MSc Program
Environmental Technology & International Affairs

Evaluating Selected Renewable Energy Sources and the Electrification Strategy of Nicaragua

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 10.06.2012

Affidavit

I, **GERALD STÖCKL**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Evaluating Selected Renewable Energy Sources and the Electrification Strategy of Nicaragua", 67 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The thesis “Evaluating Selected Renewable Energy Sources and the Electrification Strategy of Nicaragua” evaluates the four energy technologies solar power, wind energy, bio energy and hydropower according to a set of indicators. The latter are chosen according to the principle of sustainability, containing economic, ecological and social indicators, which are assessed quantitatively and qualitatively. The main interest of the research is to find out how the different renewable energy technologies perform in a broader assessment in order to find appropriate solutions, especially for rural electrification. In a top-down approach the results of the indicator evaluation are directly linked to a case study, which is the electrification strategy of Nicaragua. In general, an absolute ranking of the four technologies according to their performance is not possible, since all of them have strengths and weaknesses’ in certain indicator areas. However, the result allows the conclusion to mix the four energy technologies to maximize economic, ecological and social benefits.

Acknowledgements

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On top of it all the biggest thank you goes to my parents, Magdalena and Christian, who made it possible for me to enroll in the ETIA program, as well as my sister Verena, her husband Christian and my nephew Lorenz. For that very reason I want to dedicate this work to the lowest common denominator, Lorenz.

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1 Introduction

Today, sustainability is more than just a word or an empty phrase lacking of content and tangibility – it has become a dogma, penetrating social life, economic and business relations, as well as environmental awareness. Additionally people all over the world have come to the conclusion that fossil resources are limited and harming the environment, shifting thought paradigms towards, new, renewable energy sources that can also help to independently electrify rural areas. The latter is highly important for any development of a region, since it forms the basis of all social and economic life. In the field of renewable energy technologies the alternatives have become stronger and stronger. However, still the question remains, which of the renewable energy technologies performs best under the light of sustainability and to which extent can they be applied for rural electrification. To span the bridge between sustainability considerations and new energy paradigms, this thesis focuses on qualitatively and quantitatively assessing four renewable energy technologies with the help of a catalogue of indicators, comprising economic, social and ecological aspects. Electricity from solar energy, wind energy, biomass and hydropower are regarded and evaluated along 8 indicators (costs for investment, operation and maintenance, energy return on energy invested (EROI), aftercare, employment, emissions, noise and health aspects, landscape, scarcity and political aspects). The result will present an overview of the performance of the four energy technologies in the various indicator fields. This assessment will be followed by a practical case study, considering the electrification strategy of Nicaragua. The Central American country is ambitiously working on an increase in degree of electrification that should be reached with the help of renewable energy technologies. The strategy and the success so far will be outlined, followed by an assessment of the strategy, which is mainly focusing on rural electrification, under the indicator catalogue.

2 Methodology

Within this thesis the approach is taken that each of the four selected energy technologies, solar energy, wind energy, energy from biomass and hydropower is assessed in separate chapters. The assessment is the same for all four technologies with an introductory paragraph on the technology itself, followed by the various indicator analyses. For the indicator costs for investment, operation and maintenance either existing data on costs are taken out of various studies or, as in the case of solar energy and wind energy, calculations are done, based on data provided from sellers of the installations. The calculations for solar energy and wind energy are restricted to three scenarios, low, intermediate and high amount of sun hours/wind speeds and also take into account large grid connected systems, as well as small independent systems for rural electrification. The calculations are simple ones, not regarding interest rates in order to not exceed the limits of this thesis. For effectiveness comparisons, the concept of Energy Return on Energy Invested (EROI) is taken for the evaluation. The EROI is based on the principle of calculating how many units of energy are gained from a certain energy technology if one unit of energy is invested for generation. This energy investment includes for example energy needed for the production of a photovoltaic panel or a wind turbine, energy invested for drilling for fossil fuels or energy needed to bring a certain fuel to a power plant. The EROI is an instrument that is often criticized, since there is a lot of discretion in this concept, which investments should be included and which ones exceed the limits of the parameter. However, it is also an indicator to get a feeling for the effectiveness of an energy technology and promises to be comparable when restricted to one or two regarded studies. Under the indicator aftercare the necessity of managing the energy technology and possible risks that can occur are evaluated based on literature research. Employment creation by the energy technology is treated in a separate subsection and is based on a study by the Worldwatch Institute from 2006. To evaluate emissions, noise and health aspects the approach of investigating external cost creation by the several energy technologies is chosen. The main basis for this is formed by the work that is done in the surroundings of the EU ExternE Project. Another indicator focuses on the possible perception disturbances of energy technologies in the landscape. The evaluation is grounded mostly on the concept of willingness to pay and market research in this case. The willingness to pay approach asks people about the monetary amount they would be willing to pay to keep a certain situation, or for example a landscape without any interference. Although this concept produces relatively high amounts of money that people would invest to preserve a certain situation, since they do not have to pay it in reality, it is still an approximation to perception and preferences. Evaluating scarcity aspects is based on certain studies and qualitative descriptions of scarcity in fuel, which in this case includes solar radiation or wind, as well as scarcity in materials needed for the energy generation. Last but not least in the indicator evaluation the reader's interest is shifted towards political aspects of energy technologies. This indicator includes qualitative descriptions by the author and can be found in this thesis due to the fact that the master's program ETIA should span a bridge between technology and politics. At the end of the assessments an overview is provided, summarizing the main results. All this is followed by a practical example, namely the electrification strategy of Nicaragua. Based on the indicator analysis a top-down approach of analyzing a country's strategy towards electrification can be applied. For that, the current situation in Nicaragua will be described, also naming successes from the past years, followed by a chapter on development and future strategies by the government. Data research in this regard is based on publications of the Ministry for Energy and Mining in Nicaragua and interviews with Luis Molina from the Ministry. For completeness' sake the thesis concludes with a qualitative analysis of the electrification strategy of Nicaragua based on the indicator catalogue.

The whole assessment focuses on electricity production only, so thermal use of energy is not taken into account.

3 Solarenergy

3.1 Introduction

The first technology of energy generation that is investigated and evaluated with the indicators mentioned afore is solar energy. In the nuclear fusion process the sun releases high amounts of energy that are to be used with solar energy technology. About 1 kW of solar energy is received on one m^2 of the earth's surface, which is 17 times the energy of one single light bulb. For using solar energy there are two main approaches (Brennan and Withgott, 2011):

- The passive solar energy approach: Buildings are designed in a way to use sunlight for heating in winter and keep the interior cool (insulating against solar heat) in summer. This is mainly achieved by house building technologies and the approach will not be further taken into account within the following analysis in order to not exceed the limits of this thesis.
- The active solar energy approach: This second approach is more interesting for actively harvesting solar energy to use it as heat or electricity. Within this field there are several possibilities (Brennan and Withgott, 2011):
    - Flat-plate Solar Collectors: As seen in figure 1, flat-plate solar collectors are used to heat water and air. In a flat-plate solar collector dark-colored, heat-absorbing metal plates are placed within glass covered boxes. Water, air or antifreeze runs through tubes within the collectors, heated up by the sun. This heat is then transferred to be used in homes by heating up water in a tank (see figure 1). A controller regulates the inflow of cold water according to the heat within the collector. In case solar energy is not available (e.g. on cloudy days or during the night) a boiler can heat the water in the tank as a substitute. By now, over 1.5 million homes and businesses in the United States of America heat water with flat-plate solar collectors.

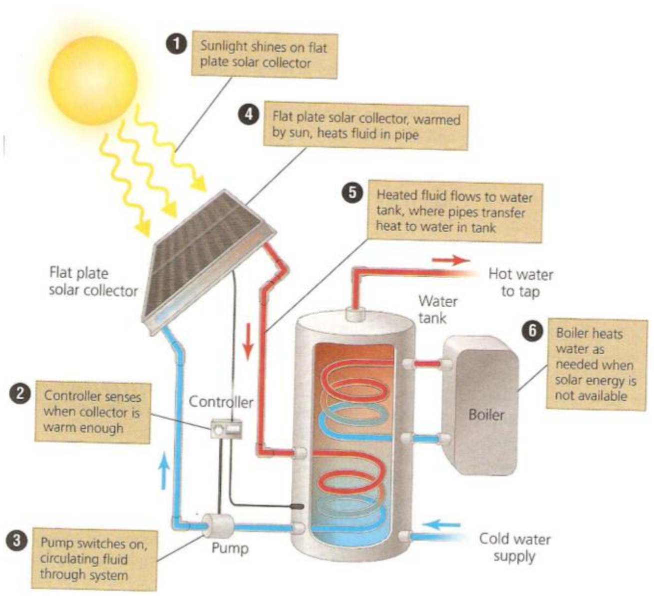

Figure 1: Flat-Plate Solar Collector for heating water (Source: Brennan and Withgott, 2011)

- Concentrated Solar Power: This technology is widely used for large scale solar power utilities producing electricity. As seen in figure 2, there are several possibilities of harvesting solar energy within this technology (Brennan and Withgott, 2011).

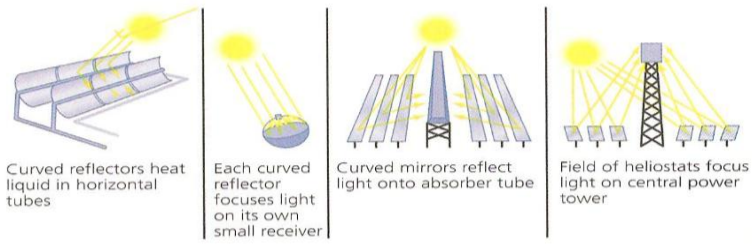

Figure 2: Possibilities to harvest solar energy with Concentrated Solar Power (Source: Brennan and Withgott, 2011)

The most widely used approach is the one shown at the very left of figure 2. Curved reflectors/mirrors concentrate solar radiation on a tube filled with synthetic oil. The heated oil is piped to heat exchanger in a facility that uses steam generators to produce electricity. The same principle can be used in different forms, by concentrating solar radiation on an own small receiver for every curved mirror (second illustration in figure 2), or by focusing it on a central absorber tube (third illustration in figure 2) or a central power tower (fourth illustration in figure 2). Currently one of the biggest concentrated solar power plant projects is the Desertec project in the

Saharan desert, which is a project with investment costs ranging in hundreds of billions of Euros (Brennan and Withgott, 2011).

- Photovoltaic Cells: This technology is probably the most direct way to harvest solar energy. By using the photovoltaic effect and semiconductor materials this technology directly converts solar energy to electricity. As shown in figure 3, as soon as sunlight reaches the silicon layers of the PV cell electrons are loosened from silicon atoms and move from the boron-enriched p-type layer to the phosphorus-enriched n-type layer. By connecting the two layers with wires, the electron imbalance causes electrical current to flow back from the n-type layer to the p-type layer. The direct current (DC) produced is then converted to alternating current (AC) to be able to make use of the electricity (Brennan and Withgott, 2011).

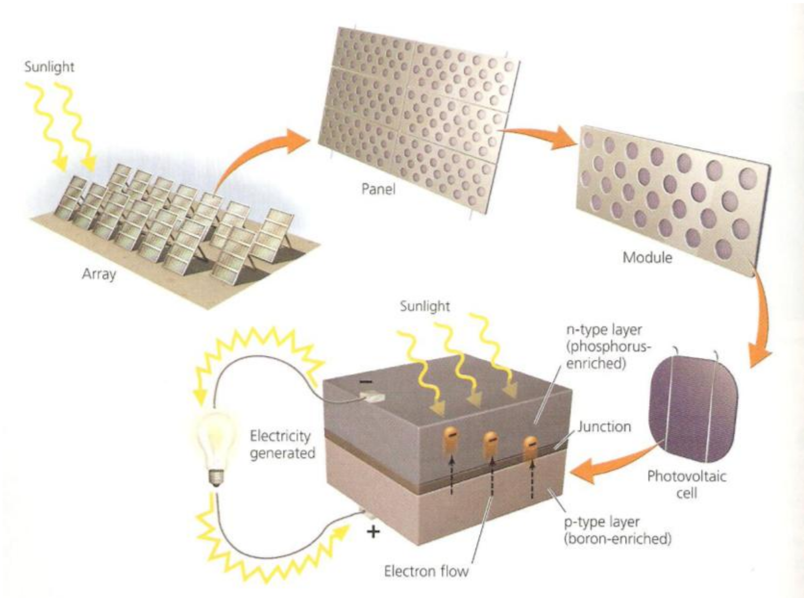

Figure 3: The Principles behind Photovoltaic Cells (Source: Brennan and Withgott, 2011)

Photovoltaic cells can be erected easily on houses or other buildings and the electricity can be used directly, fed into the grid or stored for example with the assistance of electrical cars. A new and promising development in the field of photovoltaic cells is the production of thin-film solar cells, since they are cheap to produce and easy to transport and handle (Brennan and Withgott, 2011). Economic incentives such as feed-in tariffs or subsidies for electricity from photovoltaic cells can increase the usage of this technology. However these incentives shall not lead to the argument that photovoltaic energy is not competitive without subsidies, since compared to fossil fuels the funding for research and development in this field have been very low so far.

In the field of rural electrification, 86 MW peak of photovoltaic electricity have been installed in developing countries in 2005, providing 800 000 families with electricity. It is estimated that potentially 30 GW peak of photovoltaic electricity can be installed for rural electrification until 2020 (Alliance for Rural Electrification, 2012). Worldwide off-grid solutions, which are vital for rural electrification, grew by 0.37 GW peak in 2010 (Solarbuzz, 2011).

3.2 Costs for Investment, Operation and Maintenance

This subparagraph is evaluated by taking a simple calculation approach. In the first assessment, the costs for producing one kWh of electricity with photovoltaic energy is assessed and compared to other, conventional energy technologies. In the first step costs for a solar panel are investigated. According to "Wholesale Solar" the grid-tie solar panel "Solar Edge AstroEnergy" with 4800 Watts costs 11 548 US-Dollars, producing 654.3 kWh electricity per month, assuming an average of 5 hours of sun per day. Assuming linearity, this means that with one hour of daily sun this panel can produce 130.86 kWh per month or 1570.32 kWh per year. The second solar panel that is taken into account is a small off-grid panel for 1 080 US-Dollars, producing 42 kWh per month, assuming an average of 5 hours of sun per day. Again, assuming linearity this means that the panel can produce 8.4 kWh per month or 100.8 kWh with one hour of sun per day (Wholesale Solar, 2012). This secondly mentioned panel is of special importance for remote, rural regions, building an autonomous electricity supply for a small demand to low costs. The output of the solar panel is highly dependent on the daily sun hours. Therefore, for calculating costs per kWh and output of electricity of the two mentioned panels, three scenarios are introduced. Scenario 1 simulates the output and costs for a region with a low amount of sun hours, Scenario 2 assumes intermediate amount of sun hours and Scenario 3 is calculated with a high amount of sun hours.

Scenario	**Average Sun Hours per Day**
Low Amount of Sun Hours: Edinburgh, Great Britain	3.5
Intermediate Amount of Sun Hours: Managua, Nicaragua	6.39
High Amount of Sun Hours: Amarillo, Texas, USA	8.92

Table 1: Scenarios for different amounts of sun hours (Source: EKlima, 2012)

By multiplying the average daily sun hours with the yearly electricity output per daily sun hour, the following electricity output for the two different solar panels in the three scenarios can be obtained for one year:

Grid-Tie Solar Panel	
Scenario	**Yearly Electricity Output in kWh**
Low Amount of Sun Hours	5 496.12
Intermediate Amount of Sun Hours	10 034.35
High Amount of Sun Hours	14 007.25
Off-Grid Solar Panel	
Scenario	**Yearly Electricity Output in kWh**
Low Amount of Sun Hours	352.8
Intermediate Amount of Sun Hours	644.11
High Amount of Sun Hours	899.14

Table 2: Yearly Electricity Output from Photovoltaics for different Scenarios (Sources: Eklima, 2012 and Wholesale Solar, 2012)

The low cost, off-grid solution fulfills with one panel the average demand of one person in Nicaragua for 1.5 years, while the grid-tie solution even fulfills the average yearly consumption of a person in Amarillo, Texas, USA (Worldbank, 2012).

In the next step the Levelized Costs of Electricity are calculated. For that purpose an interest rate *i* of 6,5% per annum is assumed, the yearly operation and maintenance costs are set with 1,3% of the investment costs, rising by 2% every year and finally a degression of electricity output of 0,3% per annum is taken into account (Kost and Schlegel, 2010). The following formula is used for the calculations:

$$LCOE = \frac{I0 + \sum_{t=1}^{n} \frac{At}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Mel}{(1+i)^t}}$$

In this formula I0 denotes the investment costs, the time span t is set with 20 years, At stands for the yearly operation and maintenance costs and Mel for the electricity output. The results for the two cases with the respective three Scenarios are presented in table 3. For further information the spreadsheet containing the calculations is attached in the Annex.

Grid-Tie Solar Panel	
Scenario	**Price per kWh in US-Dollars**
Low Amount of Sun Hours	0.23 (0.18 Euros, Oanda, 2012)
Intermediate Amount of Sun Hours	0.12 (0.09 Euros, Oanda, 2012)
High Amount of Sun Hours	0.09 (0.07 Euros, Oanda, 2012)
Off-Grid Solar Panel	
Scenario	**Price per kWh in US-Dollars**
Low Amount of Sun Hours	0.33 (0.26 Euros, Oanda, 2012)
Intermediate Amount of Sun Hours	0.18 (0.14 Euros, Oanda, 2012)
High Amount of Sun Hours	0.13 (0.10 Euros, Oanda, 2012)

Table 3: Price per kWh for different Scenarios

As table 3 shows, when only looking at the pure investment costs, solar energy is already a quite cheap way to get electricity. If we compare this to oil as an energy source and assume that one barrel of oil costs 70 US-Dollars and brings roughly 1699 kWh, one kWh would only cost 0.05 US-Dollars (0.04 Euros, Oanda, 2012) (Green Econometrics, 2007). However, concerning the future the price for Photovoltaic cells will decrease due to technological improvements, while the price for fossil fuels, like for example oil, will certainly increase because of growing scarcity and increasing costs for extraction. The price in the calculations might be an underestimation due to optimistic estimates of the seller.

In general, the levelized costs for solar photovoltaic electricity are expected to reach 0.1 to 0.12 Euros in 2020 in at least 10 markets around the world (UNEP, 2008a). The average of around 54 US-Dollars (41 Euros, Oanda, 2012) Operation and Maintenance Costs per kW-year for Photovoltaic cells is a quite low and negligible amount. So, once erected, it is cheap to maintain and operate Photovoltaic cells.

Additionally, compared to many other energy sources there are no fuel costs for Photovoltaic cells (ScottMadden, 2010).

3.3 EROI

The EROI for photovoltaic energy ranges from 3.75:1 to 10:1, meaning that between 3.75 and 10 units of energy can be harvested by investing one unit of energy. This is comparatively low, for example coal ranges from 50:1 to 85:1, while oil and gas has an EROI of 19:1. The comparatively low values for photovoltaic energy comes mainly from the fact that so far there is still high material input needed to produce a solar panel and the efficiency in producing electricity is still to be improved. Furthermore photovoltaic suffers from the problem of different amounts of sun hours in different locations all over the world. However, future development promises an increase in efficiency in the production process of solar panels, as well as in the conversion of solar radiation to electrical energy, while increasing resource scarcity will decrease the efficiency of oil and gas for example (Heinberg, 2009).

3.4 Aftercare

The aspect aftercare of photovoltaic cells poses some challenges to waste management, since there are heavy metals contained within the panels. Recycling is of course an important issue here, however this is difficult to achieve, because there is only a low content of valuable materials in photovoltaic cells (for example Indium contributes only with 2.5 – 5% to the total cost of a solar panel), panels have a quite long running time and are most of the time geographically dispersed. Especially the problem with the low content of valuable material creates an economically less interesting environment for recycling. In general there are two strategies for recycling of photovoltaic cells (Fthenakis, 2000):

- Centralized Strategy: Large smelters incorporate the recycling of photovoltaic cells. In this case, panels are shredded, Cadmium, Tellurium, Selenium and contact metals can be treated in copper smelters, while the glass content of the shred is used up in the fluxing operation of the smelter. The costs for the centralized strategy were estimated by Fthenakis (2000) for two scenarios. The first one is assuming dispersed, low-concentration solar panels that are collected via reverse retail or municipal solid waste channels. In this base case an incentive of 1 US-Dollar per solar module might be necessary for the primary collector, leading to costs of 0.08 US-Dollars per Watt. The second case models dispersed applications with direct shipping from the energy generator to the smelter, leading to costs of 0.11 US-Dollars per Watt. As a comparison, current landfill disposal costs for non-hazardous waste are 0.01 US-Dollars per Watt and 0.23 US-Dollars per Watt. Taking into account that part of the photovoltaic cells contain hazardous waste, the above mentioned prizes for disposal can be considered moderate and do not cause extremely high burdens in the aftercare of photovoltaic cells (Fthenakis, 2000).

- De-centralized Strategy: In this approach hazardous metals are separated from glass and the metal frame before treatment by physical (e.g. hammer mill or pyrolysis) and/or chemical (using appropriate solvents, such as acids or oxidizers) methods. Metal-containing liquids can be treated by using precipitation of metals as hydroxides and safely disposing the hazardous sludge, by concentrating the metals in solutions and recycling of the solution with processes such as ion exchange, reverse osmosis, dialysis or solvent extraction or directly recover the metals by electrochemical methods, such as electro deposition. By combining the various methodological possibilities the company Solar Cells Inc. reports for Cadmium/ Tellurium solar cells a recovery of Tellurium of 80%, as well as a complete Cadmium recovery for the use of NiCd batteries at the cost of 4-5 US-Dollar cents per Watt. Drinkard Metalox Inc. claims to be able to recover 95% of Tellurium in their recycling process, as well as 96% of Lead at the cost of 9 US-Dollar cents per Watt (Fthenakis, 2000).

3.5 Employment

In the next indicator the employment that can be created by the energy technology is investigated. Solar energy is the technology that requires most labor for manufacturing, installing, servicing and operating. Between 800 and 2100 person-years of employment are necessary for one TWh of solar energy, creating a lot of jobs with an increasing share in the energy mix. In comparison to that, coal needs 200 to 300 person-years of employment per TWh (Worldwatch Institute, 2006). Especially the factor employment is highly important for rural areas, since in this case, the energy technology not just helps with electrification, but also serves to build small businesses, for example for installation, service and operation, around it. This means additionally that photovoltaic is highly efficient as development aid, since they also create a potential for further growth and development in other economic areas.

3.6 Emissions, Noise and Health Aspects

Within the EU Project “ExternE”, external costs of several energy technologies are assessed. In this assessment also solar energy can be found, calculating the costs that arise due to emissions, noise and health impacts.

	Coal	Lignite	Gas	Nuclear	PV	Wind	Hydro
Damage costs							
Noise	0	0	0	0	0	0.005	0
Health	0.73	0.99	0.34	0.17	0.45	0.072	0.051
Material	0.015	0.020	0.007	0.002	0.012	0.002	0.001
Crops	0	0	0	0.0008	0	0.0007	0.0002
Total	0.75	1.01	0.35	0.17	0.46	0.08	0.05
Avoidance costs							
Ecosystems	0.20	0.78	0.04	0.05	0.04	0.04	0.03
Global Warming	1.60	2.00	0.73	0.03	0.33	0.04	0.03

Figure 4: Marginal External Costs of Electricity Production in Germany in Euro Cent per kWh (Source: EU Project ExternE, 2003)

As it can be seen in figure 4, there are no external costs for noise for photovoltaic cells, since they do not cause any disturbances in this respect. The quite high impact for the indicator health can be directed to the use of heavy metals and the emission of SO_2, NO_x and Greenhouse Gases in the production of photovoltaic cells. The latter also cause the external costs for the indicator global warming, while the ecosystem is mainly threatened by heavy metals that are not handled appropriately at the end of the lifetime of photovoltaic cells. The needed material input for the production of photovoltaic cells is also still quite high, therefore costs arise for the indicator material. The better the end-of-pipe technology for production of solar panels gets and with increasing efficiency in using heavy metals the costs for these indicators can be predicted to decrease (EU Project ExternE, 2003).

As figure 5 shows, the overall impact, evaluated here with external costs, is very low for photovoltaic cells in comparison to other technologies.

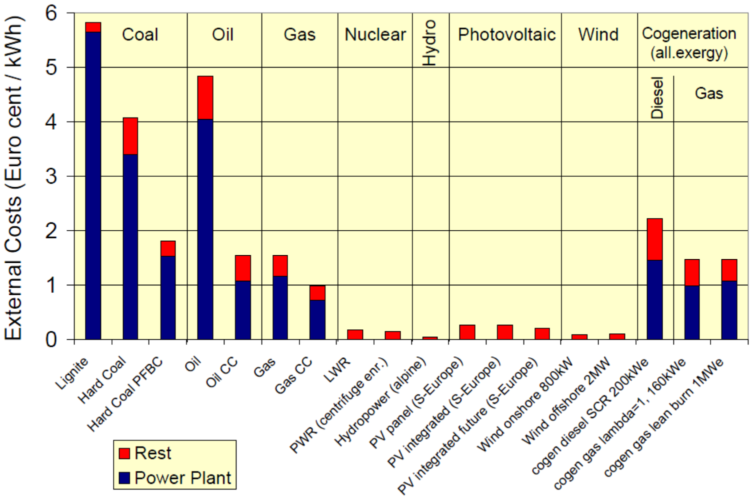

Figure 5: External Costs for Selected Energy Technologies from Operation of the Power Plant and the Rest of the Energy Chain (Source: EU Project ExternE, 2005a)

Figure 5 also clarifies that impacts on the environment and human beings only arise in production and disposal of photovoltaic cells, while the operation does not cause external effects (EU Project ExternE, 2005a). In the operation, one GWh of electricity generated by photovoltaic would prevent 10 tons of SO_2, 4 tons of NO_x, 0.7 tons of particulates and up to 1000 tons of CO2 compared to burning coal (Fthenakis, 2000).

3.7 Landscape

This indicator is a quite qualitative one that is dependent on the differing opinion of different people. All in all it shall assess the impact of a certain energy technology on the landscape. For photovoltaic there is no direct impact on landscape (assuming it is installed on buildings), however people might perceive the black surfaces on roofs of buildings, concentrated solar power plants or arrays of photovoltaic cells as disturbance in their perception of the original landscape. To quantify the public perception of photovoltaic cells, Farhar (1999) surveyed people of 12 utility service territories in the United States of America with 14 different questionnaires to find out more about their attitude towards renewable energy sources. Among the key findings of the study is that 52% to 95% of the surveyed people claim to be willing to pay an extra amount of money to receive energy from renewable energy sources. So, this already shows a highly positive perception towards renewable energy in general. When asked about their most favored ways of producing energy, 69% of the people perceived photovoltaic on public buildings as very favorable and 60% of the people perceived photovoltaic on private homes as very favorable (Farhar, 2009). This result shows that obviously people do not perceive photovoltaic cells as disturbing, but even as favorable. However, it has to be mentioned that this perception might change when it comes to popular touristic places, like for example old European cities.

3.8 Scarcity

Solar Radiation as an energy source is practically without any scarcity effects, since it is not depleted by using it. However there are restrictions, since not all regions over the world have the same amount of sun hours, as shown above in table 1, and nighttime without sunshine creates a lack of energy supply. For these cases it is important to increase energy efficiency and change energy usage patterns, as well as developing storage possibilities to store solar energy from peak times. Furthermore it has to be accompanied by other ways of energy supply to bridge hours without sun. Additionally scarcity is present for certain materials that are needed to produce photovoltaic cells. Gallium and Indium, both materials highly important as semiconductors for the production of thin layer photovoltaic are difficult to recover, while substitution is almost not possible and in both cases the world is highly dependent on China, since 75% of the world production of Gallium in 2009 was from China and 81% of Indium imports in the EU originate in China. This causes political dependencies and increases the supply risk (European Commission, 2010). Furthermore, the increasing demand for certain raw materials such as Germanium or Indium increases the exploitation and therefore also scarcity.

Raw material	Production 2006 (t)	Demand from emerging technologies 2006 (t)	Demand from emerging technologies 2030 (t)	Indicator[1] 2006	Indicator[1] 2030
Gallium	152	28	603	0,18	3,97
Indium	581	234	1.911	0,40	3,29
Germanium	100	28	220	0,28	2,20
Neodymium (rare earth)	16.800	4.000	27.900	0,23	1,66
Platinum (PGM)	255	very small	345	0	1,35
Tantalum	1.384	551	1.410	0,40	1,02
Silver	19.051	5.342	15.823	0,28	0,83
Cobalt	62.279	12.820	26.860	0,21	0,43
Palladium (PGM)	267	23	77	0,09	0,29
Titanium	7.211.000 [2]	15.397	58.148	0,08	0,29
Copper	15.093.000	1.410.000	3.696.070	0,09	0,24

Figure 6: Critical Raw Materials in tons (Source: European Commission, 2010)

As shown in figure 6, the demand for Gallium by emerging technologies, like photovoltaic increases by a factor of 22 (assuming that 25% of European electricity comes from photovoltaic), meaning that the production in tons from 2006 would have to increase by a factor of 4 until 2030. For Indium the demand rises by a factor of 8, resulting in a necessary increase of the production by a factor of 3 compared to the production in 2006 (European Commission, 2010).

Rechberger and Zuser (2011) estimated the world demand of certain raw materials for the production of photovoltaic cells in 2040 and compared it to the reserves available according to the US Geological Survey from 2010. Three different demand scenarios are used, a pessimistic scenario with a proportionally high raw material demand, a realistic scenario with an intermediate raw material demand and an optimistic scenario with a proportionally low raw material demand.

	pess.	real.	opt.	Reserves (U.S. Geological Survey, 2010)
Si (for c-Si)	27.054.050	16.917.450	10.140.600	not relevant
Ag	299.833	235.006	191.778	550.000
Si (for a-Si)	26.889	102.833	92.529	not relevant
Cd	243.774	82.350	60.097	590.000
Te	244.853	71.642	51.937	22.000
Cu	3.643.899	2.856.061	2.330.702	540.000.000
In	44.431	17.490	10.955	5.600
Ga	19.024	7.489	4.690	>1.000.000

Figure 7: Demand for Certain Raw Materials in tons for the Production of Photovoltaic Cells in 2040 compared to Reserve Estimates in tons (Rechberger and Zuser, 2011)

As pointed out in figure 7, the demand for Tellurium exceeds the reserves in 2040 according to the estimates by a factor of 2 for the optimistic scenario, a factor of 3 for the realistic scenario and by a factor of 10 for the pessimistic scenario. Another critical raw material is Indium, with the demand exceeding the reserves in 2040 by a factor of 2 in the optimistic scenario, by a factor of 3 in the realistic scenario and a factor of 8 in the pessimistic scenario.

So all in all, the resource solar radiation is not depleted by using it, however scarcity effects can occur with raw materials necessary to produce photovoltaic cells. Moreover a lack of sunny hours and nighttime can cause supply risks.

3.9 Political Aspects

There are many different political aspects for solar energy. First of all, it is highly favorable for politics to support and promote solar energy, since there is a strong shift in the society towards renewable energy sources and especially photovoltaic perceived as green solution for a less carbon intensive energy production. Furthermore with solar energy the possibilities of decentralized energy supply are increasing and therefore independence from energy imports is becoming less severe. However in this respect one may not forget that there are still high import dependencies on raw materials for the production of photovoltaic cells and insecurities due to hours with lack of sun are arising. Additionally the political dimension in this shift towards decentralized energy is complex, because the energy infrastructure still has to be kept alive for feeding in exceeding electricity from decentralized solar panels, demanding maintenance costs. Moreover, one may not forget that photovoltaic cells pose new challenges for waste management, since recycling is economically not interesting, but hazardous materials are contained in the panels that are usually widely dispersed. Another important political aspect is the financial dimension – people will have to face higher prices for energy with a shift towards solar energy and politicians have to change their subsidizing focus towards new technologies, facing a struggling fight against strong lobbies in the fossil fuel sector. All in all, a stronger focus on solar energy also brings a strategic shift towards countries with wide areas and high amounts of sun hours, like countries with desert areas, empowering many regions that have not played a big role in energy politics so far.

4 Wind Energy

The second energy technology that is investigated within this thesis is wind energy. The latter can also be regarded as an indirect solar energy, because differential heating of air masses on Earth caused by solar radiation lead to winds that can be harvested by turning kinetic energy/energy from motion into electrical energy with wind turbines

4.1 Introduction

As seen in figure 8, wind moves the blades of a wind turbine atop a tower. This movement is transferred into the so-called Nacelle, where a gearbox increases the rotational speed which is then directed to a generator transforming the movement energy into electrical energy (Brennan and Withgott, 2011).

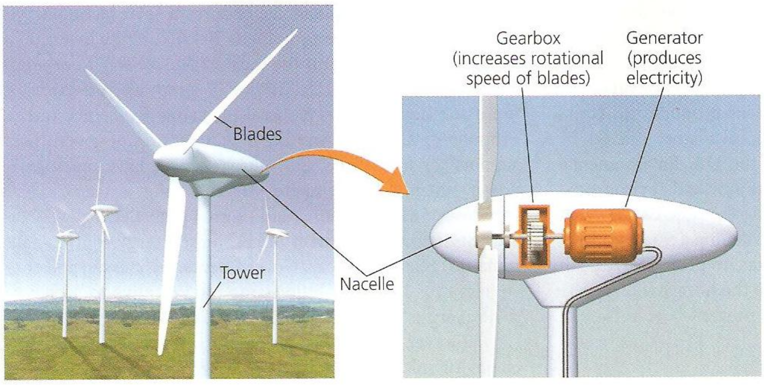

Figure 8: Structure of a Wind Turbine (Source: Brennan and Withgott, 2011)

The rotational speed of the blades can be up to 12 to 24 revolutions per minute, transformed to up to 1500 revolutions per minute by the gearbox. Rotors mostly consist of 3 blades measuring 57 to 99 meters across, while the towers range from 45 to 105 meters. The higher the tower is, the lower is the air turbulence, leading to maximizing wind speeds. Turbines are able to rotate back and forth in order to guarantee that the rotor is directed towards the wind. Additionally turbines can be engineered to turn with low wind speed, producing low levels of electricity for longer time periods, or they only turn with strong winds, resulting in large amounts of electricity less frequently (Brennan and Withgott, 2011).

The energy content of the wind increases with the square of its velocity and power output is equal to wind velocity cubed, due to the fact that higher wind speed causes more air molecules to pass through the wind turbine per time unit. Thus, doubling wind velocity increases power output eightfold, showing that differing wind speeds, even slight changes, have strong impacts on power generation (Brennan and Withgott, 2011).

Wind turbines are mainly erected in wind farms with more turbines next to each other. Those wind farms can be constructed on land, on-shore, or on water, off-shore. It is more expensive to erect and maintain off-shore wind farms, but wind speeds are roughly 20% higher and turbulence is lower over water. So far, off-shore wind parks are sunk into sediments in more shallow water. Especially Denmark is using its off-shore wind potential and supplies already 20% of its electricity with wind power. In general, wind power caught the attention of decision makers after the oil crisis of 1973, showing that alternatives to fossil fuels have to be further developed (Brennan and Withgott, 2011).

For rural electrification smaller off-grid solutions are preferred, since the costs and the energy demand are lower and they are easier and more independent to operate. Smaller applications usually have few moving parts in order to keep maintenance work as low as possible. These small wind turbines use permanent magnet alternators, producing wild alternating current (AC) power that is in turn rectified to direct current (DC) and used together with battery banks. Towers of the small off-grid wind turbines are between 4 and 6 meters, for larger applications, such as schools they reach about 18 meters. For the battery banks a charge controller is necessary, preventing over-charging of the battery, protecting from lightning and inverse direction current flow (which can lead to a discharge of the battery) and containing an easy disconnection to separate the wind turbine from the power system. Small wind turbine systems are mainly used for water pumping, battery charging, refrigeration and ice making, individual rural homes, school, remote health posts or small scale commercial applications. Compared to the big wind turbines with roughly 3 to 8 MW, off-grid solutions range from 1 kW to 900 kW (Alliance for Rural Electrification, 2012).

4.2 Costs for Investment, Operation and Maintenance

The average on-shore wind turbine installed in Europe costs 1.23 Million Euros, of which 934 800 Euros are spent directly for the turbine, 110 700 Euros are calculated for the grid connection and 86 100 Euros go into foundation works. Based on these investment costs, the resulting kWh prices for different wind ranges are presented in table 4 (European Wind Energy Agency, 2009).

Average Full Load Hours	Euros per kWh
1 700	0.09 to 0.11
2 300	0.07 to 0.08
2 900	0.05 to 0.06

Table 4: Price per kWh for different wind ranges (Source: European Wind Energy Agency, 2009)

As table 4 shows, on-shore wind energy in Europe is already today highly competitive to the above calculate 0.04 Euros per kWh for electricity from oil. With an expected increase in fossil fuel prices, wind energy becomes an even more interesting alternative.

With regard to off-shore wind turbines the investment costs are calculated to be in the range of 2 to 2.2 Million Euros per MWh, leading do deviated off-shore generated electricity costs of 0.06 to 0.08 Euros per kWh. The higher price for off-shore wind energy comes from the higher costs for building and operating wind turbines over water (European Wind Energy Agency, 2009).

Comparing costs of wind energy today with coal and natural gas, the prices per MWh do not differ a lot as figure 9 shows.

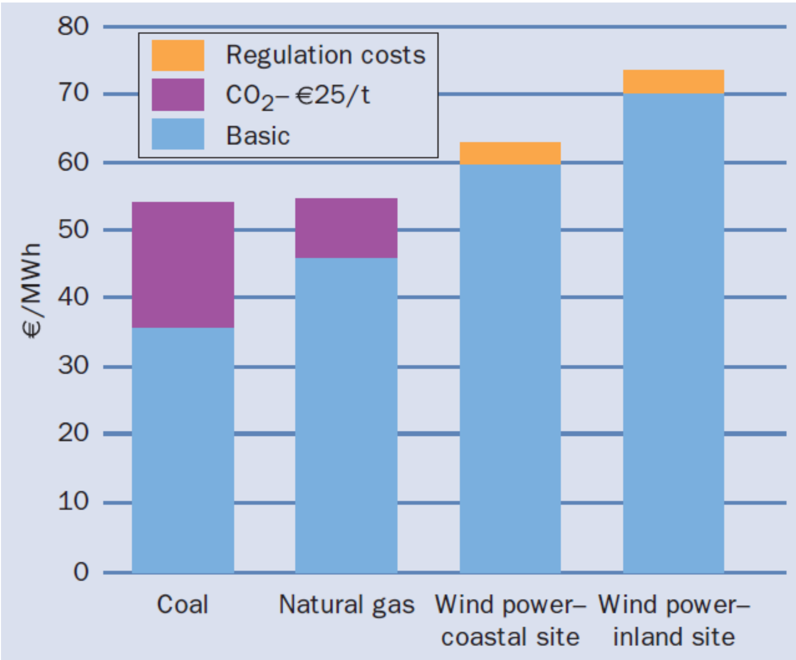

Figure 9: Comparing Costs of Wind Energy with Coal and Natural Gas (Source: European Wind Energy Agency, 2009)

If one takes into account the compensation that has to be paid for releasing CO_2 into the atmosphere (assuming a price for one ton of CO_2 of 25 Euros) and the regulation costs that have to be undertaken in order to be able to connect wind energy to the grid, coal and natural gas would create costs of around 55 Euros per MWh electricity, while wind power on coastal sites comes up to around 63 Euros per MWh electricity and wind power from inland sites costs around 74 Euros per MWh electricity. If one is assuming that the price per ton of CO_2 rises to 35 Euros per emitted ton, which is a realistic scenario, coal would cost around 61 Euros per MWh and natural gas around 59 Euros per MWh. In a further assumption future scarcities can be taken into account, expecting coal prices to increase by 50% and natural gas prices to double. In this scenario, coal would come up to around 69 Euros and natural gas to around 95 Euros per MWh electricity. In all these further scenarios wind energy can be expected to stay the same, since no CO_2 is emitted in the electricity production and there are no major future scarcity effects (European Wind Energy Agency, 2009).
For wind energy operation and maintenance costs include factors such as insurance, regular maintenance, repair, spare parts and administration and make up to 0.0012 to 0.0015 Euros per kWh electricity over the whole lifetime of a turbine. So, operation and maintenance costs are in a range of around 10% to 25% of the price per kWh taking only investment costs into account. This is a quite high amount, mainly due to the fact that wind energy is a technology that is quite difficult to maintain and spare parts are highly technological pieces. Operation and Maintenance costs are a part of wind energy that has to decrease for future competitiveness and eventually will decrease (The Facts of Wind Energy, 2009). Network improvement costs to connect wind parks to the grid and upgrade the grid for the extra capacity required to carry the increased power flows vary highly from region to region (therefore not specifically mentioned here in the general part of the thesis), but are also an important factor for wind energy costs (European Wind Energy Agency, 2009).
All the investigations for this indicator centralized on grid connected projects that are usually realized on a larger scale in industrialized countries. However, there are also possibilities to use wind energy for rural electrification on an off-grid basis as shown in the introduction. The small off-grid wind system Whisper 100 (900 Watt for 12,5 m/s) costs 2 475 US Dollars. Expecting a life-time of roughly 20 years, this would

mean yearly costs of 123.75 US Dollars (94 Euros, Oanda, 2012) (Homepower, 2008).

The yields from this system vary with wind speeds. To get a rough calculation, three regions with low, intermediate and high wind speeds are chosen to calculate their expected energy harvests with the Whisper 100.

Location	**Wind Speed in Meters per Second**	**Electricity Output per Year in kWh**
Finland	3.6	360
Nicaragua	4.9	960
Morocco	5.8	1 500

Table 5: Wind Speeds and Yearly Electricity Outputs for Selected Regions (Sources: Climate Charts, 2007 and Homepower, 2008)

As pointed out in table 5, a small and cheap off-grid solution like the Whisper 100 produces for example in Nicaragua yearly electricity for 2 people, showing that this is a quite good solution for small household applications. In Morocco the electricity output is sufficient for 2 to 3 people, while in Finland the low wind speed is not enough to produce electricity for a single person. This is also due to higher electricity demand in the Scandinavian country. Combining now the yearly investment costs of 123.75 US Dollars (94 Euros, Oanda, 2012) with the yearly electricity output creates prices per kWh that are summarized in table 6.

Region	**Price per kWh in US Dollars**
Finland	0.34 (0.26 Euros, Oanda, 2012)
Nicaragua	0.12 (0.09 Euros, Oanda, 2012)
Morocco	0.08 (0.06 Euros, Oanda, 2012)

Table 6: Price per kWh from Small, Off-Grid Wind Energy Systems for Selected Regions (Sources: Climate Charts, 2007 and Homepower, 2008)

As shown in table 6 prices per kWh electricity of small, off-grid wind energy systems are perfectly competitive to the prices of other energy sources, such as 0.05 Euros per kWh for fossil fuels, especially when taking into account that prices for non-renewable energy sources can be expected to rise sharply in the next decades. The big advantages of the off-grid solution is that there are no further costs for connecting to the grid, remote areas can be electrified easily and independently, operation and maintenance costs can be neglected since these systems are very easy to maintain and it can be expected that businesses around wind energy systems for installation and reparation are formed. On the other hand this energy source is highly variable due to changing wind conditions.

4.3 EROI

The EROI of wind energy is calculated with 24.6:1, meaning that one unit of energy input results in almost 25 units of energy output. This number is relatively high compared to other energy technologies, such as solar energy as shown above in section 1.3. According to these calculations wind energy is already more efficient than oil and gas, but still behind coal. All in all the biggest problem for wind energy in this respect is the variability of supply with the source wind (Heinberg, 2009).

4.4 Aftercare

Wind turbines do not contain large amounts of problematic materials and there are highly efficient recycling methods for some of the constituents.

Material type	Disposal method
Iron	Recycling (10% losses)
Fiberglass	Landfill (100%)
Oil	Combusted (100%)
Plastic PVC	Landfill (100%)
Other plastics	Combusted (100%)
Rubber	Combusted (100%)
Steel	Recycling (10% losses)
Copper	Recycling (5% losses)

Figure 10: Materials of wind turbines and their disposal methods (Source: Martínez et al., 2009)

As figure 9 shows, for metal materials like iron, steel and copper highly efficient recycling methods are possible, while oil, plastics and rubber can be combusted making use of their high calorific values and fiberglass and plastic PVC have to be landfilled (Martínez et al., 2009).

As long as there is not too much waste for landfills, the aftercare of wind turbines does not create big problems. However, in order to avoid future disposal difficulties related to the increasing use of wind turbines further research and development in the field of End-of-Life Management of wind turbines is already done today. The Danish company Refiber Aps for example is shredding old blades, putting them into a 500 degree Celsius oven where the plastic material is pyrolysed to a synthetic gas that can be used to produce electricity or heating for the ovens. The glass fiber is cleaned and insulation slabs are produced, mixing it with PP fibers. Another approach is taken by the company Fiberline that is shredding the waste, adding materials to increase the calorific value and sells this product consecutively to the cement industry. In the Re-Act project, funded by the European Commission, possibilities are investigated to separate impurities from the shredded waste (e.g. metals, PVC), separate the different fiberlengths and find appropriate customers for further use of fibers. Re-Act predicts 350 to 475 Euros profits per ton of waste for the companies, when correctly applying the investigated procedures (European Plastic News, 2010).

4.5 Employment

Also wind energy has a quite high potential to create employment. In general, one TWh electricity from wind energy results in 200 to 1200 person-years of employment. This number is lower than for example for photovoltaic as pointed out above in section 1.5, but higher than the 200 to 300 person-years of employment per TWh electricity of coal (Worldwatch Institute, 2006).

Furthermore, in the United States of America 35 000 jobs related to wind energy were created in 2008 (Brennan and Withgott, 2011). In Europe 192 000 people are employed in the wind energy sector and 2.8 Million jobs are to be created, contributing 1.1% to GDP growth until 2020 according to the EU Energy Targets (European Wind Energy Agency, 2009). So, to sum up, wind energy has a high employment factor and can create many small industries, especially in rural areas that take over operation and mainly maintenance and repair, which is crucial for wind energy.

4.6 Emissions, Noise and Health Aspects

As it can be seen in figure 4, section 3.6, health impacts from wind turbines are relatively low compared to other energy technologies. The quite low health costs mainly come from noise related damages to human beings, as well as from the emissions from producing wind turbines. Taking the later into account is quite important, since wind turbines do not create any emissions while running (EU Project ExternE, 2003). Compared to fossil fuels, running a 1 MW wind turbine prevents the release of 1 500 tons of CO_2, 6.5 tons of SO_2 and 3.2 tons of NO_2 (Brennan and Withgott, 2011). However, also the emissions from producing wind turbines are comparatively low, as figure 5 in section 3.6 clearly states. The external costs caused by emissions from producing wind turbines are the lowest of all

technologies, only beaten by hydropower in the alpine area. The main emittents from producing wind turbines are greenhouse gas emissions, SO_2, NO_X, Particulates and Heavy Metals. In general, wind on-shore, 0.09 Euro Cents per kWh, performs better than wind off-shore, 0.12 Euro Cents per kWh in creating external costs from emissions, because the material and energy input for off-shore wind parks is higher than for on-shore wind parks (so far the higher energy yields of off-shore wind parks do not compensate the higher costs for material and energy input). So, all in all, wind energy performs very well concerning emissions and health impacts and can therefore be considered a very clean energy technology in this respect, creating very low external costs (EU Project ExternE, 2005a).
However, the most critical, also in a political sense, problem of wind energy is the noise factor. Wind turbines create aerodynamic noise by the turning of the blades and mechanical noise with the gearbox. In order to protect people from annoying noise levels, several countries have passed laws, restricting the noise nuisance. In Germany for example noise has to be below 65 dB(A) during the day and below 50 dB(A) during the night in commercial areas, below 60 dB(A) during the day and below 45 dB(A) during the night in mixed areas, below 55 dB(A) during the day and below 40 dB(A) during the night in general residential areas and finally below 50 dB(A) during the day and below 35 dB(A) during the night for pure residential areas. Especially in summer time, when the windows in residential areas are open during the night the noise problem is present (EU Project ExternE, 1999). According to the wind turbine producer Vestas, their product V90 (3 MW) produces, directly at the turbine, between 97.9 dB(A) and 106.9 dB(A), depending on the wind speed (ranging from 4 m/s to 9 m/s) (Vestas, 2012). The European Wind Energy Association (2011) states in this respect that a wind farm at 350 meters distance creates a noise level of 35 to 45 dB, which is comparable to a busy road in a distance of 5 kilometers and still is well below the 60 dB of a conversation or the 65 dB of a truck with 50 km/h at a distance of 100 meters. To sum up, noise might be the most critical aspect for wind energy, however, as just shown nuisance created by wind turbines is relatively low, especially compared to the gains and benefits of wind energy. Furthermore, 71% of EU citizens declared their support for wind energy, compared to 42% for gas, 26% for coal and 20% for nuclear power (European Wind Energy Association, 2011). On the other hand, when talking about people’s support

for wind energy one might always take the “Not-In-My-Backyard” Syndrom into account, meaning that people want to have energy harvested from the wind, but they do not want to have turbines close to their homes, because of noise impacts. In reality wind projects often face opposition of neighboring parties. In Great Britain, at the wind site Delabole, 42% of the people surrounding the wind farm considered it as a nuisance before it was built and only 10% did so after it was built and running (EU Project ExternE, 1999). So, nuisance is quite low in reality, however people still fear an impact on their daily lives.

4.7 Landscape

Additionally to the figures about public support for wind energy in the European Union, presented above in section 3.6, in the United States of America 61% of the people regard wind energy as very favorable, while 91% strongly favor wind energy, compared to 24% for coal and 31% for nuclear power (Farhar, 2009). Also in the field of landscape, people want clean wind energy, but not in their backyard, since it changes the perception of the landscape and flickering of sunlight might appear from turning blades. In Great Britain residents were asked for their willingness to pay in order to preserve the landscape as it is and prevent wind turbines changing the perception. On average, people would be willing to pay 25 Pounds (30 Euros, Oanda, 2012) per person to preserve their perceived landscape. This shows that people perceive wind turbines as a loss of visual amenities and would be willing to prevent having wind turbines in their backyards. However, the amount paid per person is not very high, showing that the resistance and the willingness to prevent wind turbines to be built are quite low. Additionally one has to take into account that a willingness to pay survey always has the weakness that people tend to name higher amounts than they would actually pay, since they are not confronted with really paying the amount they name. Also for the losses in visual amenities people think differently once the wind turbines have been built. Again at the wind farm in Delabole, Great Britain, 56% of the population stated that the wind turbines would spoil the scenery before they were built. This number decreased to 28% once the wind park became reality (EU Project ExternE, 1999). The situation for perceived losses of visual amenities is quite similar to the noise issue: in reality the impact is quite low, but people tend to overestimate the negative consequences beforehand.

Concerning the danger of wind turbines for birds and bats, they do cause casualties. However, compared to other human activities the impact is quite low. 28 500 birds are estimated to be killed by wind turbines annually, which is relatively low compared to 550 million casualties from buildings/windows, 80 million from vehicles or 4.5 million from communication towers. All in all, further protection of birds and bats from harm caused by wind turbines is necessary, but so far the impact is relatively low (European Wind Energy Association, 2011).

4.8 Scarcity

For wind energy the supply variability is similar to solar energy. Electricity can only be produced when the wind turns the blades of the wind turbines. This creates an unpredictable supply variability and causes especially differences in energy supply between areas with a lot of wind and low-wind areas. That means that wind energy always has to be secured by other energy supply in order to guarantee constant energy for the consumer, creating a dependence on other energy sources. However, the balancing costs are expected to be quite low (European Wind Energy Agency, 2009).

Concerning the materials needed for the production of wind turbines there is no input showing danger of resource scarcity in the future so far, although one has to mention that the degree of copper in copper ore is decreasing, but the amount of copper ore with lower copper degrees is increasing.

4.9 Political Aspects

From a political point of view wind energy is a very ambiguous energy technology. On the one hand it is easy to promote for politicians, since it is a technology that is very low in emissions and can contribute to combat anthropogenic climate change. Furthermore it increases independence from natural resources, like gas or oil, coming from countries that are rich in these resources. These resource rich countries have relative political and economic power over countries that are dependent on their resources. As shown in this chapter, the public support for wind energy is very high, making it especially interesting to politicians. On the other hand, wind energy also brings some challenges with it. The “Not-In-My-Backyard” Syndrom can be considered as one of these. People do not want to have wind farms close to their home, since they fear losses of visual amenities and nuisance from noise created by the turbines. This is a factor that makes it politically difficult to promote wind energy in certain areas, especially highly populated areas. Moreover wind supply is highly variable and does not guarantee a constant supply of electricity. This creates again a dependence on other energy supply, for example oil and gas, to support wind energy and favors regions with more wind. From a political point of view off-grid wind turbines are also highly important, since they increase the possibility to empower remote regions without creating any dependencies within the existing grid. Since wind energy creates a lot of employment and businesses surrounding its maintenance, operation and repair, the technology offers additional incentives for regions to make use of it.

5 Electricity from Biomass Energy

In section 5 of this thesis electricity from biomass energy is investigated within the different indicators.

5.1 Introduction

Biomass energy is energy obtained from biomass resources, which is organic material originating from living or recently living organisms. The energy obtained is a chemical one that was built up by sunlight and photosynthesis. Especially in developing countries biomass is used for heating and cooking by burning wood or animal manure. The part of biomass energy that is treated within this thesis is bio power generating electricity from biomass (Brennan and Withgott, 2011).

Power plants that generate bio power work similarly to coal or fossil fuel combusting power plants. Biomass is burnt, heating up water, which results in steam turning turbines and generators to produce electricity. Excess heat from this process can be used to heat neighboring buildings (also called cogeneration for power plants). Biomass can also be vaporized in anaerobic conditions with extremely high temperatures to form a gaseous mixture containing hydrogen, carbon monoxide, carbon dioxide and methane. The mixture can produce electricity by turning a generator in a power plant. Further, biomass can be baked in anaerobic conditions (pyrolysis). By burning these mixtures of gases, solids and liquids electricity can be generated. Concerning the sources, there are several possibilities for bio power. First of all there are bio energy crops, including fast-growing grasses (for example bamboo, fescue, switchgrass) and fast-growing trees (for example willows, poplars). Secondly, crops and forestry residues, as well as processing waste, like for example solid or liquid waste from sawmills, pulp or paper mills, can be used. Further sources for bio power can be animal waste from feedlots, organic waste from municipal solid waste or landfill gas. The latter is a result of bacterial processes without oxygen, decomposing waste to methane and other gases (Brennan and Withgott, 2011).

The use of waste material is definitely an advantage of biomass energy. Furthermore it reduces methane emissions, which is a very strong factor for combating climate change, and emits far less SO_2 than coal fired power plants. However, if crops or plant matter are burnt, nutrients are taken away from the soil and bio energy crops might block space that is necessary for food production. With regards to CO_2, burning biomass is considered carbon neutral, since it only releases the CO_2 in the combustion process that has been captured by organic material via photosynthesis before (more on that in the subsection Emissions, Noise and Health Aspects). On the other hand, depletion of forests to grow bio energy crops reduces the CO_2 capture potential, due to the fact that forests preserve more of the greenhouse gas than crops (Brennan and Withgott, 2011).

Generally, electricity from biomass is only applicable on a medium to large scale. This results in the fact that for rural electrification biomass electricity can be of interest when taking small business offices, schools or buildings of public authorities into account. Since in developing countries the priority shall clearly be kept on using agriculture for food production, biomass for electricity shall preferably come from waste products or from plants using short rotation coppice (SRC). In the latter, plants with high biomass production are harvested in the interval of 1 to 4 years and selected species will resprout after harvest so that additional crops do not have to be replanted. This system does not compete with land for food production since it can be applied on agricultural fallows or cropland with low soil quality (Alliance for Rural Electrification, 2012).

5.2 Costs for Investment, Operation and Maintenance

The costs for biomass electricity differ a lot with the size and regional characteristics. Therefore within this section an exemplary case will be shown. The case presented here is a cost calculation for two different approaches of electricity from biomass energy. One is for combustion processes (50 MW Electrical capacity) and the other for using gas from anaerobic, bacterial digestion (0.5 MW Electrical capacity). Both calculations assume that excess heat is used to heat neighboring buildings (International Energy Agency, 2010).

	Biomass Combustion	**Gas from Anaerobic Digestion**
Investment Costs	3 000 to 6 000 US Dollars per kW	3 700 to 5 300 US Dollars per kW
Operation and Maintenance Costs	100 US Dollars per kW per year	300 US Dollars per kW per year

Fuel Costs	30 to 50 US Dollars per MWh	40 to 60 US Dollars per MWh
Economic Lifetime	20 years	20 years
Interest Rate	10%	10%
Total Electricity Production Costs	**100 to 130 US Dollars per MWh**	**140 to 200 US Dollars per MWh**

Table 7: Production Costs for Electricity from Biomass Energy (Source: International Energy Agency, 2010)

As table 7 shows, operation and maintenance costs for biomass energy is relatively low with 5-10% of the investment costs. The total production costs of 0.1 to 0.13 US-Dollars (0.08 to 0.1 Euros, Oanda, 2012) per kWh electricity for biomass combustion and 0.14 to 0.2 US Dollars (0.11 to 0.15 Euros, Oanda, 2012) per kWh electricity for a biogas power plant are quite low and can be considered competitive to the 0.04 Euros per kWh for fossil fuels, which can be expected to rise in the next decades (International Energy Agency, 2010).

5.3 EROI

The Energy Return on Energy Invested for electricity from biomass energy is highly depending on the technology and the sources used. Therefore the results are strongly varying and provide only limited reliability. In that sense, the EROI ranges from around 8:1 for anaerobic, bacterial digested gas (Livestock Research for Rural Development, 2009) to up to 40:1 for combusting wood from fast-growing trees (Sustainable Scale, 2003). The latter is a quite high and efficient ratio. However, as already stated the calculations here vary a lot, thus extensive analysis will not be provided, in order to not exceed the scope of this thesis.

5.4 Aftercare

Aftercare for bio power is mainly restricted to the decommissioning of power plants at the end of their lifetimes. The costs for decommissioning and demolition of power plants (generally applicable for all power plants with the exception of nuclear power plants) are relatively low with 10 US Dollars per kW. Additionally, by selling scrap and salvage for recycling these costs can even be neutralized (Energybiz, 2011).
The environmental impact of decommissioning of power plants is also relatively low. Mann and Spath (2000) concluded for natural gas power plants (which are perfectly comparable to biomass energy plants when it comes to decommissioning and

demolition) that the global warming potential caused by activities in the decommissioning phase contribute only 0.4% of the total global warming potential caused by the power plant over its total lifetime (Mann and Spath, 2000). To sum up, aftercare is not a big issue for power plants producing electricity from biomass, neither in an economical nor in an environmental point of view. In the end it can even contribute to reduce aftercare problems from landfills by using landfill gas, which contains high amounts of the greenhouse gas methane, to produce electricity. However, if bio energy crops are considered it is highly necessary to consider in the aftercare that crops and forests have to be handled with care in order to guarantee re-growth of the source.

5.5 Employment

Concerning employment, electricity from biomass energy creates less employment than wind energy or solar energy, however with 200 to 450 person-years per TWh the employment factor is still a bit higher than for coal for example (Worldwatch Institute, 2006). The similarity with coal can be derived from the fact that combustion processes work quite similar for the two technologies. A fact of biomass energy that is favorable for rural electrification is that it creates employment in the agricultural sector if bio energy crops are used. In most of the developing countries the agricultural sector is highly important and employs most of the people. Furthermore, especially source generation for biomass energy provides employment that does not need highly technological know-how.

5.6 Emissions, Noise and Health Aspects

Concerning Health Aspects, damages can be expected as a result of biomass combustion for gaining electricity. The external costs for health damages for a biomass power plant with a steam turbine are estimated to amount to 1.53 Euro Cents per kWh and mainly result from emissions of particulates, NO_X, SO_2, NH_3 and several heavy metals. This value is comparatively high and even exceeds coal and fossil fuel fired power plants, mainly due to the fact that biomass power plants emit relatively more nitrogen oxides and certain heavy metals, such as lead (NEEDS Project, 2009).

With regard to emissions, there is the argument that electricity from biomass power is greenhouse gas neutral, since it only emits what has been stored before by biomass. However, before confirming this hypothesis, one has to think of several issues. Whether bio power is carbon neutral or not depends on which feedstock is used, how it is procured, managed and transported, which energy generation technology is used and finally the timeframe to replenish the feedstock is of importance. For example agricultural biomass may create a higher greenhouse gas balance, since fertilizer treatments are used, while woody biomass may save additional greenhouse gas by removing wood before it decomposes, releasing emissions to the atmosphere. The transportation mode is also highly dependent. Using road traffic to bring biomass to the power plant with fossil fuel driven vehicles increases greenhouse gas emissions. Technology wise, using landfill gas in gasification saves methane emissions, while combustion creates greenhouse gas emissions. For the latter it is also decisive whether technologies are used to store or treat emissions (for example carbon capture and storage technologies). All in all greenhouse gas impacts from bio power can be expected to be relatively low, but they vary highly, depending on certain factors (Bracmort, 2011).

When it comes to noise, the sound power level of a coal fired plant with 1 200 MW is about 112 to 118 dB(A), while biomass power plants can be expected to exceed this value by 3 to 5 dB(A). This is mainly due to the fact that biomass as a fuel needs a lot of road traffic to be transported to the power plant, since the calorific value of biomass is lower than that of coal. Furthermore, biomass power plants need shredding, drying and blending devices, which can also be a factor for noise increases. However, most of the latter mentioned processes take place inside of power plant buildings (Stevens and Van Leemput, 2009). So, on average a biomass power plant emits 119 dB(A) directly at the plant. According to the laws of noise transmission (Noise Level 2 = Noise Level 1 – 20*log(Distance 2/Distance1)) this would mean that a biomass power plant creates 85 dB(A) at a distance of 50 meters (Sengpielaudio, 2012).

To sum up, electricity from biomass power creates certain health risks that have to be taken into account and, as many other power plants, can pose a noise nuisance. Greenhouse gas emissions are negligible, but vary depending on certain factors.

5.7 Landscape

Within the indicator landscape, it has to be mentioned once again that it strongly depends on the supply source for biomass energy whether there is an influence or not. For example if waste residues are used as a fuel, there is no change in the original landscape. An influence is given, however, if crop or forests are especially planted in order to yield harvests for biomass power. In this case, external costs for land use changes amount up to 0.66 Euro Cents per kWh, compared to only 0.05 Euro Cents per kWh for coal. If a forest or cropland is changed to produce certain bio energy crops also the original landscape is changed (NEEDS Project, 2009).

In the United States of America only 32% of surveyed people considered biomass power as "very favorable". This is, especially compared to photovoltaic and wind energy, quite low. However, no conclusion can be drawn that this is due to landscape changes. In general it can be expected that people fear competitiveness with food production and they do not consider bio energy as a big step forward in technological development (Farhar, 1999).

The fact that also power plants for producing electricity from biomass pose a change to existing landscape can be neglected, since most common energy technologies are based on power plants and therefore people are used to it, although this is definitely a factor that favors solar energy.

5.8 Scarcity

For electricity from biomass, scarcity is not a big, influencing factor. Biomass is renewable and can re-grow, however it is important to take into account necessary regeneration phases for biomass sources in order to not let extraction exceed re-growth. Another issue where scarcity matters is spatial restrictions. When talking of space for growing bio energy crops, there is a competition between these plants and crops used for food production. With an increase in earth's population this becomes more and more important, since the necessity to use land and available agricultural space for food production to nourish people rises.

5.9 Political Aspects

From a political point of view biomass energy can be both, critical and favorable, depending mainly on the source used for electricity generation. The critical issues arise when the growth of bio energy crops competes with crops used for food production and forests that have higher potential of storing carbon. On the other hand biomass energy is perceived quite favorably when waste products and landfill gases are used to produce electricity. All in all it is highly important to guarantee a careful management of resources and transparently promote this goal to make use of bio power in an appropriate way.

In general, electricity from biomass energy can increase the energy independence of countries rich in biomass which is geopolitically very favorable, making certain governments less dependent on energy imports and external price pressure. Examples for these countries can be the Scandinavian countries in Europe.

Another political difficulty with electricity from biomass can be that a lot of people might not perceive it as a big technological development that changes the use and generation of electricity as it is more and more demanded by consumers.

In rural areas electricity from biomass matches perfectly with the strong focus on the agricultural sector that is mainly present in such regions. Furthermore biopower does not need advanced technological Know-How, but it is even more important to have knowledge about the sources themselves. Moreover, excess heat from biomass power plants can be used to heat buildings. However, especially in remote, developing regions it is highly important to carefully plan fuel generation for biomass power plants in order to not compete with agricultural space needed for food production.

6 Electricity from Hydropower

Section 6 is now dealing with the possibilities of using water and its kinetic energy for electricity generation.

6.1 Introduction

Hydroelectric power turns kinetic energy into electricity by moving water that turns turbines. For the production of electricity with hydropower two approaches are possible (Brennan and Withgott, 2011):

- Storage Approach: Water is stored behind concrete dams. Once dams are opened to let water pass through, turbines are turned to generate electricity that is then fed into the grid via transmission lines. The distance that water falls and its volume determine the amount of electricity generated. The storage approach offers the advantage of a predictable electricity supply that is not suffering from dry periods (Brennan and Withgott, 2011).

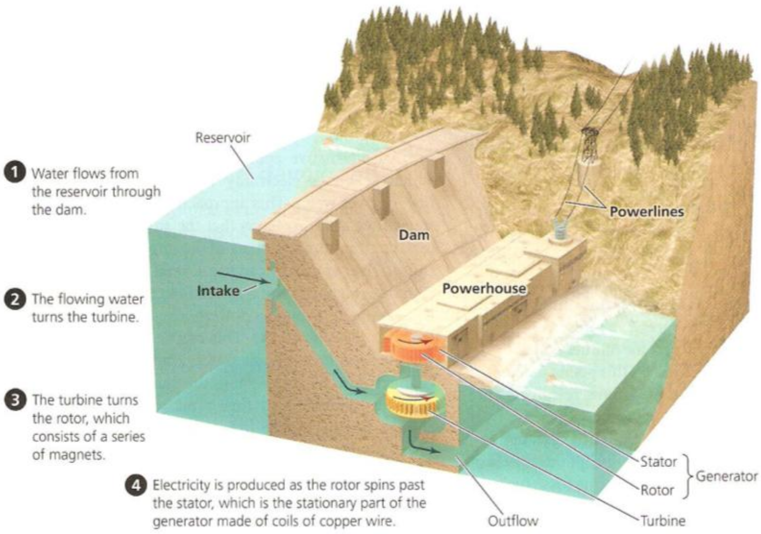

Figure 11: Storage Dam (Source: Brennan and Withgott, 2011)

- Run-of-River Approach: This possibility does not greatly affect the flow of the river. There are several ways to use the run-of-river approach. One of these is to channel a portion of the river's flow, let it pass through a powerhouse and then return it to the river (Brennan and Withgott, 2011).

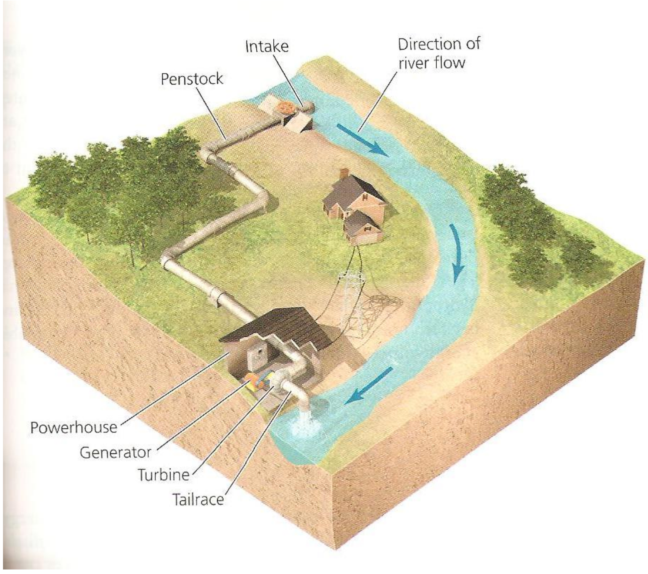

Figure 12: Run-of-River Approach (Source: Brennan and Withgott, 2011)

Water can also be flown over a small dam that does not affect fish, siphoning off water that turns turbines before directing it back to the river. Run-of-river methods are less affecting for the ecological environment and are of special importance for rural areas with small hydropower plants, although it is completely dependent on the water content of the river (less water means less electricity) (Brennan and Withgott, 2011).

Small hydropower plants can be either connected to the grid or they can be used off-grid to provide electricity for rural areas that do not have connection to the main grid infrastructure. The term “small hydropower plants” usually considers plants below 10 MW, while mini hydropower plants are below 1 MW and micro hydropower plants below 100 kW. Especially the latter two use the run-of-river approach to electrify remote areas. In China these possibilities are widely used with 100 000 micro hydropower plants installed (Alliance for Rural Electrification, 2012).

6.2 Costs for Investment, Operation and Maintenance

The costs for electricity generation from hydropower vary strongly, depending on the technology applied, the installed capacity and the regional characteristics. Therefore costs can only be evaluated accurately on a regional basis.

In the United States of America the average price for hydropower is around 4 US Dollar Cents (0.03 Euros, Oanda, 2012) per kWh. Operation and maintenance costs are calculated to amount up to 0.6 US Dollar Cents (0.005 Euros, Oanda, 2012) per kWh, which is relatively low with around 14% of the average price. Most expenses for hydropower plants, especially for big ones, appear with the building of dams (University of Oregon, 2012).

In the rural application a project in Todomè village, Togo, can serve as an orientational example for cost calculations. In Todomè village, the river provides a maximum flow rate of 0.8 m^3/s and an average head of 3.95 meters. The hydropower plant shall operate isolated from the grid with two small turbines in the size of 20 kW and 50 kW. They shall further provide 16 hours a day the electricity necessary for the whole village (for medical purposes, schools, public authorities, sanitation, agriculture and businesses, public lighting and domestic use). The estimated costs are presented in table 8 (Alliance for Rural Electrification, 2012).

Purpose	**Costs in Euro**
Barrage	35 000
Electromechanical Equipment	40 000
Civil and Hydraulic Works	12 000
Others	5 000
Total	**92 000**

Table 8: Costs for a Rural Hydropower Plant in Todomè, Togo (Source: (Alliance for Rural Electrification, 2012))

As it can be seen in table 8, investment costs for providing a whole village with electricity from hydropower are quite low. Operation and maintenance costs are considered to be negligibly low and can be expected to be neutralized in the regional economy by gains in business activities around operation and maintenance of the power plant. With this investment of 92 000 Euros electricity for 16 hours a day for the whole village worth 21 400 Euros a year is generated. This means that the break-even point for the project in Todomè is reached after 4.29 years (Alliance for Rural Electrification, 2012).

6.3 EROI

As pointed out above in section 6.2, the characteristics of a hydropower plant project vary strongly with its size and especially regional characteristics. Also the Energy Return on Energy Invested shows a broad range for electricity from hydropower from 11.2:1 to 267:1. This stems from the major differences between for example a run-of-river plant with a river with a relatively low flow rate and an enormous alpine storage dam. What can be seen from the calculations is that big hydropower plants might be expensive as an investment, but they are highly efficient and return reliable amounts of energy. However, also small hydropower plants in rivers with quite low flow rates are still relatively efficient, with 11.2 energy units as output for 1 energy unit input in the worst case. This is soon to be highly competitive to fossil fuels for example (even in the worst case, with expected decreases in the efficiency of burning fossil fuels for energy). The broad range also shows, that especially compared to electricity from coal, hydropower is the only renewable alternative that already provides efficiencies that can easily compete and even exceed the values of coal (Heinberg, 2009).

6.4 Aftercare

Concerning the decommissioning of a hydropower plant, the demolition of big plants with dams 100 years after construction causes 128 to 380 grams of CO_2 equivalents per kWh if 11% of the total sediment organic carbon at the dam is mineralized and 35 to 104 grams of CO_2 equivalents per kWh if 3% of the total sediment organic carbon at the dam is mineralized (Pacca, 2007). These are quite low emissions over the whole lifetime, especially compared to electricity generation with combustion processes for example coal (847 CO_2 equivalents per kWh) (Mann and Spath, 2004). More information on emissions over the rest of the life cycle will be provided in section 6.6.

The major cost aspect from decommissioning hydropower plants stems from dismantling dams. These costs however vary strongly with the size of the dam and certain regional characteristics. For example the demolition of a 6 MW hydropower plant with its dam in Oregon was calculated to amount to 4.7 Million US Dollars, while a 7 MW hydropower plant in Arizona causes decommissioning costs of 11.8 Million US Dollars (Manahan and Verville, 2005).

For small hydropower plants, using river-run-of systems, decommissioning is very uncommon. Usually existing power houses are renovated, modernized and uprated to be used again. So, demolition is not necessary, but only modification, which is not connected to high costs (Varun et al., 2008).

All in all, decommissioning large hydropower plants is cost intensive and also causes emissions, which however are quite low taking into account the lifetime of the hydropower plant and its energy output. The lack of necessity to dismantle small hydropower plants provides a big advantage, especially to rural areas.

6.5 Employment

The employment opportunities created by hydropower are relatively low and vary strongly depending on the size of the hydroelectric power plant and specific regional characteristics. For example building a large dam for a big hydropower plant creates more jobs than small river-run-of facilities that do not need high construction, operation and maintenance effort.

To provide some data also in this section, in Germany 9 400 people were employed in the hydropower sector in 2006, compared to 82 100 for wind energy and 40 200 for solar energy. Although the latter two branches are especially strong in Germany, the figures are still a proof of the fact that hydropower does not create as many jobs as other energy technologies (UNEP, 2008b). Solar energy and hydropower are in the same range concerning their supply contribution in Germany (Gizmag, 2011).

6.6 Emissions, Noise and Health Aspects

As shown in figure 4, section 3.6, noise of hydropower plants in Germany do not cause any external costs. This is mainly due to the fact that run-of-river systems do not cause additional noise nuisance and storage systems are mainly located away from residential areas. Furthermore, even the release of high amounts of water from a storage is mostly not perceived as disturbing, unless living right next to it. However, noise nuisance can appear during construction of a dam, which is on the other hand limited in time and as mentioned above, mostly not close to residential areas. Therefore no continuous and valuable noise disturbance can be detected from hydropower plants (EU Project ExternE, 2003).

With regards to emissions, electricity generation from hydropower does not cause any relevant emissions during operation, as shown in figure 5, section 3.6. Small amounts of greenhouse gas emissions and mainly particulates are caused in the construction phase, when building dams, as well as when decommissioning dams due to carbon sediments, as shown in section 6.4. The emissions caused by run-of-river systems over the whole lifetime are negligible, especially because there is no big effort in constructing and decommissioning these plants (EU Project ExternE, 2005a).

As figure 4, section 3.6, shows, there is a small health impact from electricity generation from hydropower, which, however, is very small compared to other energy technologies (EU Project ExternE, 2003). These health impacts mainly stem from two aspects (EU Project ExternE, 1999):

- Health Impacts caused by Emissions in the Construction and Demolition Phase: This is mainly valid for storage systems. The construction and demolition of dams causes a small amount of emissions that consist mainly of particulates harming people's health.
- Health Impacts from Changes in Water Quality: Hydropower plants can shorten water supply and change the flow regime of a river. Especially the latter can lead to impacts on aquatic culture and water quality (it can eventually lead to eutrophication of the river). In general, hydropower plants applying the storage approach have a greater impact on water supply and water quality, because they pose a strong change on the existing water flow regime. Run-of-river plants have a smaller impact on water supply and water quality, since there is less change to the natural conditions of the river, especially when part of the river is detoured for electricity generation. All in all, one can say that the smaller the hydropower plant is, the smaller is the impact on water supply and water quality. In developing countries it is highly important to make sure that the impact on water supply by hydropower plants is negligible (EU Project ExternE, 1999).

To sum up, impacts from emissions and noise disturbance from hydropower plants are negligible, while health impacts may appear due to changes in water quality caused by a change in the water flow regime. It is highly important to take the latter into account when planning a new hydropower plant.

6.7 Landscape

Depending on the size, technology and regional characteristics, hydropower can have strong impacts on landscape. Run-of-river systems, especially if water is detoured for electricity generation, keeping the impact on the natural flow regime of the river low, cause little changes to the existing landscape. Big hydropower plants with dams, however change the perception of the landscape firstly with big, concrete dams and secondly by flooding areas upstream the dam. The latter can deplete ecosystems and destroy residential areas. On the other hand dams are mostly not perceived negatively in the landscape and even highly visited by tourists.

Also, according to a survey in the United States of America, 85% of the people have a preference for hydropower, compared to 88% for new renewable technologies (solar energy, wind energy, geothermal energy and biomass energy), 55% for natural gas, 39% for nuclear power and 14% for coal (Farhar, 1999).

The impacts of dam building on landscapes and people are only treated superficially within this paper in order to not exceed the limits and scope of the thesis. Additionally the main focus is on small hydropower plant applications.

6.8 Scarcity

Within this analysis, electricity from hydropower means using the 3% freshwater resources of the total water resources on planet earth. So, to some extent hydropower is limited. However, it cannot be considered scarce, since the natural water cycle is continuous and cannot be depleted. Furthermore, there is no loss in water, when using it for electricity generation for hydropower. On the other hand, electricity generation from hydropower is not applicable everywhere around the world, since flat and arid areas do not provide enough water flow and head to generate electricity. So, in order to be able to use hydropower for generating electricity certain circumstances need to be fulfilled and the resource (water in rivers) needs to be present.

6.9 Political Aspects

In political terms, hydropower offers an easily applicable (unless big projects with dams are considered), reliable and cheap possibility for electricity generation. However, especially big projects with dams include a lot of problems like high investment costs, special know-how that is needed for the construction and in some cases residential areas and ecosystems are destroyed. The latter is a big political problem of huge hydropower projects, since the storage and flooding of a river causes the depletion of ecosystems and the resettlement of people. Resistance against such projects is therefore strong. Furthermore, hydropower can cause changes in

water supply and water quality, which is of special importance in developing countries. Run-of-river systems cause less impact on water quality and smaller hydropower plants do so as well.
Moreover the application of hydropower in arid, flat areas is only possible to a limited extent and therefore not appropriate for all regions around the world. Especially mountainous, humid areas are empowered by hydropower.
Finally, hydropower does not create as many jobs as other renewable energy technologies and for that lacks behind solar energy and wind energy.

At the end of the overview on four energy technologies a summarizing table is provided that catches the results in short.

Indicator	**Solar Energy**	**Wind Energy**	**Biomass**	**Hydropower**
Costs for Investment, Operation and Maintenance	Grid-Tie Solution: 0.07 to 0.18 Euros per kWh Off-Grid Solution: 0.10 to 0.26 Euros per kWh O&M: 41 Euros per kW-year	Grid-Tie Solution: 0.05 to 0.11 Euros per kWh O&M: 0.0012 to 0.0015 Euros per kWh Off-Grid Solution: 0.06 to 0.26 Euros per kWh	0.08 to 0.15 Euros per kWh	Large Installations: 0.03 Euros per kWh O&M: 0.006 Euros per kWh
EROI	3.75:1 to 10:1	24.6:1	8:1 to 40:1	11.2:1 to 267:1
Aftercare	Poses Challenges	Quite uncomplicated	Quite uncomplicated	Varies strongly depending on size and technology
Employment	800 to 2100 person-years per MWh	200 to 1200 person-years per MWh	200 to 450 person-years per MWh	Low Employment Creation
Emissions, Noise and Health Aspects	Intermediate Impact	Intermediate Impact	Intermediate Impact	Low Impact

Landscape	No severe interference	Intermediate interference	Varies strongly	Varies strongly
Scarcity	Intermediate Impact	Intermediate Impact	Intermediate Impact	Intermediate Impact

Table 9: Summarizing the results of the various indicators for the four investigated energy technologies (created by the author)

7 The Electrification Strategy of Nicaragua

In this chapter the case of Nicaragua and its Electrification Strategy is evaluated. First of all, the situation in Nicaragua and the main content of the electrification strategy are presented, before a conclusion about the strategy based on the indicator evaluation from chapters 3 to 6 is drawn.

7.1 Key Facts of Electricity Production in Nicaragua

The primary energy production in Nicaragua mainly relies on biomass. Additionally, geothermal energy, wind energy and hydropower are used (Ministry for Energy and Mining Nicaragua, 2010).

Primary Energy Source	Share in % in 2009	Share in % in 2010
Hydropower	3.7	8.8
Geothermal Energy	5.9	5.2
Wind Energy	0.7	0.9
Biomass: Firewood	69.9	65.3
Biomass: Agricultural Waste	19.6	19.5
Other Biomass	0.2	0.3

Table 10: Primary Energy Production in Nicaragua 2009 and 2010 (Source: Ministry for Energy and Mining Nicaragua, 2010)

As table 10 shows, the primary energy sources in Nicaragua stem from renewable energy sources with biomass having the highest share. This is mainly due to the fact that in developing and emerging countries firewood constitutes a major source for cooking and heating. Therefore this cannot necessarily be assumed to be an environmentally friendly energy source. However, in Nicaragua also the agricultural waste and hydropower have a quite high share of all primary energy sources. In total, primary energy production in Nicaragua amounted up to 16.2 TWh in 2009 and 17.4 TWh in 2010 (Ministry for Energy and Mining Nicaragua, 2010).

Concerning electricity, 2.4 TWh in 2009 and 2.3 TWh in 2010 were produced in Nicaragua. Electricity comes mainly from thermal power plants.

Source	Share in Electricity Production in % in 2010
Thermal Power Plants	63.2
Geothermal Energy	8.3

Wind Energy	4.5
Hydropower	13.8
Other Plant Residues (e.g. Sugar Cane)	10.3

Table 11: Electricity Production in Nicaragua in 2010 (Ministry for Energy and Mining Nicaragua, 2010)

The electricity consumption per capita in Nicaragua was 454.1 kWh in 2010, rising by 16% from 2005 to 2010. If one extrapolates the electricity consumption per capita from 2010 to the roughly 5.7 Million inhabitants of Nicaragua, a total consumption of 2.6 TWh would be the result, meaning that national production is not sufficient to serve the total electricity demand. In total, Nicaragua imported 10.2 GWh electricity in 2010 and 1.2 GWh in 2009. The amount of imported electricity also depends on the world market prices, since it can be the case that imported electricity is cheaper than producing it within the country (Ministry for Energy and Mining Nicaragua, 2010).

7.2 Development and Current Status of Electrification

Between 2006 and 2010 the electrification has increased strongly in Nicaragua.

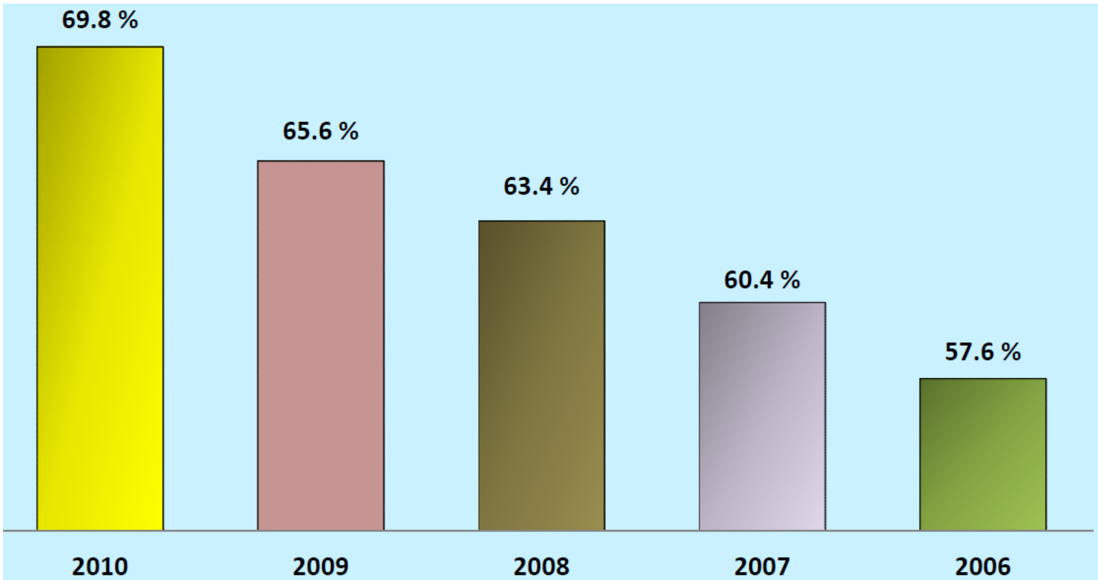

Figure 13: Degree of Electrification in Nicaragua between 2006 and 2010 (Source: Ministry for Energy and Mining Nicaragua, 2011)

As Figure 13 shows, the degree of electrification in Nicaragua has risen from 57.6% of the people having access to electricity in 2006 to 69.8% in 2010. The government of Nicaragua put a lot of effort into increasing electrification and will do so in the future. In the period 2006 to 2010, 43 540 households, with 260 343 people have benefitted from the increase in electricity access (Ministry for Energy and Mining Nicaragua, 2011).

Additionally it is estimated that in the last ten years 1.2 million people in Nicaragua benefitted from efforts in increasing energy access, by investing 185.4 million US-Dollars in electrification programs with a special focus on rural electrification. The Ministry for Energy and Mining in Nicaragua is convinced that rural electrification plays a key role in the country's plans to eradicate poverty (Interview Luis Molina, 2012).

Although the overall access to electricity has risen strongly in the years between 2006 and 2010, there are still rural areas with very weak infrastructure in Nicaragua.

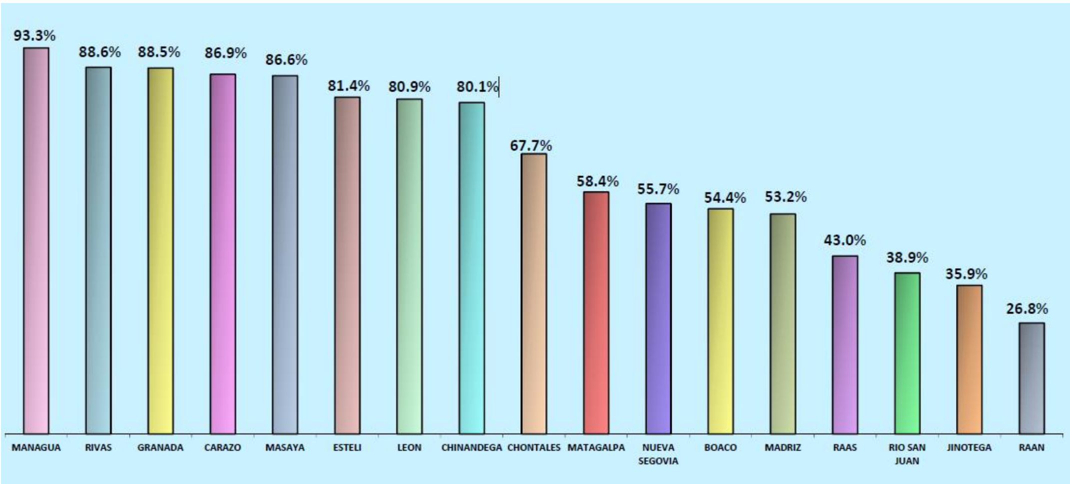

Figure 14: Degree of Electrification in Nicaragua by Region (Ministry for Energy and Mining, 2011)

As figure 14 outlines, in 4 out of the 17 regions in Nicaragua less than 50% of the people have access to electricity, reaching a low of 26.8% in RAAN. So, there are still regions that need a strong increase in electricity access in order to reach the goals of increasing rural electrification (Ministry for Energy and Mining Nicaragua, 2011). The future goals and strategies for electrification in Nicaragua are presented in the following chapter.

7.3 Electrification Strategies in Nicaragua

The electrification strategy of Nicaragua is built on two main pillars, namely rural electrification with the help of grid extension and rural electrification with renewable energy sources. The category grid extension has the final goal of reaching electricity access for 117 790 households without grid connection, living in 3 600 communities. Furthermore existing grids shall be upgraded and kept in good status. So, the focus lies on building new infrastructure, operating and maintaining existing infrastructure, keep transformation equipment up to date and assist end users of electricity. In total, 6 755 kilometers of grid lines are to be installed, including 1 256 kilometers of three-phase lines to reach a balanced national distribution of electricity. The second pillar of the electrification strategy in Nicaragua focuses on rural electrification with renewable energy sources. This is mainly for areas where it is difficult to build grid lines, the population is highly dispersed or there is low electricity demand. The first pillar, focusing on grid extension is funded with 112.6 million US-Dollars, while the second pillar, rural electrification with renewable energy sources is granted 19.4 million US-Dollars in the national electrification plan of Nicaragua, “Programa Nacional De Electrificación Sostenible y Energía Renovable (P.N.E.S.E.R.)” (Interview Luis Molina, 2012).

In the field of solar energy the project EURO Solar, funded by the Commission of the European Union is focusing on rural electrification with solar energy in 8 countries of Central America, including 42 target areas in Nicaragua. For wind energy, roughly 500 000 US Dollars are granted to Nicaragua by the Interamerican Development Bank to investigate the wind potential in the three coastal areas Puerto Cabezas, Sandy Bay Sirte and Laguna de Perlas. The capacity potential for electricity from Biomass was calculated to amount up to 700 MW in Nicaragua and is therefore a worthy alternative for the electrification strategy of the future. In the field of Hydropower, 16 potential hydropower plants below 30 MW and 11 potential hydropower plants above 30 MW have been identified, amounting up to a total potential of 1 063 MW. Small hydropower plants below a capacity of 30 MW can be realized by anyone, while larger hydropower plants above a capacity of 30 MW need a permit of the national parliament. This facilitates the formation of smaller hydropower plants for rural electrification. Most of the potential smaller hydropower plants in Nicaragua concentrate geographically in the regions Jinotega, Matagalpe, RAAN and RAAS, which are all regions at the lower end of the degree of electrification, as shown in figure 14. So, all in all, first steps are taken for all of the for energy technologies to increase electrification by using renewable energy technologies in Nicaragua (Ministry for Energy and Mining Nicaragua, 2012).

Luis Molina from the Ministry for Energy and Mining in Nicaragua stated in an interview that the main criteria deciding which energy technology is used are the energy potential, the abundance of a grid network and the distance between the electricity source and the consumers. According to him, solar energy would be highly useful for rural electrification in Nicaragua, however these systems still have high investment costs and therefore the best available alternative at the moment is hydropower, since Nicaragua has a high potential for hydropower plants, they are easy to build and maintain and deliver reliable electricity. Furthermore, Luis Molina sees the main benefits of the current electrification strategy of Nicaragua in the electrification of schools, hospitals and family homes via rural electrification. On the other hand there are still problems with financing the grid extension and especially the maintenance of the grids and generation facilities to work on. The clear goal of the electrification strategy of Nicaragua for the next ten years is to achieve an energy mix with more than 95% energy from renewable energy sources, reach a degree of electrification of more than 90% on the national level and build up a strong, trustworthy energy system that goes along with the values of sustainable development. Additionally, the national electricity demand shall be exceeded in 10 years to even be able to export energy (Luis Molina, 2012).

7.4 Evaluation of the Electrification Strategy of Nicaragua

In this subchapter the electrification strategy of Nicaragua will be assessed under the light of the indicators presented in the chapters 3 to 6 for the various energy technologies.

7.4.1 Costs for Investment, Operation and Maintenance

As pointed out in subchapter 7.4, the main focus in Nicaragua lies on hydropower for electricity generation with a lot of potential in that field. Concerning the costs for investment, operation and maintenance this is according to the evaluation from chapters 3 to 6 the cheapest option, especially for rural electrification. This mainly stems from the fact that small hydropower plants have very low investment costs and are cheap and easy to operate and maintain. The goal of increasing also solar energy from photovoltaic cells will play a role in the future, but so far is still quite costly for rural areas, as pointed out by Luis Molina in the interview. However, the lower investment costs for photovoltaic cells get, the more interesting it will become for Nicaragua. The share of wind energy so far is negligible in Nicaragua's electrification strategy, whereas biomass will certainly play an important role in electricity production in the future in Nicaragua. The latter also performs quite well when it comes to cost calculations, however, the starting investment and the operation and maintenance costs are higher compared to other technologies. So, all in all, by putting a focus on hydropower plants investment, operation and maintenance costs can be kept quite low, especially for rural electrification.

7.4.2 EROI

In the EROI comparison hydropower and wind energy perform best, followed by electricity from biomass and solar energy. So, again in this case, the strategy of Nicaragua seems to make perfectly sense when it comes to efficiency. However, one can expect the efficiency of solar energy to increase in the next decades, since the research and development in this field is quite new and making rapid progresses. This argument also underlines the future possibilities of photovoltaic energy for Nicaragua.

7.4.3 Aftercare

When it comes to aftercare, especially small hydropower plants, as mostly used in Nicaragua for rural electrification perform very well, since their lifetime can be easily prolonged by reparations. The only problematic energy technology when it comes to aftercare is solar energy, as pointed out in chapter 3 of this thesis. Therefore, the government of Nicaragua has to make sure for future investments in this field to also have plans for the aftercare of solar photovoltaic cells to avoid problems that will arise a few decades after the installation of energy facilities.

7.4.4 Employment

Concerning employment creation hydropower creates far less jobs compared to wind energy, electricity from biomass and solar energy. So, from a point of view regarding the job opportunities created with the electrification strategy the strong focus in hydropower in Nicaragua, especially in rural electrification, does not have the potential to create a lot of jobs around it. Solar energy, which will be an important pillar in the future in Nicaragua on the other hand creates the most jobs and performs very well for this indicator. Electricity from biomass creates an intermediate number of jobs, but still has a higher potential than hydropower. All in all, when it comes to job creation from electrification a stronger shift towards solar energy will be necessary in the future for Nicaragua.

7.4.5 Emissions, Noise and Health Impacts

In this category there is no clear advantage for one of the four technologies, since especially wind energy, solar energy and hydropower perform very well in this regard. Electricity from biomass is causing certain emissions and is therefore a bit weaker in its performance under this indicator. As pointed out in chapter 1, hydropower causes the lowest amount of external costs concerning emissions, noise and health impacts. So, also in this regard, the electrification strategy of Nicaragua sets the right directions towards a good performance.

7.4.6 Landscape

Except for wind energy, which is often perceived as a disturbance for the landscape, all four mentioned energy technologies perform very well under this indicator. Since wind energy only plays a minor role in the electrification strategy of Nicaragua and the main focus is on hydropower, solar energy and electricity from biomass no severe interference with the existing landscape can be expected, although bigger hydropower plants, as also planned in the future, certainly can have an impact and have to be assessed before building them to avoid disturbances.

7.4.7 Scarcity

Certain scarcity problems appear for all four energy technologies. However, hydropower and biomass and their scarcities can be controlled and observed within the country and are therefore less severe than material constraints for photovoltaic cells, since there is no influence by Nicaragua on reserves outside the country. In the dry season in Nicaragua, from January to June scarcity also can appear for hydropower plants and has to be observed. Since most hydropower plants are of a small size, dryer conditions do not influence them severely, unless a river completely lacks of water. So, between January and May, with a precipitation of only one to two centimeters hydropower generation can be critical for Nicaragua. During the wet season, solar energy can lack of sun hours, therefore a combination of these two technologies, also combined with small wind turbines, can be a valid alternative to avoid bottleneck situations of energy supply.

7.4.8 Political Aspects

The electrification strategy outlined by the government of Nicaragua is highly ambitious, especially with the goal to achieve more than 95% electricity from renewable energy sources and a degree of electrification of 90%. However, the past years have shown that a lot of effort is put into the realization of these goals and success already became measurable. To reach all future goals, a lot of work has to be done in a long term perspective. Politics on the other hand is quite short lived, creating the danger of changing perspectives on the energy targets with a shift in politics. The latter cannot be foreseen at the moment, but still remains as a factor of future uncertainty. The focus on renewable energy technologies, especially on a small scale, brings independence from energy imports, which is a highly valuable position from a political point of view. However, the government has to be careful to not take too many grants to realize the projects in order to not slip into dependencies on international banks or other countries. Furthermore the increase in independence from fossil fuel imports can create tensions with governments like Venezuela or Mexico, although they can be expected to play only a minor role. The strategy in the field of hydropower to demand a parliament controlled license for big power plants, while small power plants can be operated without big bureaucratic inconvenience is highly effective in empowering small communities, foster and facilitate rural electrification and still keep some control over power plants that demand a strong infrastructure provided by the government. All in all the strategy of the government of Nicaragua is very balanced and on a good way to develop small, independent facilities for rural electrification, while also improving the grid network and big electricity suppliers.

8 Conclusion

As assessed throughout this thesis, the four energy technologies solar energy, wind energy, electricity from biomass and hydropower already perform on a technologically quite high level, also showing a good performance when it comes to costs of investment, operation and maintenance. The big advantage of these four technologies is the possibility to run them independently and therefore use small facilities for rural electrification. All of the four energy technologies have their advantages and disadvantages, as pointed out in the qualitative and quantitative assessment with selected sustainability indicators comprising costs for investment, operation and maintenance, the energy return on energy investment (EROI), aftercare, employment, emissions, noise and health aspects, landscape, scarcity and political aspects. The summary of the assessment was presented in table 9 and will be outlined here again for completion.

Indicator	**Solar Energy**	**Wind Energy**	**Biomass**	**Hydropower**
Costs for Investment, Operation and Maintenance	Grid-Tie Solution: 0.07 to 0.18 Euros per kWh Off-Grid Solution: 0.10 to 0.26 Euros per kWh O&M: 41 Euros per kW-year	Grid-Tie Solution: 0.05 to 0.11 Euros per kWh O&M: 0.0012 to 0.0015 Euros per kWh Off-Grid Solution: 0.06 to 0.26 Euros per kWh	0.08 to 0.15 Euros per kWh	Large Installations: 0.03 Euros per kWh O&M: 0.006 Euros per kWh
EROI	3.75:1 to 10:1	24.6:1	8:1 to 40:1	11.2:1 to 267:1
Aftercare	Poses Challenges	Quite uncomplicated	Quite uncomplicated	Varies strongly depending on size and technology
Employment	800 to 2100 person-years per MWh	200 to 1200 person-years per MWh	200 to 450 person-years per MWh	Low Employment Creation

Emissions, Noise and Health Aspects	Intermediate Impact	Intermediate Impact	Intermediate Impact	Low Impact
Landscape	No severe interference	Intermediate interference	Varies strongly	Varies strongly
Scarcity	Intermediate Impact	Intermediate Impact	Intermediate Impact	Intermediate Impact

Table 12: Summarizing the results of the various indicators for the four investigated energy technologies (created by the author)

As table 12 shows, in the fields of cost and effectiveness (represented by the EROI), as well as in aftercare there is still potential for development within solar energy. However, this technology is still quite young and experiences high research and development efforts leading to a big potential for the future. Additionally solar energy performs very well when it comes to employment creation connected to the energy technology. Wind energy is facing problems in the fields of noise creation, as well as landscape, since it is often perceived as disturbing by neighbors in these regards. Employment creation is relatively low for electricity from biomass and especially for hydropower. When it comes to scarcity, all four technologies face certain problems. Therefore, a combination of different technologies is necessary to overcome shortages in supply. In this regard electricity from biomass and water can serve to supply the base current additionally to the peak current delivered by wind energy and solar energy. A general ranking between the four technologies as an overall result will not be provided, but left to the reader's opinion. However, one has to bear in mind that within the variety of the various indicators every technology has stronger and weaker aspects.

With respect to the electrification strategy of Nicaragua, a lot of effort is put into this field by the government to reach a degree of electrification of more than 90% in ten years, supplied by more than 95% renewable energy. In the past ten years the country has made a lot of progress towards this goal increasing the degree of electrification from 57.6% in 2006 to 69.8% in 2010. The strategy for the future will mainly rely on hydropower, biomass and also solar energy, once the investment costs for this technology decrease. The main focus in Nicaragua is on independent rural electrification and improvement of grid infrastructure. The strategy putting the focus on hydropower is a cheap and effective solution, causing little harm to the environment. However, when it comes to job creation, hydropower does not perform very well and also scarcity has to be taken into account, since there is a dry season in Nicaragua with almost no precipitation between January and May. For electrification with the help of biomass it is highly important to develop strategies to avoid competition of plant growth for biomass plants with agricultural land for food production. Additionally, emission controls and mitigation plans have to be effective for this technology.

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10 List of Tables

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12 Annex

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
A_t: Jährliche Gesamtkosten in Euro im Jahr t
M_{el}: Produzierte Strommenge im jeweiligen Jahr in kWh/Jahr
i: realer kalkulatorischer Zinssatz in %
n: wirtschaftliche Nutzungsdauer in Jahren
t: Jahr der Nutzungsperiode (1, 2, …n)

	A	B	C	D	E	F	G	H	I	J
3	Zeitraum in Jahren	20			Gesamtkosten 1	150,24	Stromoutput 1	5496	Zinssatz 1	0,938967136
4	Investitionskosten	11548			Gesamtkosten 2	153,2448	Stromoutput 2	5479,512	Zinssatz 2	0,881659283
5					Gesamtkosten 3	156,309696	Stromoutput 3	5463,073464	Zinssatz 3	0,827849092
6					Gesamtkosten 4	159,4358899	Stromoutput 4	5446,684244	Zinssatz 4	0,777323091
7					Gesamtkosten 5	162,6246077	Stromoutput 5	5430,344191	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	165,8770999	Stromoutput 6	5414,053158	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	169,1946419	Stromoutput 7	5397,810999	Zinssatz 7	0,643506215
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11					Gesamtkosten 9	176,0301054	Stromoutput 9	5365,472713	Zinssatz 9	0,567353228
12	**Case 1**				Gesamtkosten 10	179,5507075	Stromoutput 10	5349,376295	Zinssatz 10	0,532726036
13	**Scenario 1**	**0,227589784**			Gesamtkosten 11	183,1417217	Stromoutput 11	5333,328166	Zinssatz 11	0,50021224
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20					Gesamtkosten 18	210,3722708	Stromoutput 18	5222,331249	Zinssatz 18	0,321889685
21					Gesamtkosten 19	214,5797162	Stromoutput 19	5206,664255	Zinssatz 19	0,302243836
22					Gesamtkosten 20	218,8713106	Stromoutput 20	5191,044262	Zinssatz 20	0,283797029

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
A_t: Jährliche Gesamtkosten in Euro im Jahr t
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i: realer kalkulatorischer Zinssatz in %
n: wirtschaftliche Nutzungsdauer in Jahren
t: Jahr der Nutzungsperiode (1, 2, …n)

	A	B	C	D	E	F	G	H	I	J
3	Zeitraum in Jahren	20			Gesamtkosten 1	150,24	Stromoutput 1	10034,35	Zinssatz 1	0,938967136
4	Investitionskosten	11548			Gesamtkosten 2	153,2448	Stromoutput 2	10004,24695	Zinssatz 2	0,881659283
5					Gesamtkosten 3	156,309696	Stromoutput 3	9974,234209	Zinssatz 3	0,827849092
6					Gesamtkosten 4	159,4358899	Stromoutput 4	9944,311507	Zinssatz 4	0,777323091
7					Gesamtkosten 5	162,6246077	Stromoutput 5	9914,478572	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	165,8770999	Stromoutput 6	9884,735136	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	169,1946419	Stromoutput 7	9855,080931	Zinssatz 7	0,643506215
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15					Gesamtkosten 13	190,5406472	Stromoutput 13	9679,0146	Zinssatz 13	0,441016765
16					Gesamtkosten 14	194,3514602	Stromoutput 14	9649,977556	Zinssatz 14	0,414100249
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21					Gesamtkosten 19	214,5797162	Stromoutput 19	9506,09379	Zinssatz 19	0,302243836
22					Gesamtkosten 20	218,8713106	Stromoutput 20	9477,575508	Zinssatz 20	0,283797029

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
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	A	B	C	D	E	F	G	H	I	J
3	Zeitraum in Jahren	20			Gesamtkosten 1	150,24	Stromoutput 1	14007,25	Zinssatz 1	0,938967136
4	Investitionskosten	11548			Gesamtkosten 2	153,2448	Stromoutput 2	13965,22825	Zinssatz 2	0,881659283
5					Gesamtkosten 3	156,309696	Stromoutput 3	13923,33257	Zinssatz 3	0,827849092
6					Gesamtkosten 4	159,4358899	Stromoutput 4	13881,56257	Zinssatz 4	0,777323091
7					Gesamtkosten 5	162,6246077	Stromoutput 5	13839,91788	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	165,8770999	Stromoutput 6	13798,39813	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	169,1946419	Stromoutput 7	13757,00293	Zinssatz 7	0,643506215
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15					Gesamtkosten 13	190,5406472	Stromoutput 13	13511,22666	Zinssatz 13	0,441016765
16					Gesamtkosten 14	194,3514602	Stromoutput 14	13470,69298	Zinssatz 14	0,414100249
17					Gesamtkosten 15	198,2384894	Stromoutput 15	13430,2809	Zinssatz 15	0,388826524
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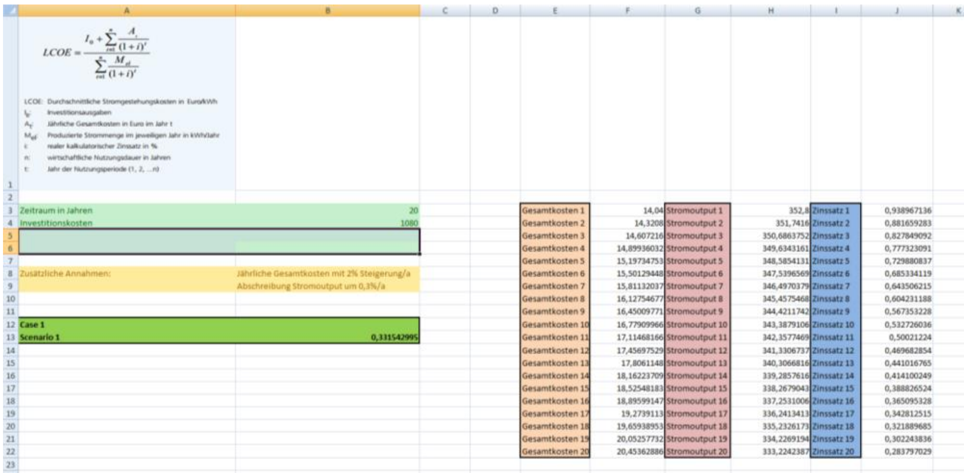
21					Gesamtkosten 19	214,5797162	Stromoutput 19	13269,84132	Zinssatz 19	0,302243836
22					Gesamtkosten 20	218,8713106	Stromoutput 20	13230,03179	Zinssatz 20	0,283797029



$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
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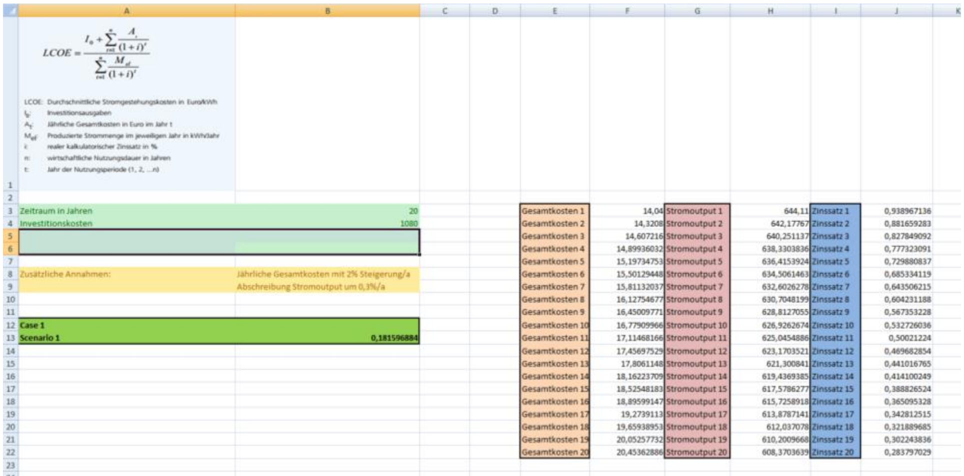
t: Jahr der Nutzungsperiode (1, 2, ...n)

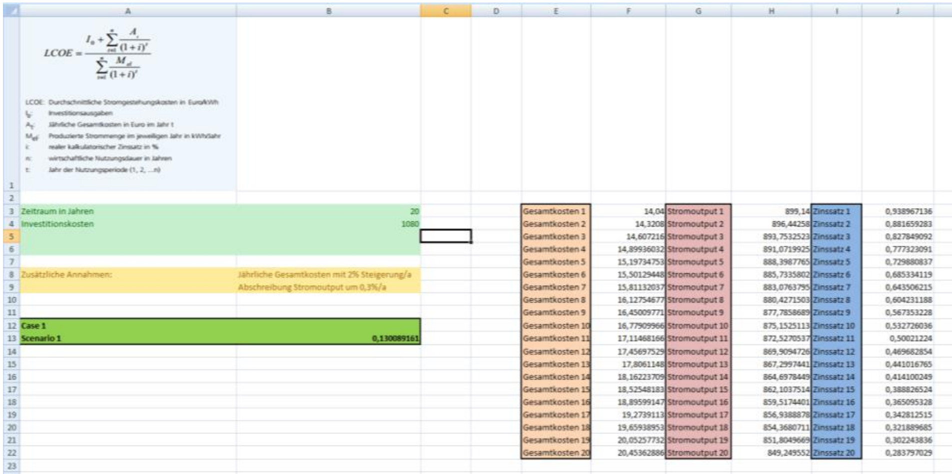
	A	B	C	D	E	F	G	H	I	J
2										
3	Zeitraum in Jahren	20			Gesamtkosten 1	14,04	Stromoutput 1	352,8	Zinssatz 1	0,938967136
4	Investitionskosten	1080			Gesamtkosten 2	14,3208	Stromoutput 2	351,7416	Zinssatz 2	0,881659283
5					Gesamtkosten 3	14,607216	Stromoutput 3	350,6863752	Zinssatz 3	0,827849092
6					Gesamtkosten 4	14,89936032	Stromoutput 4	349,6343161	Zinssatz 4	0,777323091
7					Gesamtkosten 5	15,19734753	Stromoutput 5	348,5854131	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	15,50129448	Stromoutput 6	347,5396569	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	15,81132037	Stromoutput 7	346,4970379	Zinssatz 7	0,643506215
10					Gesamtkosten 8	16,12754677	Stromoutput 8	345,4575468	Zinssatz 8	0,604231188
11					Gesamtkosten 9	16,45009771	Stromoutput 9	344,4211742	Zinssatz 9	0,567353228
12	**Case 1**				Gesamtkosten 10	16,77909966	Stromoutput 10	343,3879106	Zinssatz 10	0,532726036
13	**Scenario 1**	**0,331542995**			Gesamtkosten 11	17,11468166	Stromoutput 11	342,3577469	Zinssatz 11	0,50021224
14					Gesamtkosten 12	17,45697529	Stromoutput 12	341,3306737	Zinssatz 12	0,469682854
15					Gesamtkosten 13	17,8061148	Stromoutput 13	340,3066816	Zinssatz 13	0,441016765
16					Gesamtkosten 14	18,16223709	Stromoutput 14	339,2857616	Zinssatz 14	0,414100249
17					Gesamtkosten 15	18,52548183	Stromoutput 15	338,2679043	Zinssatz 15	0,388826524
18					Gesamtkosten 16	18,89599147	Stromoutput 16	337,2531006	Zinssatz 16	0,365095328
19					Gesamtkosten 17	19,2739113	Stromoutput 17	336,2413413	Zinssatz 17	0,342812515
20					Gesamtkosten 18	19,65938953	Stromoutput 18	335,2326173	Zinssatz 18	0,321889685
21					Gesamtkosten 19	20,05257732	Stromoutput 19	334,2269194	Zinssatz 19	0,302243836
22					Gesamtkosten 20	20,45362886	Stromoutput 20	333,2242387	Zinssatz 20	0,283797029
23										



$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
A_t: Jährliche Gesamtkosten in Euro im Jahr t
M_{el}: Produzierte Strommenge im jeweiligen Jahr in kWh/Jahr
i: realer kalkulatorischer Zinssatz in %
n: wirtschaftliche Nutzungsdauer in Jahren
t: Jahr der Nutzungsperiode (1, 2, ...n)

	A	B	C	D	E	F	G	H	I	J
2										
3	Zeitraum in Jahren	20			Gesamtkosten 1	14,04	Stromoutput 1	644,11	Zinssatz 1	0,938967136
4	Investitionskosten	1080			Gesamtkosten 2	14,3208	Stromoutput 2	642,17767	Zinssatz 2	0,881659283
5					Gesamtkosten 3	14,607216	Stromoutput 3	640,251137	Zinssatz 3	0,827849092
6					Gesamtkosten 4	14,89936032	Stromoutput 4	638,3303836	Zinssatz 4	0,777323091
7					Gesamtkosten 5	15,19734753	Stromoutput 5	636,4153924	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	15,50129448	Stromoutput 6	634,5061463	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	15,81132037	Stromoutput 7	632,6026278	Zinssatz 7	0,643506215
10					Gesamtkosten 8	16,12754677	Stromoutput 8	630,7048199	Zinssatz 8	0,604231188
11					Gesamtkosten 9	16,45009771	Stromoutput 9	628,8127055	Zinssatz 9	0,567353228
12	**Case 1**				Gesamtkosten 10	16,77909966	Stromoutput 10	626,9262674	Zinssatz 10	0,532726036
13	**Scenario 1**	**0,181596884**			Gesamtkosten 11	17,11468166	Stromoutput 11	625,0454886	Zinssatz 11	0,50021224
14					Gesamtkosten 12	17,45697529	Stromoutput 12	623,1703521	Zinssatz 12	0,469682854
15					Gesamtkosten 13	17,8061148	Stromoutput 13	621,300841	Zinssatz 13	0,441016765
16					Gesamtkosten 14	18,16223709	Stromoutput 14	619,4369385	Zinssatz 14	0,414100249
17					Gesamtkosten 15	18,52548183	Stromoutput 15	617,5786277	Zinssatz 15	0,388826524
18					Gesamtkosten 16	18,89599147	Stromoutput 16	615,7258918	Zinssatz 16	0,365095328
19					Gesamtkosten 17	19,2739113	Stromoutput 17	613,8787141	Zinssatz 17	0,342812515
20					Gesamtkosten 18	19,65938953	Stromoutput 18	612,037078	Zinssatz 18	0,321889685
21					Gesamtkosten 19	20,05257732	Stromoutput 19	610,2009668	Zinssatz 19	0,302243836
22					Gesamtkosten 20	20,45362886	Stromoutput 20	608,3703639	Zinssatz 20	0,283797029
23										



$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE: Durchschnittliche Stromgestehungskosten in Euro/kWh
I_0: Investitionsausgaben
A_t: Jährliche Gesamtkosten in Euro im Jahr t
M_{el}: Produzierte Strommenge im jeweiligen Jahr in kWh/Jahr
i: realer kalkulatorischer Zinssatz in %
n: wirtschaftliche Nutzungsdauer in Jahren
t: Jahr der Nutzungsperiode (1, 2, ...n)

	A	B	C	D	E	F	G	H	I	J
2										
3	Zeitraum in Jahren	20			Gesamtkosten 1	14,04	Stromoutput 1	899,14	Zinssatz 1	0,938967136
4	Investitionskosten	1080			Gesamtkosten 2	14,3208	Stromoutput 2	896,44258	Zinssatz 2	0,881659283
5					Gesamtkosten 3	14,607216	Stromoutput 3	893,7532523	Zinssatz 3	0,827849092
6					Gesamtkosten 4	14,89936032	Stromoutput 4	891,0719925	Zinssatz 4	0,777323091
7					Gesamtkosten 5	15,19734753	Stromoutput 5	888,3987765	Zinssatz 5	0,729880837
8	Zusätzliche Annahmen:	Jährliche Gesamtkosten mit 2% Steigerung/a			Gesamtkosten 6	15,50129448	Stromoutput 6	885,7335802	Zinssatz 6	0,685334119
9		Abschreibung Stromoutput um 0,3%/a			Gesamtkosten 7	15,81132037	Stromoutput 7	883,0763795	Zinssatz 7	0,643506215
10					Gesamtkosten 8	16,12754677	Stromoutput 8	880,4271503	Zinssatz 8	0,604231188
11					Gesamtkosten 9	16,45009771	Stromoutput 9	877,7858689	Zinssatz 9	0,567353228
12	**Case 1**				Gesamtkosten 10	16,77909966	Stromoutput 10	875,1525113	Zinssatz 10	0,532726036
13	**Scenario 1**	**0,130089161**			Gesamtkosten 11	17,11468166	Stromoutput 11	872,5270537	Zinssatz 11	0,50021224
14					Gesamtkosten 12	17,45697529	Stromoutput 12	869,9094726	Zinssatz 12	0,469682854
15					Gesamtkosten 13	17,8061148	Stromoutput 13	867,2997441	Zinssatz 13	0,441016765
16					Gesamtkosten 14	18,16223709	Stromoutput 14	864,6978449	Zinssatz 14	0,414100249
17					Gesamtkosten 15	18,52548183	Stromoutput 15	862,1037514	Zinssatz 15	0,388826524
18					Gesamtkosten 16	18,89599147	Stromoutput 16	859,5174401	Zinssatz 16	0,365095328
19					Gesamtkosten 17	19,2739113	Stromoutput 17	856,9388878	Zinssatz 17	0,342812515
20					Gesamtkosten 18	19,65938953	Stromoutput 18	854,3680711	Zinssatz 18	0,321889685
21					Gesamtkosten 19	20,05257732	Stromoutput 19	851,8049669	Zinssatz 19	0,302243836
22					Gesamtkosten 20	20,45362886	Stromoutput 20	849,249552	Zinssatz 20	0,283797029
23										

Original Interview Luis Molina

1. ¿Cuál es el grado actual de la electrificación en Nicaragua? ¿Cuál ha sido el desarrollo en los últimos diez años?
   - *Durante el período 2007-2011, el índice de electrificación pasó del 53% en el año 2006 a casi el 70% en el año 2011, lo que equivale a un incremento mayor al 3%promedio anual.*

   - *Incrementar cobertura servicio eléctrico en 20% adicional, para mejorar la calidad y nivel de vida de aproximadamente 1.2 millones de habitantes, al facilitar acceso a servicios básicos y nuevas oportunidades productivas, para lo cual se tienen programados US$185.4 millones.*

2. ¿Existe una estrategia nacional / regional para la electrificación rural? En caso afirmativo, ¿puede describir la estrategia y qué importante están las energías renovables?

   a. *El Componente 1: Electrificación Rural por Extensión de Redes*

      Tiene por objetivo incrementar la cobertura eléctrica a nivel nacional, garantizando la electrificación de 117,790 viviendas ubicadas en aproximadamente 3,600 comunidades a través de extensiones y repotenciaciones de redes de distribución, es decir, las inversiones están dirigidas a la construcción de líneas primarias de distribución (conductores. postes, estructuras), líneas secundarias con sus transformadores de distribución, mano de obra y transporte, así como las acometidas, medidores e instalaciones internas de los usuarios. Se plantea a nivel nacional la construcción de 6,755 kilómetros de red, esto incluye 1,256 kilómetros de red trifásica que reforzarán el sistema de distribución actual. Para su ejecución se han creado ocho zonas geográficas y se ha considerado un proyecto para cada zona.

   b. *El Componente 3: Electrificación Rural con Fuentes Renovables*

      Expansión de Cobertura en Zonas Aisladas con Fuentes Renovables, está orientado a solucionar el acceso a la electricidad en las zonas aisladas donde la electrificación mediante extensiones de redes no es viable debido a:

(i) la distancia desde estas zonas a la red de distribución.

(ii) la alta dispersión de la población y

(iii) una demanda relativamente baja.

Concretamente este componente incluye la construcción de pequeñas centrales hidroeléctricas. micro turbinas, otras soluciones de energía renovable y la ampliación de redes de distribución en el área rural.

3. ¿Hay una estimación de costos para la estrategia de electrificación rural?

   Objetivos del PROGRAMA NACIONAL DE ELECTRIFICACIÓN SOSTENIBLE Y ENERGÍA RENOVABLE (P.N.E.S.E.R.)

   a. *US$112.6 millones corresponden al Componente 1, para la electrificación de las zonas rurales por extensión de redes;*
   b. *US$19.4 millones del Componente 3, para el incremento de la cobertura eléctrica a través de fuentes renovables en zonas fuera de red;*
   c.

4. ¿Cuáles son los criterios decidiendo que tecnología energética está utilizada para la electrificación rural?
   - *Distancias entre el punto más cercano de una red de distribución y la población a servir.*
   - *Potencial del recurso renovable (ríos, principalmente para las hidroeléctricas).*
   - *Fotovoltaicos para demandas pequeñas y dispersas.*

5. ¿Observó beneficios o problemas sociales y económicos de la electrificación rural?.
   - *Beneficios:*
     - *en la mayoría de los casos, el acceso a la electricidad por primera vez en la vida de una familia, por ejemplo.*
     - *Electrificación de escuelas, de centros de salud (mantenimiento de vacunas, medicamentos, alimentos, etc.).*
   - *Problemas*
     - *Económicos: principalmente con la extensión de redes e hidroeléctricas. Su sostenibilidad para la gestión de sus usuarios.*

- ○

6. ¿Qué usted piense es la tecnología energética más apropiado para la electrificación rural? ¿Y por qué?.
    - *Por su abundancia los sistemas solares, pero siguen siendo bastante costosos.*
    - *En algunos sitios y sobre todos en las áreas rurales y no atendidas por la distribuidora comercial, el potencial hídrico para nano, micro y pequeñas centrales hidroeléctricas es bastante considerable.*
    -
7. ¿Existe también una estrategia para el tiempo después de la utilización de las tecnologías energéticas?

8. ¿Qué es la importancia de proyectos CDM (=Clean Development Mechanism) en la electrificación rural?

    a. *Es un valor agregado que todavía no hemos podido aprovechar, debido principalmente a los costos de transacción. Sin embargo, se puede aprovechar como un programa, desde la institución que los planifica y ejecuta.*

9. ¿Existe una coordinación con otros países en la electrificación rural?
    - *Están establecidas en la Estrategia energética sustentable 2020.*
    -
10. ¿Usted piense que la electrificación rural es un de los desafíos mas importantes de nuestro tiempo? ¿Y por qué?.

    a. En el caso de Nicaragua si, porque el actual gobierno encontró un índice de electrificación de solo el 53% uno de los más bajos de la región centroamericana, pero en tan solo 5 años pasó al 70% y se pretende alcanzar un 20% más en los próximos 5 años.

11. ¿Cómo está Nicaragua en 10 años?
    a. *En el tema de energía, Nicaragua estará aproximándose al pico mas alto del cambio radical de la actual matriz eléctrica, mayoritariamente dependiente de combustibles fósiles (65-67%), a una matriz amigable con el medio ambiente, donde predominarán las fuentes renovables (mas del 95%).*
    b. *El índice de cobertura será mayor del 90%.*

c. *Un sistema energético fortalecido, confiable y amigable con el medio ambiente.*
d. *Demanda nacional cubierta y exportando.*