



OR for RURAL ELECTRIFICATION projects in developing countries

OR has traditionally focused on the optimization of commercial companies' problems in developed countries. However, it can also be used to solve social problems and to promote human development. OR for development deals with classical routing, location, planning and scheduling problems, as well as social constraints and requirements. These OR applications are mathematically as challenging as any other and, in our opinion, can be much more inspiring and fairer. Here, we present the location and network problem of designing electrification projects for rural communities.

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Electricity for development

In 2000, the United Nations established the Millennium Development Goals (MDGs): 8 targets to meet to assure human development around the world [1]. The MDGs set objectives to tackle key issues such as extreme poverty and hunger, primary school education, gender equality, maternal health, major diseases (AIDS, malaria, etc.) and environmental sustainability. None of the goals explicitly mentions the right to access energy and electricity, but it is accepted that a guarantee of energy/electricity access is indeed needed to fulfill the goals. In fact, there is a clear relation between electricity consumption and the Human Development Index (HDI), as shown in Figure 1 [2].

The recently published report entitled Energy Services for the Millennium Development Goals [3] states that it is necessary to "Provide access to modern energy services (mechanical power and electricity) at the community level to all communities" in order to achieve the MDGs, which were supposed to be fulfilled by 2015.

In 2004, over 2.500 million people depended on traditional biomass for cooking and heating, and about 1.6 billion lacked access to electricity [4], so a lot of work and effort is still needed. This lack of electricity particularly affects rural areas in developing countries.

The conventional strategy for increasing access to electricity in rural areas is to extend the national electrical grid. However, in some regions, due to an extensive terrain, a complex geography and the dispersed nature of villages, the expansion of the electrical grid would reach a limited number of people. Under these circumstances, autonomous electrification systems that use renewable energy sources are a suitable alternative to provide electricity to isolated communities, and are often much cheaper than grid extension. Moreover, one of their main advantages is that they use local resources and avoid external dependence, which can promote the long-term sustainability of the projects.

The available technical options include micro hydro, photovoltaic systems and micro wind. When water is available, micro hydro projects are usually the best option as they provide 24 h energy at a low cost per kWh. When there is no water, photovoltaic systems have frequently been chosen, although they are an expensive option. Wind power is also worth taking into consideration, though it has been used infrequently to date. In windy regions, wind systems can be much cheaper than photovoltaic ones. Moreover, wind turbines can be locally manufactured. The existence of local manufacturers facilitates system maintenance and has the advantage of promoting enterprise development. On the other hand, micro wind projects may be more difficult to design, especially due to the resource assessment that constrains the location of wind turbines. Thus, the key issues in decision-making in the design of an electrification project include the available resources, the technical capabilities of promoters, and the socioeconomic conditions of the region and the community.

Wind electrification projects

Wind power has recently been used in electrification projects in Cajamarca, a region in the northern highlands of Peru [5]. The first demonstration of a community micro wind project in Peru took place in the village of El Alumbre. The project was promoted by the following non-governmental organizations (NGOs): Soluciones Prácticas – Intermediate Technology Development Group (Peru), Engineers without Borders – Catalonia (Spain), and Green Empowerment (USA) [6].

El Alumbre is located at 3,850 meters above sea level. It has 151 inhabitants and 33 families, who live in an area of 3.5 km². People in El Alumbre are mainly engaged in subsistence agriculture and livestock rearing. Most families subsist on dairy cows, sheep, guinea pigs, barley and native tubers. In the centre of the town are primary and secondary schools, a health centre with 3 permanent nurses and a church. >>

Figure 1. Human Development Index (HDI) according to electricity consumption (kWh) per capita.

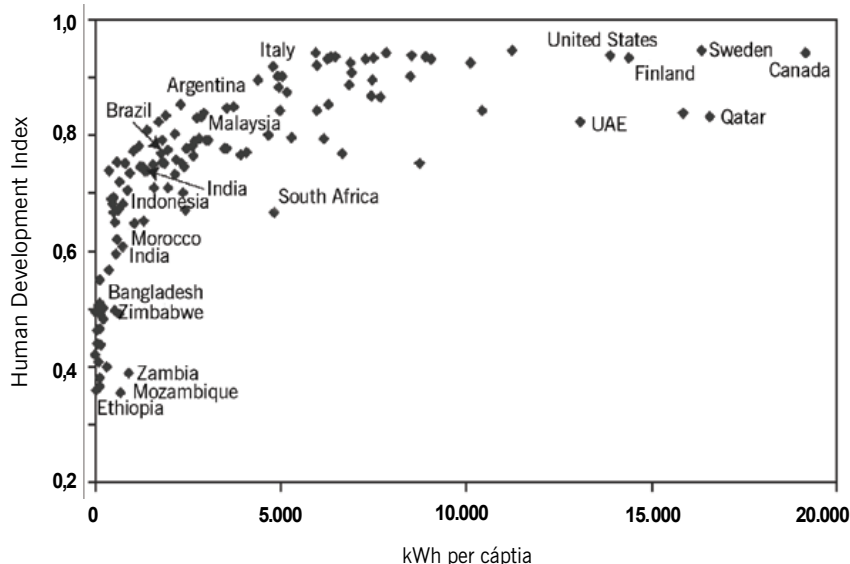




Figure 2. Centre of El Alumbre, one IT-PE-100 installed at a household and one SP-500 installed at the school.



Figure 3. Installation process of the turbines and the battery controllers.

The electrification project was designed to cover basic household needs and community services (the schools and the health center). In the first phase, 21 wind turbines of 100 W (IT-PE-100) were installed in 21 homes and a wind turbine of 500 W (SP-500) was installed in the school. In a second phase, 12 more family systems and a 500 W wind turbine at the health center were installed. Both types of turbine were models developed by ITDG and manufactured by local companies in Lima (Figure 2). At each point of consumption, the equipment included a controller, a battery bank and an inverter to facilitate the use of AC equipment. The inhabitants of El Alumbre actively participated in the installation process (Figure 3).

Wind turbines installed in each home cover the domestic use of electricity for 5 hours per day. Households use the electricity for lighting, weaving or knitting in the evenings, studying, listening to the radio and charging cell phones. Energy in the school powers four computers (with electronic encyclopedias) and a DVD for educational videos. The health centre, which provides care for people in 4 communities, now has electricity for lights and a vaccine refrigerator. As a result of the wind turbines, families state that they spend less on other energy sources such as kerosene or candles. Moreover, families have been using energy in a direct or indirect way to establish small business such as a radio station, a sweater manufacturer, and a cheese producer.

Improving wind electrification projects

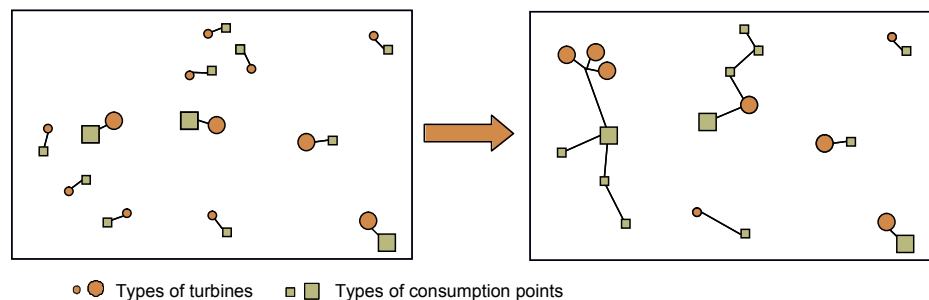
Due to the characteristic dispersion of households in communities, wind projects in the Andean region tend to install individual wind turbines at each consumption point. However, this solution scheme may have some potential limitations. First, in mountainous areas, the wind resource is not uniform, and may vary significantly from one point to another point of the same village. Therefore, the shortage of wind at some points may restrict the electricity consumption of some families. Furthermore, small individual turbines are proportionally more expensive than more powerful ones. Finally, individual systems are not easily adaptable to increases in demand: small increases may require the replacement or duplication of the entire system.

Alternatively, we propose a design solution that considers both individual generators and micro grids to ensure to meet the energy demand (Figure 4). Consumption points that are close to

each other could share the energy generated by more powerful turbines at a lower cost/energy rate. However, individual systems may still be the best option for isolated users, as micro grid extension may be too expensive. This solution has the following characteristics:

- The scheme does not constrain the energy of a consumption point to the wind resource of its location. Turbines can be placed at the windiest points and the electricity can be distributed to consumption points by means of a micro grid.
- The use of more powerful wind turbines is incorporated, to feed groups of consumption points at a reasonable distance. The cost of turbines is not proportional to their nominal power and the generated energy, so the use of more powerful turbines reduces costs.
- The system may be more easily adapted to increases in demand, specifically for those consumers fed by the micro grids. Extra turbines can be easily included >> in phases and their additional energy can be shared.

Figure 4. Individual and micro grid solution schemes.



The scheme of elements in these wind systems is as follows:

- As the energy generation is not constant and does not coincide with consumption, batteries are needed. The energy generated by the turbines is first stored in a bank of batteries and then consumed from the batteries.
- The capacity of the batteries is calculated according to the demand and the autonomy required, i.e. how many days with no energy production should be covered by the energy stored in batteries.
- Each bank of batteries has a battery charge controller (AC/DC) and an inverter (DC/AC) as the micro grid distributes in alternating single-phase current. Power relations constrain which turbines, controller and inverters to use.
- The micro grid design should take into account the voltage drop limit.
- At the consumption points that are fed by a micro grid, a meter is needed to limit the energy consumption of each user. Thus, the energy stored in the batteries is shared fairly between all the consumers.

The problem to address is the combinatorial problem of the location of each type of wind turbine and the design of the possible micro grids. The developed model also provides the location and sizing of the other equipment involved in the projects (batteries, inverters, controllers and meters). The optimization objective is to minimize the initial investment costs and meet demand and the technical constraints. We propose a model and mixed integer linear programming to solve the problem.

The model was initially validated by applying it to the real case study of El Alumbre. As available generation equipment we considered the turbines used in El Alumbre project plus two more powerful models, to be used feeding micro grids. In terms of demand, we generated different scenarios. All the solutions combined the use of individual wind turbines and micro grids, where the consumption points are closer to each other. In the high demand scenarios, the number of more powerful wind turbines and the number of micro grids was higher. All the solutions required lower initial investment costs than the use of individual systems. The range of obtained cost reductions was from 15% to 25%.

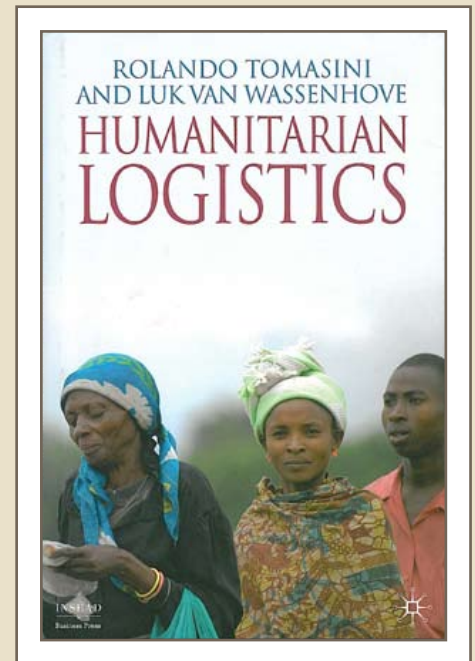
Improving electricity planning

The design of the electrification project is the last step in rural electrification planning, which involves identifying which communities to electrify, proposing the technology to use in each community, establishing priorities between the projects and communities, and designing the project in detail. A criteria-based decision must be taken at each step. Most of these are multicriteria decisions, in which technical and socioeconomics conditions must be considered.

NGOs, companies and governments are increasingly involved in developing policies to improve energy services and to spread renewable energy technologies. >>

BOOK REVIEW

The number of natural disasters and those man-made are plentiful and seem to be increasing annually. Given such a disaster, one of the first actions is to assist those affected. This is where humanitarian logistics comes into play. Medical supplies, food, clothing, etc. are some of the needs of those affected that have to be satisfied.



Humanitarian organisations have played, and are still playing, a vital role in supporting those who are suffering. These organisations have realised the need for more efficient and effective solutions to the logistics problems. Simultaneously, professionals such as Luk van Wassenhove got involved in relief operations and started focusing on providing better solutions. Working in an environment where disasters are on the rise, more complex, and where donor support is increasingly unpredictable, it became clear that anyone operating in this environment needs to understand the humanitarian space and the link to supply chain management. That is where the book, *Humanitarian Logistics*, originated from. The ultimate aim of the book is to sensitise those involved about the various and diverse issues experienced in the humanitarian community.

Humanitarian logistics is defined as “the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, customs and clearance” (Thomas, 2004). Noticeably there is no reference to profit, in this regard, as humanitarian organisations seek a balance between speed and costs in their supply chains.

Chapter 1 of *Humanitarian Logistics* focuses on logistics in humanitarian aid. Similarities are shown between commercial supply chains and those used for humanitarian relief. In a humanitarian supply chain, there is the flow of materials (or products), information and financial information, the same as in normal supply chains. However, two additional flows are present in humanitarian supply chains, namely people and knowledge and skills. The latter is very important in the humanitarian sector since each time a supply chain is re-established for a new disaster, the required skills need to be reconfigured, indicating the uniqueness of every supply chain. Humanitarian supply chains are designed similar to commercial supply chains and they also have to be agile, adaptable and aligned. There are differences, however, in that the objectives of a humanitarian supply chain are ambiguous, resources are limited, there is high uncertainty, urgency is acute while the environment is typically politicised. Speed in the supply chain is overriding at the start, after a disaster, to ensure as many lives as possible are saved. Complexity and dispersion are two fundamental characteristics of humanitarian supply chains. Relief operations can take place anywhere, any day, affect any numbers of people while it is typically not clear what should be contributed and what the state of the local infrastructure is. Another huge risk in humanitarian supply chains is the inherent coordination risks of matching supply and demand.

Humanitarianism is the topic of Chapter 2 and the authors show clearly that the three widely accepted principles of humanity, neutrality and impartiality must be present to constitute a humanitarian operation. These three principles define the humanitarian space and humanitarians live and operate within this space. Maintaining this space is very difficult; there are a number of key challenges that organisations face, namely ambiguous goals, impact, levels of influence, political humanitarian relations, funding, willingness and consent. Humanitarian operations are judged by their impact and humanitarian workers need to operationalise their mandate without compromising their principles or producing negative impacts.

Chapter 3 is devoted to preparedness, one of the four steps in disaster management. The other three are mitigation, response and rehabilitation. Preparedness can be defined as putting mechanisms in place to respond immediately to disasters to ensure that the right goods, at the right time, get to the right place and are distributed to the right people. >>



However, the difficulties of project design and the complexity of multicriteria decision-making may lead to solutions that are not well evaluated, causing failure and environmental or social impacts. Operations research can significantly help to reduce these problems and to improve the efficiency of projects by developing design models and decision support tools to aid the projects and the planners. It can significantly improve access to energy and electricity in rural communities, and promote human development.

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In putting preparedness plans in place, the five essential flows mentioned previously, namely materials, information, financials, people and knowledge flow, become critical. Up to fairly recently, one of the big stumbling blocks to better preparedness in the humanitarian sector has been the failure to recognise logistics as an essential element of the relief operation. Humanitarian organisations nowadays spend a lot of time and effort on developing plans, processes and protocols that need to be followed, thereby ensuring preparedness and fast response time.

Coordination is another very essential function in any humanitarian operation. In Chapter 4, this is discussed and, as in all the chapters, "stories" illustrate and explain the need of the function. Coordination between humanitarian organisations is needed but it should not add another level of bureaucracy – instead, it needs to add value. There are three levels of coordination, namely at international, national and the field levels. What is required and what happens at these different levels are outlined in detail. Every disaster or crisis has a life cycle with three main stages, namely a ramp-up stage, a sustained stage and finally, a ramp-down stage. At each stage, a different kind of coordination is required. Several factors affect proper coordination in emergencies. These are diversity of structures, funding, costs (coordination is expensive), branding (it is problematic if one agency's brand is linked to another's brand) and finally leadership. Successful emergency coordination is a mix of different styles for the different stages of the disaster life cycle, and needs to happen at different levels.

The next two chapters address two of the most crucial issues, namely information management and knowledge management. Information is the foundation upon which the humanitarian supply chain is designed, formed and managed. At the onset of a disaster, information flows to indicate the demand or requirements and soon after that, information flows back to indicate what is being supplied. Overriding in this process is the need for visibility, transparency and accountability around the information provided. It is also very important to understand the process of information flow. Firstly the data need to be gathered, and then need to be processed and disseminated. The next stage in this process is the audience - those to whom the information must flow; the information should be accessible, accurate and timely. One of the main challenges with any relief operation is to capture and channel the information appropriately.

Knowledge management is in essence the need and ability to learn from the past and tap into the "organisational memory" of people who were involved in past relief operations. By capturing such lessons learnt, one can ultimately add further value. With each disaster there is new learning and, with a proper knowledge management system in place, this learning can be retained for future emergency teams. Knowledge is created by capturing raw, unprocessed material such as facts, adding value to obtain information. Through interpreting and a decision-making process, knowledge is created. This information and knowledge need to be communicated and shared equally between partners, giving real collaboration. The authors show that knowledge is created and needed at different levels. Knowledge resides in the people, in processes, i.e. different levels of an organisation, but also among different organisations and lastly, knowledge resides in the context, providing the bigger picture. Given the fact that there is a wide spectrum of organisations involved in humanitarian aid, there are difficulties in sharing knowledge. A few of these are presented such as that knowledge is power, exchanging knowledge can be threatening, etc. Knowledge management is key in an environment where there is high staff turnover and where multiple crises happen simultaneously.

The final chapter of the book deals with all the aspects necessary for building a successful partnership between humanitarian organisations and the private sector. A comprehensive view is given of how to establish partnerships, the challenges in setting them up, the various forms of partnership, the process of transferring best practice, how to select partners and also how to make it work. Partnerships are vital if aid organisations want to succeed, since they don't have an option but to cooperate and collaborate.

Humanitarian Logistics is the first book on the topic and as such, is a welcome addition to the growing literature on the topic. It is not so much about logistics or supply chain management that is required for effective and efficient humanitarian logistics, but rather an essential outline and view on the humanitarian space, the way it currently operates, the many challenges that need to be addressed, etc. The book illustrates the wealth of knowledge that the authors have about humanitarian aid. They do succeed in sensitising those interested in working in this complex environment about the main aspects to take note of and the many pitfalls that exist.

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Humanitarian Logistics by Rolando Tomasini and Luk van Wassenhove, 2009, Palgrave Macmillan, England, pp. 178. ISBN-13: 978-0-230-20575-8. US \$ 29.95.

