

# Assessment of Sustainability Indicators for Off Grid Energy System

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**Abstract:** *Due to the fact that reliable and sustainable electricity supply has been regarded as essential for economic development, Renewable energy resources are a favorable alternative for energy supply. Commonly Renewable energy systems use solar, wind, and hydro energy sources. In order to handle their fluctuating nature, these sources can be integrated together. These systems use different energy generators in combination, by this maintaining a stable energy supply in times of shortages of one the energy resources. For instance, winds are usually relatively strong in winter and solar radiation is higher in summer. A balanced system provides stable outputs from sources such as these and minimizes the dependence of the output upon seasonal changes. Main hope attributed to these systems is their good potential for economic development.*

*This paper discusses the sustainability of integrated energy systems for off grid electrification in developing countries by integrating ecological and economic aspects. It is concluded that hybrid systems are suitable to achieve ecological objectives, since integrated systems are an environmental sound technology with high quality electricity supply, by this offering a good potential for economic development.*

**Keywords:** Emissions, Energy Cost, Renewable energy, Sustainability

## 1. Introduction

Around 20% people world-wide do not have access to modern energy services. Global consumption of primary energy resources is likely to increase; with the increase being mainly based on fossil fuels [1]. The effect of increasing global CO<sub>2</sub>-emissions will be the consequence. Today, energy services are indeed seen as a major driving force to economic development, but additional measures are required as well. Better energy services lead to higher availability of jobs, productivity increases or improved economic opportunities. The challenge is to improve access to modern energy services without increasing reliance on fossil fuels. This challenge can be met with a focus on decentralized systems of electrification. Main hope is here attributed to the application of renewable energies as wind, solar and hydro power, which is especially suited for decentralized electricity generation. Renewable energies use environmentally sound technologies, their consumption does not result in the depletion of primary resources and effect climate is better than other currently used options. A major Concern related to the application of renewable energies in decentralized systems is unstable nature of energy supply due to the fluctuating nature of these resources. An option to solve this problem is to integrate these energy generations. A number

of researches have been done on this approach of electricity generation.

However, the question is to which extent these systems satisfy the expectations with regard to sustainable development considering the ecological & economic aspects, has not been investigated yet and shall be objective of this paper.

## 2. Off Grid Energy System

Off Grid Energy System can become competitive due to lower investments and maintenance costs compared to large scale electrification by expanding interconnected grids [2]. Different technological options are in practice, most commonly diesel generating sets and renewable energies.

### 2.1. Diesel Generating Sets

Diesel generators have been the traditional way to address the problem of the lack of electricity. They can be designed for different capacities, to satisfy the needs of the consumers. Diesel generators have problems with short durability, which is due to the fact that they work very inefficiently when running just at fractions of their rated capacity. Typically, the efficiency of operation is between 25-35%. Moreover, frequent start-up and shut-down procedures decrease their

lifetime as well and the transportation of diesel fuel can result in severe environmental damage.

## 2.2 Renewable Energy System

Renewable Energy technologies include energy from solar, wind and hydro energy sources. The power produced by the wind and hydro generators is an AC voltage that can then be transformed into DC to charge the battery. The controller protects the battery from overcharging or deep discharging. As high voltages can be used to reduce system losses, an inverter is normally introduced to transform the low DC voltage to an AC voltage of 110V or 230V, depending upon the power system used in the region.

### 2.2.1 Solar Energy System

The solar resource is determined by the solar radiation received at a particular site in kWh/m<sup>2</sup>. The principal feature of solar radiation is the strong seasonal dependence with a minimum in winter and maximum in summer. Solar radiation consists of direct and diffuse components. Energy captured from direct solar radiation depends on the tilt angle of the collector, and is attenuated by atmospheric effects such as cloud and pollution. Diffuse irradiance on the other hand is due to reflection and scattering and is dependent on the surroundings and atmospheric effects, and the energy captured is not dependent on the tilt angle of the collector. Although the maximum direct irradiance can be calculated, the actual direct irradiance plus the amount of diffuse irradiance, or the global irradiance, is difficult to calculate and is usually estimated from historical records. Maximum annual energy collection can be achieved by setting the collector tilt angle to the angle of latitude of the site [3].

### 2.2.2 Wind Energy System

The energy that a wind turbine will produce depends on its wind speed power curve and the wind speed frequency distribution at the installation site. The wind frequency distribution measured at a height of 30 m above ground level, demonstrating that a high frequency over 800 hours per year occurs for the wind speed range of 3.2 m/s to 7.9 m/s [3].

### 2.2.3 Hydro Energy System

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for micro hydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity.

## 2.3 Integrated Energy System

One of the main problems of solar as well as wind energy is the fluctuation of energy supply, resulting in intermittent delivery of power and causing problems if supply continuity is required. This can be avoided by the use of hybrid systems. A system using complementary energy supply technologies has the advantage of being able to supply energy even at times when one part of the hybrid system is unavailable [4].

A common hybrid system for the application in developing countries generally consists of the following main components:

1. A primary source of energy, i.e. a renewable energy resource;
2. A secondary source of energy for supply in case of shortages, i.e. a diesel genset;
3. A storage system to guarantee a stable output during short times of shortages

## 3. IMPACT ANALYSIS

Although several projects with off grid energy systems have been carried out already, surveys investigating these systems are so far very limited. In fact, no ecological & economic aspects studied together for finding the sustainability of integrated energy systems in developing countries. This paper led to the idea of discussing the application of integrated systems in developing countries to compare their sustainability relative to other likely scenarios of rural electrification. Aim is to analyze the impacts of electrification systems in developing countries relative to the different technological integrated energy options. In doing so, it is tried to find out to which degree integrated system likely provide a sustainable option for off grid energy electrification.

### 3.1. Sustainability Indicators

Indicators are used to give a comprehensive view on sustainability, summarizing complex information and, thus, creating a transparent and simplified system to provide information on the degree of sustainability both to decision-makers and the interested public. Relative comparison of different technologies, evaluating their current state of sustainability relative to each other, and also offering a comprehensive view on the their weak points from a perspective of sustainability. Additionally, the results being obtained by such an indicator set can provide a data base for the evaluation of the sustainability of a society as a whole [5].

Sustainability aspects considered – ecological and economic issues broken down to a set of criteria describing these issues. Next step, a set of indicators measuring these criteria was developed. These indicators weighted relative to their importance for the respective aspect.

The weightage of the indicators is explained as follows:

- For the ecological aspect, emphasis is given to climate and resource protection due to their high importance for environmental sustainability.
- For the economic aspect, the criteria of low costs and tariffs as well as maintenance are seen as most important criteria because of their high influence on the success of electrification projects.

**Table 3.1:** Indicators for the Assessment of Energy Technologies

Aspects	Scenario	Indicator	Weightage
Ecology	Climate Protection	Greenhouse Gas Emissions/kWh	0.3
		Emissions of Air Pollutants/kWh	0.3
	Noise Reduction	Noise Pollution	0.1
Economic Issues	Low Costs and Tariff	Investment Costs/W	0.2
		Electricity Generating Costs/kWh	0.3
	Maintenance	Requirements	0.25
	Economic Independence	Supply Security	0.1

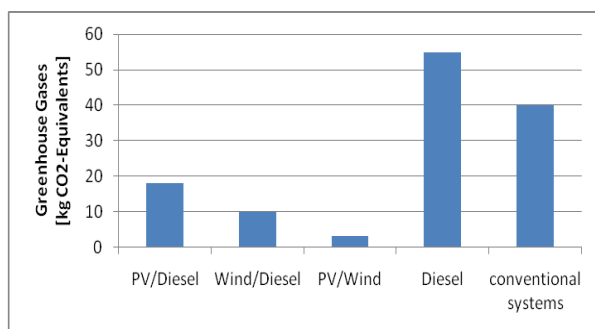
## 4. Analysis of Sustainability

### 4.1. Ecological Aspect

The degree of climate sustainability is here determined with two different indicators,

- Greenhouse Gas Emissions per kWh, and
- Emissions of Air Pollutants per kWh.

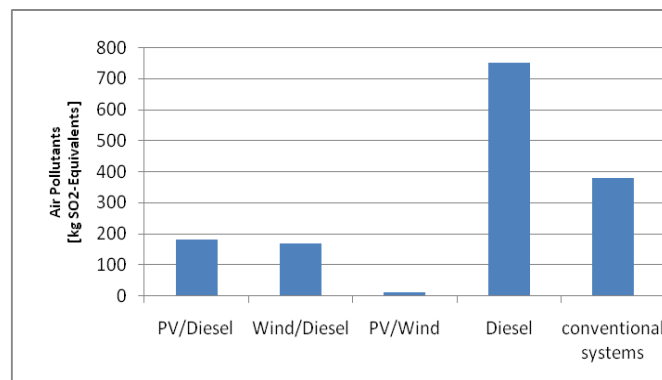
Greenhouse gas (GHG) emissions are here measured in CO<sub>2</sub>-Equivalents per kWh. CO<sub>2</sub>-Equivalents aggregate the different greenhouse gas emissions as CO<sub>2</sub>, CH<sub>4</sub> or N<sub>2</sub>O<sub>14</sub> due to their contribution to the greenhouse effect over a time frame of 100 years. All of these gases are emitted as products of combustion processes [6].



**Figure 1:** Greenhouse Gas Emissions per kWh

The analysis of GHG emissions on the basis of the comparative assessment scheme shows that hybrid systems

can be assessed as being supportive for the objective of decreasing GHG emissions compared to conventional energy systems. Purely renewable hybrid systems as PV/Wind are here performing even better than diesel based systems.



**Figure 2:** Emissions of Air Pollutants per kWh

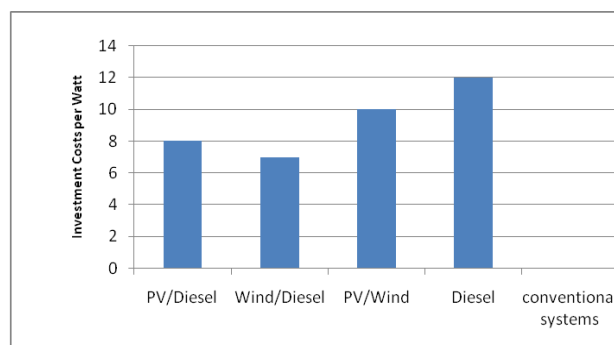
Diesel based system result in the highest amount of air pollutants due to NO<sub>x</sub> emissions in the combustion process. They are therefore strongly disadvantageous in this respect. While PV/Wind almost do not result in any emission of air pollutants due to the absence of a combustion process

### 4.2. Economic Aspect

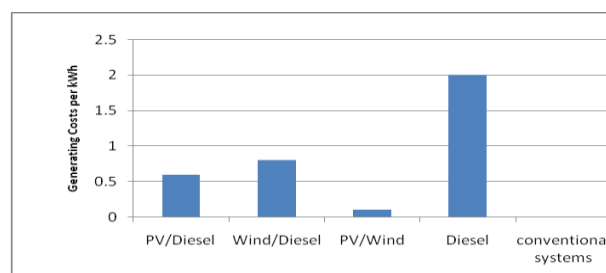
The question of low costs and tariffs mainly depends on three different aspects:

- Investment costs per W,
- Electricity generating costs per kWh,

Investment costs must be seen as a major hurdle for the implementation of electrification projects. If first investment is too high and requires substantial financial expenditure, potential customers are likely to decide for a cheaper option, not accounting for the fact that electricity generating costs in the end might be lower [5].



**Figure 3:** Investment costs per Watt



**Figure 4:** Electricity generating costs per kWh

## 5. Conclusion

The conclusion of the assessment of the indicators is aggregated according to the weight, which was attributed to the individual indicators. From which, it is tried to come to a conclusion on the degree of integrated renewable energy systems are likely to be a sustainable option for off grid electrification

The analysis of the ecological aspect shows good potential for integrated renewable systems. Especially compared to conventional electrification solutions, integrated systems indeed have the potential to reduce emissions of greenhouse gases and air pollutants. Integrated systems have advantages with regard to supply security compared to other decentralized options. But high investment costs, high electricity generating costs and the problem of high requirements on maintenance are main problems associated with the application of integrated renewable systems.

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