per kW installed capacity. This is common practice as it can be seen within literature (IEA 2012); (IEA 2012a); (IEA 2010); (IEA 2009); (EIA 2010); (Tidball, et al. 2010). This treatment makes sense because a generation facility costs a certain amount of money, regardless its production. Using € per kWh as investment cost unit makes sense when the subject is a storage facility. The lower utilisation of most renewable energy sources has to be incorporated in thorough calculations of the LPC. Furthermore the demand curves of identified projects are not available at the state of a pre-assessment. Therefore the actual demand in kWh is not available. The pre-assessment only utilises an assumed peak demand per connected household of around 300Wp, which has to be available at any given point in time. Therefore the installed capacity has to be able to cover this demand regardless its actual production. In other words: Investment cost is the price for a certain amount of capacity being available not the amount of money to be invested to produce a certain work.

O&M cost are given as a share of the investment cost. This is applicable if the share of variable investment cost is small. This is the case for most renewable generation technologies. In case of high fuel cost (Diesel & Biomass), these are not included within the given O&M shares.

8.2 Further Investigations

Of course a generalised view as it was applied throughout this thesis leaves room for discussion. This section introduces several topics, which have risen during the process of composing this thesis but could not be incorporated. Furthermore it will argue why those topics were not pursued any further.

Subsidies: Possible subsidies are an important topic within rural electrification and definitely worth to be investigated. They are also most likely to have a big impact on the success of rural electrification projects. But the level of detail, which comes with a thorough investigation of different subsidy schemes, would firstly exceed the boundaries of this thesis and secondly exceed the boundaries of a pre-assessment methodology since subsidies should be handled very carefully and be adjusted to local conditions thoroughly. This is also shown in earlier work of the author (Parajuli, et al. 2013).

Environmental Impact Assessments: As already mentioned in section 1.4.2.1 environmental effects and cost of a certain project are usually identified using an Environmental Impact Assessment (EIA). But this procedure requires a lot of detailed input regarding the specific location. Since this information is usually not available during the state of an pre-assessment, Incorporating such a process into the pre-assessment methodology would be not feasible. Therefore the most common and most likely environmental effects of different generation technologies, distribution schemes and tariff systems are introduced shortly within the sections 2 to 5.

Energy storage: The cost of utilising energy storage installations is not included in this thesis. It is a common practice especially regarding individual generation approaches to use Lead Acid batteries as a storage device. This is mentioned as a possible environmental effect in section 5. Anyhow it has to be mentioned, that a usual Solar Home System including a 45Wp PV module is definitely not able to supply the necessary amount of electricity to gratify the in section 1.4.2 introduced definition of electrification. In order to do so larger installations including bigger storage capacities, maybe on a mini grid bases, have to be introduced. A investigation of how those facilities might look like and how they could play a role within the rural electrification sector is of great interest but could not be included in this thesis because it would exceed its boundaries. Nevertheless a small assessment, which shows, that larger-scale storage facilities would increase the investment cost of a 100kW solar PV installation by more than 156% is conducted during section 1.4.1.

8.3 Conclusive Summary

The discussion shows, that a lot of details, which are important on the way toward the least cost rural electrification solution are not or not as thorough incorporated within this thesis. Nevertheless a methodology is developed, which might improve the way of how decisions are made. Therefore room for improvement is left and further studies have to show, how other factors, which may not be included in this thesis are actually influencing the cost of rural electrification measures an how the developed pre-assessment methodology can be improved by integrating those. It is further shown, that the thesis might be a positive influence on the decision making process, if it is kept in mind, that a pre-assessment is not compiled by the same level of detail as a pre-feasibility or feasibility study.

9. Conclusion

Myriad factors influence the real cost of rural electrification measures. Besides technical and economic influences, a keen observer can notice political and institutional forces at work. In order to enable national or regional decision makers to find the least cost electrification solution this thesis tries to develop a pre-assessment methodology, supplying them with the necessary level of information to evaluate statements and influences taken by external donor organisations and consultancies. Therefore this pre-assessment is designed in a way, that it can be conducted without the need for in-depth research or extensive site inspections. This also means, that it can never be a substitute to pre-feasibility- or feasibility studies. But it may be able to supply decision makers with arguments and objective information on their way towards a efficient rural electrification program.

The following Table 24 summarises the pre-assessment methodology as it is developed throughout this thesis within a checklist to be used by decision makers.

Table 24: Pre-assessment checklist

Steps of the pre-assessment	How to do it	Input from	Check
Project identification	**Research**	**Research**	
Resource availability	**Research**	**Research**	
Choice of technology	**Informed decision**	**Resource availability & section 2**	
Grid accessibility	Calculation	Section 6.2.1	
Investment cost rating	Apply rating	Section 6.2.2	
O&M cost rating	Apply rating	Section 6.2.3	
Environmental and social cost assessment of chosen technology	Qualitative assessment	Section 2	
Choice of distribution scheme	**Informed decision**	**Load density & sections 3; 5; 6.4**	
Choice of tariff system	**Informed decision**	**Sections 4; 5; 6.5**	
Environmental an social cost assessment of chosen distribution and tariff system	Qualitative assessment	Sections 3; 4; 5;	
Project comparison	**Informed decision**	**Section 6.5**	

In order summarise and conclude what the developed pre-assessment methodology can accomplish and what it cannot, a S.W.O.T. analysis is conducted. The analysis as well as its results are displayed and elaborated on below:

Table 25: Pre-assessment methodology S.W.O.T. analysis

Strengths	• Simple and fast • Small amount of information is required • Cheap • External cost are part of the methodology and therefore included • Choice awareness
Weaknesses	• Not precise • Questionable cost data (assumptions)
Opportunities	• Informed therefore more objective and defendable decision making • Further investigations can be concentrated on least ”real” cost solutions
Threats	• Environmental and social cost could be underrated • Least cost projects may not be feasible • Least cost solution might not be identified

While conducting a S.W.O.T analysis external and internal statements are combined, by answering the following questions:

Table 26: S.W.O.T. Questions to be answered

	Strengths	**Weaknesses**
Opportunities	**A)** How can the strengths be used to utilise the opportunities?	**B)** How weaknesses hinder the utilisation of opportunities?
Threats	**C)** How can strengths protect from threats?	**D)** How are weaknesses the reason for threats?

A) Due to the small amount of information required to conduct the pre-assessment as developed throughout this thesis it is a simple task which can be done within probably one day. Therefor it is a cheap instrument to lead to a more informed and therefore more objective decision. Additionally external costs are included in the pre-assessment as qualitative information. This raises awareness for external costs and their effects. This also means, that further investigations can be concentrated on the most probable least cost solutions as well as external costs within these possible projects since a first idea of possible external costs has already been given to the decision makers while conducting the pre-assessment. Finally, the decision makers are aware of their choices and possible effects and impacts of their choices. They are therefore able to choose between alternatives instead of believing lobbyists or biased NGO’s.

B) Due to the low amount of information, which is needed to conduct the pre-assessment as developed throughout this thesis, the result is not a precise assessment of all possible solutions and should never be sold as such. It is much more a rough estimation of possible choices. This leads to a questionable position. Pre-feasibility- or feasibility studies can never be waived aside arguing, that the pre-assessment has shown that another solution might be more favourable. Furthermore, the assumptions made by the author may be questionable, especially regarding cost input data. Therefore it is strongly advised, to gather local input data whenever possible. A rough cost estimation in regard to the local circumstances should be available for every technology. It has to be said, that the outcome of the pre-assessment can only be as precise, as its input. Therefore using local input data will enhance the chances to find the least real cost solution for rural electrification during further pre-feasibility- and feasibility studies.

C) Due to its simplicity the developed pre-assessment methodology is a fast and cheap way to come up with informed decisions. Even though, feasibility studies might show, that the most favourable projects identified by the pre-assessment are not feasible. It could also be the case, that the least cost solution can not be identified because it was left out during the stage of project identification. Furthermore Environmental and social cost are only available as qualitative information. They might therefore be underrated during the pre-assessment. Nevertheless, the low cost and time exposure justify a pre-assessment even if it is incorporating the displayed threats. Additionally the act of performing such an analysis may sharpen decision makers wits towards influencing factors external costs and choice awareness and therefore lead to a more efficient and informed process of rural electrification.

D) Because a generalised view on rural electrification measures cannot result in precise conclusions. Therefore it might be the case, that the actual least cost solution for rural electrification is not identified during the pre-assessment. Furthermore, the cost data applied during this thesis can be considered questionable as discussed in section 8. This is mostly due to broad cost ranges given in literature, whereby the actual cost depend on local conditions and plant sizes. Additionally excluding local states from such an assessment leads to the possibility, that the identified most favourable solution might not be feasible.

It is shown, that a general view on rural electrification as taken by this thesis incorporates many quite problematic assumptions as well as uncertainties. If the developed pre-assessment methodology is applied this has to be kept in mind. Decision maker should always be aware of the fact that successful rural electrification can only be reached when all the specific local conditions, including social and environmental conditions, are considered. But additionally they should also be aware of all their choices in order to make an informed and well-founded decision. Therefore the pre-assessment methodology developed throughout this thesis can only be a starting point on the road towards more efficient and successful electrification of the rural areas of development countries.

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Annexes

All calculations carried out throughout the thesis are displayed as annexes below. All calculations were done using Microsoft Excel. The references of utilised input data can be found within the thesis (section 3).

Annex 1 (Cost Calculations): In order to calculate the presented EDL's the LCC's of all generation technologies have to be calculated. Due to calculatory reasons all cost data is displayed as negative values. The results of all cost calculations are shown below:

Cost calculation											
Capacity:	100	kw									
Interest rate	20%										
Technology	**Investment cost by sources [€]**	**As-sumed inv. Cost [€/ kW]**	**As-sumed inv. Cost**	**Discount-ed Re-inv. Cost [€]**	**Lifetime [years]**	**O&M/ year in % of inv.**	**O&M cost [€/year]**	**Discount-ed O&M cost excl. Fuel [€]**	**Fuel cost [€/kWh]**	**Discounted Fuel cost [€]**	**Discounted O&M incl. Fuel [€]**
Diesel	880 - 1040	-1000	-100000	-237.341 €	20	2	-2000	-9.999 €	0,26	-1.109.095 €	-1.119.094 €
Grid	5844 / km	Dependent on grid length									
PV	3100 - 4700	-4650	-400000	-410.706 €	20	1	-4000	-19.998 €	0	0,00 €	-19.998 €
Wind	1000 - 1900	-1450	-145000	-148.881 €	20	10	-14500	-72.492 €	0	0,00 €	-72.492 €
Hydro	760 - 7620	-7000	-700000	-700.000 €	50	3	-21000	-104.988 €	0	0,00 €	-104.988 €
Biomass	1830 - 7470	-4650	-465000	-477.445 €	20	6,5	-30225	-151.108 €	0,027	-115.175 €	-266.284 €

Annex 2 (Replacement Plan and Investment Cost Calculation): The replacement plan and Investment cost calculations, which is also presented in section 6.2.2 is fully displayed below. Due to calculatory reasons all cost data is displayed as negative values:

Replacement plan and investment cost calculation						
	Diesel	**PV**	**Wind**	**Hydro**	**Biomass**	**Grid inv.**
Assumed inv. Cost [€]	-100000	-400000	-145000	-700000	-465000	-205060
Lifetime [years]	3	20	20	50	20	20
NPV [€]	-237.341 €	-410.706 €	-148.881 €	-700.000 €	-477.445 €	-210.548 €
1	-100000	-400000	-145000	-700000	-465000	-205060
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	-100000	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	-100000	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	-100000	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	-100000	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	-100000	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	-100000	0	0	0	0	0
20	0	0	0	0	0	0
21	0	-400000	-145000	0	-465000	-205060
22	-100000	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	-100000	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	-100000	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	-100000	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	-100000	0	0	0	0	0
35	0	0	0	0	0	0
36	0	0	0	0	0	0
37	-100000	0	0	0	0	0
38	0	0	0	0	0	0
39	0	0	0	0	0	0
40	-100000	0	0	0	0	0
41	0	-400000	-145000	0	-465000	-205060
42	0	0	0	0	0	0
43	-100000	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	-100000	0	0	0	0	0
47	0	0	0	0	0	0
48	0	0	0	0	0	0
49	-100000	0	0	0	0	0
50	0	0	0	0	0	0

Annex 3 (EDL Calculation): The calculation of the EDL’s as mentioned in section 7.2.2 is displayed below:

EDL calculation								
	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**	**Diesel**	**Grid**	
LCC alt. [€]	**221.373 €**	**804.988 €**	**430.704 €**	**743.729 €**	**430.704 €**	**1.356.435 €**	Grid inv. [€]	5844
Load demand [kW]	100	100	100	100	100	100	t&d losses	20%
Annual operation hours	8760	8760	8760	8760	8760	8760	transf. Inv. [€/piece]	520
Project lifetime [years]	50	50	50	50	50	50	No. Of transf.	3
Discount rate	20%	20%	20%	20%	20%	20%	Project lifetime [years]	50
							O&M fraction	1%
EDL [km]	**7,4**	**82,4**	**34,3**	**74,5**	**34,3**	**153,4**	Discount rate	20%
							Generation cost [€/kWh]	0,03
							Load demand [kW]	100
							Annual operation hours	8760
							LCC gen	**164.232 €**
							LCC grid	**7.774 €**