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Village electrification technologies—an evaluation of photovoltaic cells and compact fluorescent lamps and their applicability in rural villages based on a Tanzanian case study

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Abstract

Electrification of remote sites in developing countries is often realised trough diesel generator sets and an electric distribution network. This was also the technology used in the village Urambo, where the first rural electrification co-operative in Tanzania was started in 1994. Climate change however calls for decreased fossil fuel combustion worldwide and new technologies have been further developed since the erection of the diesel generator sets in Urambo. It is therefore not obvious that electrification of other rural areas shall follow the Urambo example.

In this article, the situation for 250 electricity consumers in Urambo will be demonstrated and the implications for them of introducing new technologies will be evaluated. Technology options regarded in the study are individual photovoltaic (PV) power systems and either incandescent lamps, tube lights or compact fluorescent lights (CFLs) supplied by diesel generation. The different options have been evaluated with respect to consumer costs and environmental impact.

The results of the comparison show that PV generation is able to compete with diesel generation if combined with incandescent lamps, but not when tube lights or CFLs are used in the conventional supply system. It should be noted, however, that while the diesel option offer financially more attractive solutions, individual PV systems do not result in any CO_2 emissions. Furthermore, PV systems normally have a higher reliability. However, since the diesel option is not only cheaper but also offers a wider range of energy services and facilitates, future connection to the national electric grid, the conclusion is that this is preferable before individual PV systems for communities similar to Urambo, if the consumers shall pay the full cost of the service.
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1. Background

Since the first diesel generation set was installed in the small town of Urambo in Tanzania in 1985, the situation for rural electrification has changed:

- power sector reforms have been introduced which are resulting in a more developed deregulated energy market,
- global energy policies are increasingly focussed on CO_2 reduction, and
- technology development offers new options; for example, photovoltaic (PV) systems and energy efficient lighting devices.

During the years, experiences on load development in rural areas have also somewhat increased, even if knowledge is still scarce. Load development is often slower than anticipated and the dominating energy end-use devices are commonly lighting, radios and TV's rather than directly income-bringing devices. While the increased standard of living is as well an aim, it is often assumed when launching the scheme that electricity will be used for productive activities in agricultural, industrial or other sectors.

In view of this situation, it becomes imperative to investigate what technologies are most appropriate for villages to be electrified in the near future. The

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technologies considered for rural electrification in Tanzania are still more or less the same as those used in the mid-1970s, i.e. predominately extension of the national grid. Sites where connection to the national grid cannot be justified are most commonly equipped with two or three suitably sized diesel generator sets. The village Urambo is a typical example of such a case.

There are however several reasons why other technologies should also be considered. The high cost for supplying electricity to the consumers in newly electrified rural areas calls for careful examination of possible cheaper technologies. This should be of interest regardless of who is actually paying: the consumer, the national utility or an international donor. Moreover, it is difficult to attract bank loans or development funds for projects unless they are designed to be financially viable.

From the national economy point of view, rather than automatically expanding the use of fossil fuels in remote areas, promotion of indigenous renewable energy sources is an aim since imported fossil fuels amount to about half of Tanzania's total export earnings. Another reason for examining other options is the growing concern about the global environmental effects of increasing use of fossil fuels. Many donors' energy policy reflects the international commitments to freeze and eventually decrease the use of such fuels.

2. Approach

Electricity service needs in a large village like Urambo where poverty is still a prevailing problem, are deemed to increase. The resources for Tanzania to invest in oversized supply systems are, however, highly limited. In this article, the implications of the experiences from Urambo for the potential of two technologies, namely compact fluorescent lamps (CFLs) and PV electricity generation will be discussed. The first of these can give lower costs for lighting in ordinary high voltage networks. The second can either on its own be a cost-efficient electricity supply option for some applications or when equipped with a converter, supply electricity to the common grid. Also, PV electricity generation would certainly comply with greenhouse gas mitigation policies, since it is not associated with any emission of polluting substances when it is used. For the comparison between these options, the costs for power generation and distribution, excluding service line, house wiring and meters, are based on those for new equipment.[1] In order to view comparative options, we design both diesel and PV systems assuming 100% degree of utilisation during 4–5 h per evening. It is important to realise however, that while the PV system is designed for a certain Wh demand, the diesel option is designed based on peak load. The diesel option becomes more expensive should the number of consumers decrease. On the other hand, a diesel system based on only 5 h daily utilisation allows for lower specific costs, should the utilisation increase.

For the reason of technical and financial comparability, it is the connected consumers' lighting demand that is in focus when evaluating technology options in this article. Other electricity end uses will be considered in the discussion on possibilities for industrial development and systems expansion. In order to prepare a base for comparison between technologies, lighting demand will be expressed in average continuous light output in lumen during an evening where a high load and a low load case will be considered. Further, the environmental impacts associated with the different options will be explored and especially their contribution of CO_2. Global warming is one strong argument for why developing countries should leapfrog the technical design of their infrastructure and opt for renewable technologies.

A wide range of electricity generation technologies exist on the market today, and many retailers provide hybrid systems, i.e. a combination of technologies, such as diesel/PV systems equipped with converters, hydro/wind systems, etc. Moreover, energy efficient end-use devices develop continuously, including as well entire industrial processes as single household appliances. There are certainly opportunities for investors in developing energy infrastructures to make use of these new technologies. In each specific case, it is likely that a combination of solutions is the most suitable. For clarity, however, we have sought to separate the different solutions as far as possible so that their comparative features are independent. No hybrid systems are therefore elaborated on.

3. Load development in Urambo

Load development with almost exclusively lighting during the first years is typical for rural electrification projects in developing countries, and this is commonly a barrier for the power system to sustain. Refer, for example, to Gerger and Gullberg (1997) or Kjellström et al., (1992). Often, industrial development, or some other income-bringing use of electricity is necessary. From a technical perspective there are two main arguments for promoting income-bringing uses of electricity within a power system. For one, a higher load that is also more evenly spread over time results in lower per unit electricity prices as installed equipment is more efficiently utilised, i.e. the system load factor is

[1] For investment costs see another article in this publication; "Electrification co-operatives bring new light to rural Tanzania" (Kjellström et al., 2004).

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