CIGRÉ WG C6-13/IWD5

# Rural Electrification: a scoping report


**by G.Dagbjartsson (Switzerland), C.T.Gaunt (South Africa), A.N.Zomers (Netherlands)**

**with contributions from members of Cigré Working Group C6-13 "Rural Electrification"**


## 1. Introduction

Many people in rural areas in developing countries do not have access to electricity and even electrification of the metropolitan areas and suburbs is incomplete or unreliable. It has been reported that more than 1.6 billion people, mostly in developing countries, do not have access to electricity and that most of them live in rural areas.

If one would provide all people on earth with access to electricity by the year 2030 we should realize that the number of new consumers during this coming 23 years will be some 4 billion taking the projected global population growth into account. From this perspective, we have to understand that today just over 4 billion people have access to electricity and that this achievement has taken over 100 years. According to projections of the International Energy Agency the electrification rate in 2030 will be 65% for rural areas and 94% for urban areas (table 1). Today these figures are 60% and 91% respectively. The challenges are enormous, from the technical as well as from the financial and organizational perspective. All need innovation and new ways of thinking; "business as usual" is not applicable.

Unfavorable technical conditions (long distances, low load densities, low average loads), limited government resources, and limited ability of customers to pay for electricity characterize rural electrification.

These observations induced Cigré to address the subject of electricity supply to rural and remote areas.

In 2005 a Cigré Regional Conference and a SC C6 Colloquium in South Africa (Cape Town) addressed problems, difficulties and opportunities in extending electrification in the rural areas of Southern African countries. The outcomes of these events were among the motives that inspired Cigré to establish in autumn of 2006 the international Working Group C6-13 "Rural Electrification". This Group was assigned the task to specifically address the electrification of rural and remote areas.

**WG members as per September 2007**

Gudni Dagbjartsson (CHE) (convenor), Dr. Adriaan Zomers (NLD) (secretary), Prof.Dr. Trevor Gaunt (ZAF), Dr. Joseph Mutale (GBR), Subbiahthever Dukkaiappan (IND), Sissy-QianQian Zhang (CHN), Halim Osman (MYS), Tomislav Baricevic (HRV), Benjamin Sierra-Rodriguez (MEX), Ms. Helen Iosfin (CAN), Keiji Shiraki (JPN), Dr.Hendri Geldenhuys (ZAF), Dr. Ing. Michel Vandenbergh (DEU), Prof.Dr.Gerard Ledwich (AUS), Ken Ash (AUS),Philipp Strauss (DEU), Juergen Reekers (DEU), Alan Drew (USA), Dr. Tatjana Konjic (BIH), Rick Stagi (USA),Fernando Calderon (USA), P.E., Peter E. Sutherland (USA), Ph.D, P.E, B.Sc, Peter Martino (USA), Dr. Anders H. Nordström (SWE), Christophe Nappez (FRA), Dr.Toshihisa Funabashi (JPN).
Prof.E.Lakervi (FIN) -corresponding.

Table 1. Projections of urban and rural electrification rates by region (%) and total people without access [Source: IEA World Energy Outlook 2004].

| Year | 2002 | | 2010 | | 2020 | | 2030 | |
|---|---|---|---|---|---|---|---|---|
| Region | Urban | Rural | Urban | Rural | Urban | Rural | Urban | Rural |
| *North Africa* | *99* | *88* | *100* | *96* | *100* | *96* | *100* | *97* |
| *Sub-Saharan Africa* | *52* | *8* | *55* | *12* | *62* | *21* | *70* | *30* |
| Africa | 62 | 19 | 65 | 23 | 69 | 30 | 75 | 38 |
| China and East Asia | 96 | 83 | 98 | 88 | 100 | 88 | 100 | 89 |
| South Asia | 69 | 33 | 73 | 40 | 81 | 46 | 88 | 50 |
| Latin America | 98 | 61 | 100 | 68 | 100 | 73 | 100 | 76 |
| Middle East | 99 | 78 | 100 | 85 | 100 | 90 | 100 | 95 |
| **Developing countries** | **85** | **52** | **88** | **57** | **90** | **59** | **92** | **61** |
| **World** | **91** | **58** | **92** | **61** | **93** | **63** | **94** | **65** |
| Total number of people without electricity (million) | 275 | 1347 | 289 | 1267 | 295 | 1210 | 287 | 1106 |

The Malaysian National Committee of Cigré invited Study Committee C6 to hold its 2007 annual meeting in Malaysia in conjunction with an International Colloquium on “Electricity for Rural Socio-Economic Development”. This colloquium served as a platform for stakeholders to discuss specific aspects of the electrification of rural and remote areas in the context of socio-economic development.

Working Group C6-13 “Rural Electrification” was required to:

- Identify the specific subjects to be addressed as perceived by organizations involved in electricity supply to rural and remote areas.
- Prepare contributions to the 2007 Colloquium in Malaysia.
- Prepare a scoping report showing what could additionally be addressed by SC C6 taking into account the results of both Colloquia.

The deliberations in the working group made it clear that many documents on the technical and organisational aspects of the electrification of rural areas have already been published. Therefore the Working Group avoided repeating what has already been published and addressed in its contributions to the 2007 Colloquium a limited number of specific subjects not sufficiently dealt with elsewhere. These subjects (including but not limited to electricity demand, cost effective supply alternatives and organisational issues) refer to both the developed and developing world, and the needs of suppliers, utilities, consultants, local entrepreneurs and others.

This scoping report summarises the most important results from the Colloquia in South Africa and Malaysia. It also presents the findings of the Working Group, based on the results from both Colloquia and the collective expertise of the members. The report seeks to inform Cigré’s Study Committee C6 “Distribution and dispersed generation” on what has been done by WG C6-13 in the available time, what has been learned and what is still needed in the context of the electrification of rural and remote areas.

Though the report is primarily intended to support decision making in Study Committee C6, it could also be useful to other organisations such as donors, national and local authorities, NGOs, and development banks.

## 2. Outcome of Cape Town Colloquium

Most people in Africa do not yet have access to electricity; in some countries less than 10% of the entire population, and a considerably lower percentage in rural areas have access. In some countries, governments already committed to significantly develop electrification face technical, financial and institutional problems. The electricity supply utilities responsible for electrification in many countries, and especially in the rural areas, face poverty and unemployment, lack of education about the use of electricity, theft and vandalism, dispersed settlements and lack of road infrastructure. Delegates to the Colloquium shared their experience and achievements, as well as solutions for the further electrification and for the improvement of performance. The main observations can be summarised as follows.

- ✓ Most of the electrification effort in Southern Africa has been in the urban and peri-urban areas. As supply is extended to more remote regions, the costs per connection with conventional three-phase technology increase to levels that are unaffordable. Lower cost approaches are needed, and one of the most significant is single-phase supply. For very small electrical loads, supplied by light feeders on which the minimum conductor size is constrained by mechanical strength, the three phase conductors are only limitly utilised to carry current. One alternative to reduce electricity delivery costs is to omit one of the three conductors, giving only a single phase supply with two phase conductors or a phase and neutral; another is to omit two conductors and use the earth for the return circuit. With adaptations to suit local conditions, this single wire earth return (SWER) technology was introduced in Botswana, Namibia and South Africa during the 1990s.

  Shieldwire systems (SWS) have been used in Brazil, West Africa and Laos, and feasibility studies have been made for 220kV lines in northern Mozambique. The approach is to use a 20 or 25kV SWER conductor as the shieldwire for a higher voltage line. A three-phase supply can be achieved with two shieldwires and earth return. Ordinary SWER laterals supply loads near the HV line.

  The adoption of such solutions has significant potential for delivering electricity into new, unserviced areas at low cost and with acceptable performance.

- ✓ Traditional solutions can also be adapted to facilitate the development of expanded rural electrification programmes.

  In South Africa, parts of rural networks operate at 11 kV, while the remainder are 22 kV. A significant part of the rural networks needs to be upgraded to a higher MV voltage. The 33 kV level, which is the preferred MV distribution voltage in Namibia, Mozambique and Tanzania, offers increased power transfer and back feeding capability.

- ✓ The government goals for electrification encounter difficulties where the distance of new customers from the grid is more than several kilometres and, in some cases, in mountainous areas. Non grid solutions based on the use of photovoltaic “Solar Home Systems” (SHS) provide limited services, mostly for a few lights, radio and black and white television, for a monthly fee. SHS customers are not happy because refrigerators, electric stove or hotplates, and other appliances cannot be supplied. Customers also have concerns about reliability because repair is too slow. Therefore, education is an important issue for such supplies: customers need to understand how the system works, what maintenance is needed, and what the installation and service costs are.

- ✓ The use of hybrid power generation systems that combine one or more renewable energy sources with other technologies such as batteries and conventional diesel generators offers improved off-grid generation systems without neglecting operational performance, maintenance requirements and overall costs. However, appropriate institutional arrangements are vital.

- ✓ In several countries the debt arising from non-payment of electricity bills by customers has been growing with no immediate solutions. Utilities have tried various ways to recover the debt owed, including disconnection, legal actions and consumer education, but none of these has solved the problem. The introduction of prepayment metering to replace the credit metering that requires billing after consumption has improved payment, reduced debts and offered consumers an option to control the electricity consumption to affordable level; this results in reduced customer energy consumption and technical distribution losses.

- ✓ Vandalism of distribution transformers and theft of the transformer oil is a real problem in some Southern African countries and a threat to electrification. Reengineering of transformer design, relocation of transformers, public awareness of the dangers of the oil and introduction of penalties may reduce but not completely eliminate the problem. This problem requires collaboration between utilities and manufacturers in the development of improved anti-vandalism practices and designs in addition to security and legal deterrents.
- ✓ Electrification of rural and remote areas requires new and cheaper technologies, but the infrastructure to co-operate on technical standards is often missing or ineffective. Donor funding from many countries with historically different standards has given Africa a legacy of equipment based on diverse standards: the consequences include unavailability of spares, non-upgradeable aging networks, and equipment incompatible with the environment, all contributing to low reliability. Important standardization initiatives in Africa include those of the African Electrotechnical Standardization Commission (AFSEC) since 2005, the Power Institute of East and Southern Africa (PIESA) since 1999, and the Union of Power Transporters & Distributors of Electricity in Africa (UPDEA).

The presentation of the contributions and the debate at the Colloquium clearly demonstrated the importance of electrification development, the interest in exchanging experience gained in electrification programmes everywhere, and the need to share information about new and innovative technologies suitable (from technical, economic and institutional points of view) for unserviced or poorly serviced areas.

Rural electrification in South Africa [C.Young]

## 3. Outcome of Malaysia colloquium

The theme “Electricity for Rural Socio-Economic Development” was chosen to focus not only on discussion of technical aspects but also to understand and create awareness for the development impact. The theme is consistent with the urgent requirement for all stakeholders to consider and share local, regional and global issues on rural electrification and to offer possible solutions that could ultimately improve the socio-economic well-being of many deprived rural communities. The colloquium dealt with technical, economic, social and organisational issues related to rural electrification. Members of Working Group C6-13 prepared eight papers and contributed to another four. The main observations can be summarised as follows.

- ✓ Access to modern and affordable energy services helps to alleviate poverty, improve living conditions and supports socio-economic development. Access to electricity increases the country GDP through, e.g., productivity improvements in industry and agriculture, new economic activities in the service sector and small scale enterprises, enhancing local employment and reducing urban migration. Education level and health conditions of the local communities improve and all these contribute to a better quality of life.
- ✓ A stable political environment, sound institutional and legislative conditions as well as full commitment of national government and the local community are the main success factors of rural electrification programmes. Theses programmes should be part of well-developed long-term national electrification and rural development plans.
- ✓ One of the main reasons for the slow pace of electrification is the enormous cost associated with extending electricity grids to rural areas or establishing isolated mini power systems for rural communities. Rural electrification has always required subsidies which must be properly targeted together with an appropriate tariff setting. A strong public sector initiative is needed as the private sector is not interested in the larger scale provision of electricity services to poor rural and remote areas without private-public partnership.
- ✓ An area still lacking clarity is the electricity service requirements in rural areas for domestic consumption and for productive use and services. An appropriate and clear definition of service requirements underlies the investment and operating cost. The cost of service affects the affordability and sustainability of electrification programmes for rural communities. One element contributing to the high cost is the common practice of applying the same planning criteria and design standards for urban and rural supplies. The main attributes of electricity supply affecting both customer acceptance and the cost of supply are: load capacity (including estimates of initial load and load growth), voltage variation and availability / quality of the power supply
- ✓ Grid-based solutions are still the dominant approach for the provision of electricity services. However, the cost of electrifying low load or remote consumers may entail high costs. The main issue is to reduce construction, maintenance and administration costs. Grid connection technologies that are used where the cost is too high for conventional 3 or 4 wire three phase connections, includes: single wire earth return (SWER), single phase with two wire feeders, shield wire systems (SWS), capacitor coupled substation (CCS) and 1000 V low voltage distribution systems. The supply reliability and power quality is quite variable in some of these grid connected networks. However, a pilot project has demonstrated that a significant improvement in the power quality can be achieved in remote rural networks by a combination of local generation and energy storage.
- ✓ Distributed Generation (DG) using small-scale generation powered by fossil fuels and/or renewable energy sources is playing an increasingly important role in the power supply of rural areas. An important advantage of renewables is the capability of using locally available energy sources and the easily adaptable capacity to growing electricity demand. In a number of countries, Hybrid systems (HS) combining fossil fuel and/or renewable energy generation together with storage systems have been successfully introduced for power supply to rural areas. Installation in Malaysia revealed that benefits of using Solar HS as compared to the operation of a diesel generator plant, include fuel saving of 50-75%, reduced emissions and noise pollution as well as increased operational life time of the system.

- ✓ Power sector reforms in industrialised countries aim to enhance innovation, sound financial efficiency of electric utilities and cost efficient services to the consumer. In many developing countries, reforms of the power sector are needed due to sub-standard performance of utilities, including unacceptable availability and quality of supply, large-scale electricity theft, unsustainable tariffs, low billing and revenue collection rate and unsuitably targeted subsidies. However, reforms of the power sector in developing countries should not mimic reforms in industrialised countries but must be realistic and effective in the prevailing circumstances and context. For example, unbundling of vertically integrated systems and an introduction of competition in immature or small power markets is irrelevant, i.e. the same pattern does not fit all.
- ✓ Financial sustainability and a proper planning and implementation are among the critical success factors. Rural electrification to poor communities needs special programmes, subsidies (or grants) on initial investments and long-term and low interest loans in order to set affordable electricity tariffs. Different business models are applied for electrification programmes around the world. The choice of the model will depend significantly on the electricity supply industry structure and on the regulatory model in the country. Finances are not the sole criteria applicable for decision making in the case of rural electrification. The triple bottom line, i.e., the social, economic and environmental development impact must be considered. Traditional cost-benefit analysis which reduces all the impacts to a single financial criterion is inadequate. In several papers it was argued that subsidies for the capital expenditure do not create an unviable infrastructure but operating subsidies do.

Solar Hybrid Power Station [TNB, Malaysia]

- ✓ Various technological solutions are currently available but additional targeted research and development are needed in the areas of low cost power supply solutions, energy efficient appliances, energy storage equipment, modular PV-based systems and hybrid power systems. There is a need to develop network and system design tools to aid system planners to implement rural electrification based on low cost technologies. There seems to be room for further international standardization on e.g., medium voltages for distribution networks, cost-effective active networks with dispersed generation and equipment for hybrid power systems. Finally, decision makers need information structures and tools for quality decision making and, ultimately, secure the success of the project.

## 4. Findings of the working group

The subjects discussed during the colloquia can be divided into seven main areas: (i) The scope of rural electrification, (ii) Social and socio-economic issues, (iii) Technical issues, (iv) Financial issues, (v) Institutional issues, (vi) Environmental issues and (vii) Issues of project development and decision making.

### *4.1. The scope of rural electrification*

There are many different interpretations and classifications in use today to describe rural and/or remote areas for the purposes of discussing methods of electrification. Some useful examples are as follows:

1. By density and concentration or clustering – setting the context of the environment or geography:
    - Small communities, villages or even towns remote from other habitation,
    - Dispersed households, farms and enterprises of low density over wide areas or regions,
    - Community clusters or villages surrounded by lower density dispersed households,
    - Communities on the same land mass but separated by physical obstacles such as mountainous terrain, or on islands separated by water,

2. By energy use:
    - By power and energy (or load factor=f(energy/power)) and load profile,
    - By application: household, commercial enterprise, institution, agricultural processing, etc

3. By choice and method of energy provision:
    - Reticulated electricity, connected to some form of larger grid, or a local micro grid,
    - Reticulated/piped fuel such as natural gas, LPG, fuel oil, diesel,
    - Transported fuel such as natural gas, LPG, fuel oil, diesel, by land or sea transport,
    - Reliance on renewable energy products such as hydro, solar photovoltaic (PV), wind, waves, tides,

The most suitable method of electricity provision (technology, institutional model, etc) will usually depend on the combination of the geographic context, the consumer need, and the possibilities that are available and affordable to provide the energy requirements. Therefore, the most appropriate solutions in one place might be quite unsuitable in another.

Clusters and communities that are very remote from other habitation are generally supplied by some form of centralised local generation, or via a connection to a larger but somewhat remote grid.

If centralised local generation is the system chosen for such communities or clusters, then these will be larger than the isolated generation systems used for individual consumers, and are likely to be diesel, gas or fuel oil generators, supplemented by renewable methods if these are available, such as hydro driven generators or hybrid (wind, PV, battery) systems. These community supply systems are often called

Micro Grids, as they often include small grid systems radiating from the generation source, often at low voltage or they can be stepped up to medium voltage (11kV, 22kV) for distribution to customers further away from the community centre. SWER technologies are discouraged on these microgrid networks due to the impact of phase imbalance on small generators.

In contrast, evenly or widely dispersed households and farms, are generally supplied by small single customer systems, with little or no opportunity for interconnection. These days such supply systems are primarily smaller diesel generators with a growing number of hybrid (wind, PV, battery) systems supplemented by a fuel based generator at peak times. If, as an alternative to local generation, network interconnection is available and adopted, then appropriately low cost, limited capacity systems are required.

The choice between alternatives is usually made on a financial basis taking into account capital construction costs, losses, and operating/maintenance costs. Where fossil fuel based generators are selected, the costs of the selected fuel is generally the dominant cost driver. The greatest uncertainty arises in areas of mixed types of electrification (load magnitude, density and clustering), where no single technology is distinctly better than the alternatives, and small changes in the assumptions about power and energy forecasts affect the ranking of alternative technologies and business models.

### *4.2. **Social and socio-economic issues***

Many studies have investigated the impact of rural electrification on development, with a wide range of results. Some of the studies can be criticised for apparent bias in the scope of the surveys or of the investigators, and some of the surveys are quite old. This does not mean that, in themselves, they are wrong, but the concepts of development (such as in respect of gender, environment or social objectives) have changed substantially during the past 20 years and the earlier studies or a more recent study primarily carried out to justify a project may be incomplete. It is also intrinsically difficult to assess the impacts of electrification, such as by comparing communities or households with and without electricity, because access to electricity is usually associated with access to other services or facilities.

The link between GDP and electricity growth has been noted and also the importance of good or reliable demand estimation.

The need to go beyond merely supplying electricity was noted and also the lead times before results in poverty reduction are achieved. China's experience of the link between poverty reduction and electrification suggests that it takes time for the benefits of electrification to be realised or to become visible. South African experience corroborates this finding. There does not appear to be information indicating that these are not typical of the general case.

Development can be characterised as having three components, with which are associated characteristic categories of electricity supply:

- Economic development pursues efficiency, growth and financial return. Electrical energy contributes to productive output and the users ultimately meet fully the financial costs of electricity supply.
- Socio-economic development seeks long-term sustainable changes of lifestyle. The financial costs of electricity supply are not completely paid by the customers and the necessary subsidies are justified by broader economic benefits derived from supplying electricity.
- Social development is concerned with equity, justice and poverty alleviation. Most use of electricity is entirely consumptive, without making significant contributions

to financial or economic development, but important for a social benefit generally derived from enabling people who could not otherwise afford electricity to use modern energy supplies to alleviate their poverty.

An important aspect of these different objectives is that some countries define electrification only in respect of access for purposes of economic development (e.g. agriculture and industry) or socio-economic development (e.g. schools, clinics and government offices), while in other countries electrification refers to the proportion of households with access to electricity.

Process of change

When a household is electrified several things change, including fuel substitution, expenditure patterns, the family roles of collecting or being responsible for energy resources (which may have significant gender implications), fire risk, reduction of indoor air pollution and social and family behaviour as affected by good lighting. The transition from non-electrified to electrified households and communities is a complex social process, even beyond the consideration of the effects of health and education services associated with electrification.

It has been observed that electrification reduces the time spent on fuel wood collection and allows household tasks to be done during the evening, freeing time for more productive work during the day. Confounding factors, such as the availability of extra employment, proximity to markets and whether households exist in a predominantly economic (cash) or subsistence setting, increase the complexity of assessing the effects of electrification on household (or per capita) income or production.

Many studies have shown how wide are the claims of the benefits of electrification and electricity subsidies, including reduced total energy costs so that more food can be purchased, access to entertainment, cleaner houses, lower concern about safety, children having a place to study and being less afraid to go to bed in their previously un-electrified bedrooms, and even having dreams of a future in which people and communities will break out of poverty. Conversely, there have been reports of a sense of injustice in households and villages without electricity, especially where electricity subsidies are implemented nearby. Clearly, therefore, these benefits provide scope for electrification to be used as a political tool, such as rewarding or promising reward to supporters at elections, but this dimension of electrification is seldom openly identified.

### *4.3.* ***Technical issues***

A small survey carried out by the WG clearly identified that many different standards are implemented in different countries and in different contexts. Technical standards are influenced by the nature of the loads, cost-effective supply alternatives, and organisational issues.

Electrification of rural areas is a challenge because of a number of factors:

- Economic factors affect determination of long-term load growth.
- Difficulty in developing estimates of revenue produced by the sale of electricity to meet the future load.
- Difficulty in obtaining funding for system expansions when revenue streams are inadequate and/or uncertain.

It is extremely important to develop cost-effective strategies that can be used to optimize the use of available funding, and focus on the critical elements of planning, finance, design, construction, operation, and maintenance.

As loss of supply arising from shortages caused by under-design and under-capacity of a distribution system supplying economic customers will be costly, most electric systems for economic objectives tend to be designed to be robust – as illustrated in Figure 1. In contrast, electrification systems implemented for social objectives have lower penalties associated with under-capacity. Given the three challenges highlighted above, the optimum investment will tend to be below the apparent minimum of the lifetime or total cost, and under-capacity will be preferred to over-capacity where the costs of under-performance are relatively low. Accordingly, minimum cost solutions are needed for socially directed electrification, and loads should not be forecasted too generously.

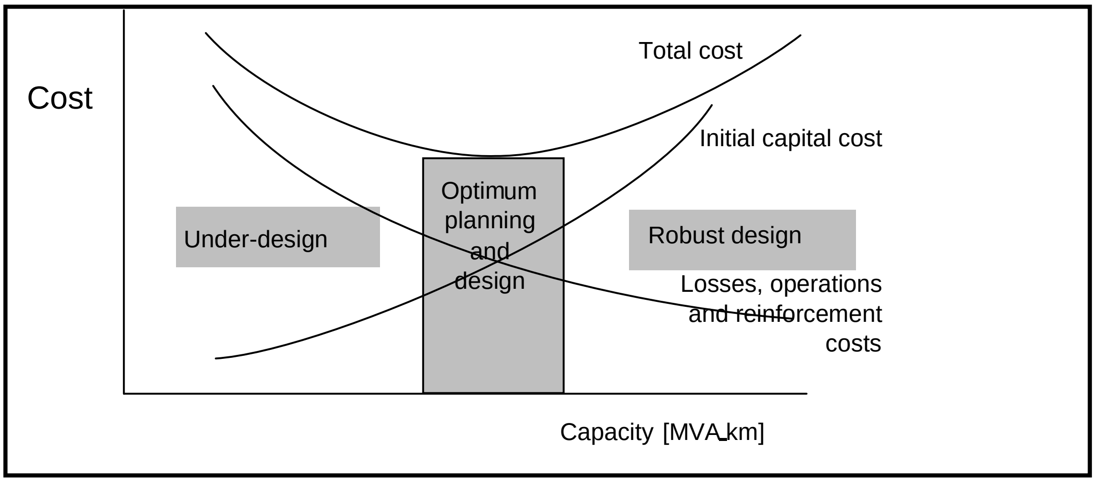


Figure 1. Capacity Design and Associated Costs.

Rural electrification is not a mature technology. Innovation and cost efficiency is needed not only for network configurations and products but also for renewables and energy storage as well as for frameworks, codes and standards for both the supply side and for connected electrical equipment on the consumer side.

The challenge of reconciling different service requirements for different customers and hence the value placed on services was noted. In this context the differences between domestic and industrial use of electricity were seen to affect the appropriate technologies and standards. A process orientation would seem appropriate: from supply, operation and maintenance to the use of electricity.

Existing grid connection technologies are in widespread use for connecting large numbers of rural and remote consumers, whether they are in small communities, or in more widespread single households and farms. The most significant are listed below.

- SWER – Single Wire Earth Return, very low cost single conductor, bare wire, overhead systems, making use of an earth return path, sometimes with an isolating transformer at the source converting two active phases to one active phase and the return through a ground (earth) electrode.
- Single phase, 2-wire feeders with light (small) conductors, generally deriving supply from 3 or 4 wire three phase systems.
- 1000V low voltage distribution systems, in use in Scandinavia. These are in between conventional 20kV MV systems and 400V LV distribution. There are standard LV UG and ABC cables that can be used, and the feasible capacity is up to 100kW and up to 5km in length.
- SWS – Shield Wire Systems, connecting dispersed small communities or single customers to MV networks on transmission or sub-transmission shield

wires, and converting to local SWER networks, providing very cost efficient sources to customers close to existing transmission easements,

- CCS – Capacitor Coupled Substation as the source for a distribution network. It uses a capacitor divider instead of an inductive transformer to reduce the voltage, and usually incorporates an air-core series inductor and filter circuits for good voltage control and to avoid ferro-resonance.

The voltage of the connection to a remote source or network is generally higher than the distribution voltages (low and medium voltages) of micro-grids and grid electrification.

There are known technical issues with all of the above options. For example, care is needed with the earthing systems for SWS and SWER, as earth return currents can increase to hundreds of amps in large dispersed systems, and have been known to burn down timber poles when earth resistances have increased because of soil drying out.

The supply reliability and power quality is quite variable on some of the large, dispersed grid connected networks. Reliability can be quite poor, as many outages can occur due to the weather exposure, such as wind and storm damage, including lightning. Restoration times can be long due to the limitations of fault finding and repair over vast distances. Power quality issues such as unbalanced voltages, harmonics, large voltage fluctuations and poor regulation, sags dips & swells, flicker etc, become more pronounced as more customers are connected to these thin networks, and their individual loads grow. These dispersed grids must be designed for quite high peak loads, often for summer cooling or water pumping, while suffering from very high levels of losses due to the small conductors employed.

Technical innovations for grid connected supplies include:

- Electronic voltage regulators, such as switched reactors and compensators, Unified Power Flow Controllers (UPFC) at Medium Voltages, and applied to long, weak networks at 3 phase, or SWER lines to improve power quality for all customers over the entire feeder length.

Rural Community Power Station
[Ergon Energy, Australia]

- Single- to three-phase converters.
- Reliability improvement techniques such as lightning surge reduction, earthing improvements for SWER, improved insulation co-ordination and insulator materials, greater use of covered conductors, multiple reclosers linked with intelligent SCADA systems for monitoring and fault response.
- Small capacity, multi-terminal HVDC systems might change distribution technology significantly. Substantial reductions in losses and costs have been achieved already in VSC technology HVDC systems with extruded polymer cables. Techniques for a DC version of LV distribution, with electronic voltage controllers and inverters, are being developed.

Voltage variation is an important constraint for grid connected systems. There is much work occurring in the field of voltage support of long, weak grid networks, by the addition of small distributed generation units at either the remote end, or at large load points along the feeder/s. This is quite relevant in the Australian context, where many trials are under way of large reciprocating fossil fuel engines ( 500kW) being synchronised onto the grid at high load times, or small micro supplies (fuel cells or fossil fuel engines up to 50kW) at farms or homes also being used at high load times. These techniques are an attempt to provide a lower cost solution to providing grid voltage support, as opposed to expensive line upgrading projects or new line extensions.

This type of technical innovation in dispersed generation and active networks may be limited in the long run due to the limited voltage and power performance of small generators, especially dip ride-through, and non-active power management, but may provide power quality and reliability improvement for some customers.

Existing non-grid technologies are well known and used in many combinations of those described below, and these local solutions (sometimes called autonomous generation) are generally combined with a micro grid to supply small communities:

- Fossil fuel based generation, using diesel, natural gas, LPG, CNG, fuel oil, using either large marine style medium speed reciprocating engines, or turbines for larger power centres
- Hydro (small and micro hydro, generally smaller than 1MW), using run of river hydro systems, or small dam based turbines run on demand,
- PV, usually conventional flat plate PV in large solar farms combining plates of 150 – 200 Watt capacity in large quantities, together with some form of storage technology for cloudy periods or night supply,
- Wind generation of varying size, whether of the newer style multi MW machines, or a number of small many kW machines, often with some form of storage,
- Hybrid systems made up of combinations of the above. The constraints of power fluctuation usually limit wind generation to round 30% of the station capacity.

Technical innovations for local generation include:

- Small PV/battery systems for small isolated loads, (less than 1 kW in China is common) probably combined with higher efficiency lighting.
- PV, which has moved on from flat plate PV as standard, now includes concepts like solar concentrator dishes combined with high efficiency cells at the focal point of the parabolic reflector dish – up to 40kW each, combined with some form of storage technology and operating totally in quiet mode with appropriate inverter/connection technology. This style of solar supply arrangement is encouraging new developments in inverter software and hardware so that large communities can now be supplied totally by renewable energy sources. The cost of PV panels might be reduced in the near future but whether the cost of the balance systems will be reduced is uncertain.
- Solar thermal, where concentrator dish technology can concentrate heat energy on to fluid containment equipment, which run more or less conventional steam based turbines. Solar thermal has the intrinsic advantage that it can store energy for cloudy periods or night generation.
- The development of fuel cells has the potential to provide the electricity needs (and heat in some CHP systems) for small consumers. Commercial fuel cells are currently available for Hydrogen fuel, and they are being developed to burn Natural Gas and LPG. The side benefit of water production may also be an advantage for some consumers. The use of Solar techniques to divide water into the required hydrogen to run fuel cells in times of high sun

availability and low energy demand is also developing into an energy storage technique.

- Energy management systems for hybrid generation (Fuel Cell, PV, wind, storage battery, and small fuel based generation for peak loads).
- Enhancements in inverter technology and power/voltage control for micro-grids.

Innovation is also occurring in beyond-the-meter technologies and ancillary services, regardless of the supply system involved:

- Cell phone (mobile) based payment and revenue collection systems in conjunction with prepayment meters.
- Remote system monitoring & control.
- Improved load data collection, modelling, and design methods to reduce unproductive investments by utilities.
- Demand management and load limiting - It was noted that demand limitation is a particularly critical factor for off grid systems.
- Energy efficiency.

Large PVHybrid system with diesel genset [SMA Technologie, Germany]

### *Technical standards*

The biggest potential for improvements in grid electrification appear to be in reducing the cost of long connections to the central grid, and in “light” distribution networks, by using technologies (SWS, SWER, higher voltage light lines, etc) that avoid over-capacity and offer high capacity/cost ratios.

In some cases such low cost electrification may need to be upgraded as the loads grow, possibly only after 20 years.  Techniques and technologies that reduce or modify consumer demand will also be important to reduce cost issues.

Increased application of local generation for small dispersed consumers generally appears to require further cost reduction, reductions in installation and operating complexity, and improvements in reliability before it would be adopted for widespread use in some developing nations.

The adoption of new techniques and new fuels for small community based centralised micro-grid generation systems, also seems to be some years away. Trials of these new techniques while underway in many parts of the world, do not seem to have entered mainstream use as yet, and also need to overcome some of the issues mentioned above, with respect to capital cost, operating complexity, and functional reliability.

The most appropriate approaches (including technology, business models, and regulatory regimes) will depend on the combination of the geographic context, the consumers' needs, the presence or otherwise of appropriate fuels or renewable sources, and the dynamic relationship in the costs of network distribution and local generation.

There appears to be a very wide range of voltage levels for MV distribution: 11, 15, 20, 22/12.7, 25/14.4, 30, 33/19 and 35 kV systems are used. There would appear to be room for further international standardisation,

Except for a rationalisation of system voltages, it is thought that greater standardisation at this stage would be premature, since significant technical innovation appears necessary to speed up the widespread electrification of the more remote communities in the worlds developing countries.

### *4.4.* ***Financial issues.***

One of the big hurdles in rural electrification is that supply to remote villages with low incomes is often not economically viable. Many programs have addressed this issue by capital cost reductions and central government subsidies on the capital and operating cost. It has been seen in many applications that a subsidy on the operating costs is not sustained and the maintenance of the supply receives lower priority because the sector does not contribute to supply company profits.

In financially viable electrification, the revenues (connection fees and energy sales) exceed the financial costs of investment (design and construction) and operations (generation and network operations, maintenance, revenue collection and administration). The cost/connection of electrification can be reduced in real terms through various approaches, but if electrification is not financially viable even with adapted technologies, it must be justified by socio-economic or social benefits, and supported by subsidies. As soon as subsidies are introduced several additional issues arise:

- Should subsidies be limited only to investment costs, or can they be applied to operating costs?
- Should subsidies be for finite periods?
- Should uneconomic customers be subsidized by the government or aid agencies, or cross-subsidized by other customers?
- Should the capacity and technical standards (reliability and voltage quality) for subsidized supplies be the same as for economic customers?
- Under what conditions should higher costs be incurred for subsidized supplies, such as to meet environmental objectives?
- Could the subsidies be used more effectively to support socio-economic or social development?

In several papers it is argued that subsidies for the capital expenditure do not create an unviable infrastructure but operating subsidies do, since they require on-going institutional commitment.

Directed assistance in support of poverty alleviation, health, education and environmental improvement offers significant benefits. However, only in a few developing countries is the economy strong enough to afford the subsidies and, in many, the mechanisms for allocating the resources are insufficient. Although the cost of supporting social electrification is not substantial in global terms, international financiers need to be confident that the institutions can identify suitable objectives, and use the funds and technology effectively, without wasting resources or leaking the benefits to those for whom they are not intended, especially through corruption and inefficiency. Aid and subsidies for social electrification must be managed in terms of suitable objectives.

*Tariffs and theft of electricity*

The socio-economic and social benefits cannot be achieved if people, including those in the poorest households, cannot use the electricity made available by electrification. Three aspects appear to be critical: the households must have appliances to use the electricity; the tariff must be affordable, if necessary supplying at very low charge an effective quantity (demand and energy) of electricity; and there should be monitoring and appropriate disincentives to discourage the theft of electricity by physical or administrative methods.

The government in South Africa has introduced Free Basic Electricity, under which households receive 50 kWh per month at no charge, funded from the National Treasury. This provision can be made with both prepayment and conventional meters. While there is criticism of the concept of providing any services at completely no cost, the scheme does address the need to help really poor households to have access to the use of electricity. The Free Basic Electricity provision does not prevent the theft of electricity by those who desire more, and loss prevention approaches are necessary to limit the losses by theft.

### *4.5.* ***Institutional issues***

Political stability, a consistent policy framework and clear predictability are needed for successful implementation of rural electrification programmes. These are factors of institutional structure.

Generally research into the institutional structures for electrification suffers from the problems of hypothesis definition, with a narrow range of alternatives or targets, so that the more complex data is not collected, collated or released. There appears to be a need for more international collaboration on the assessment of institutional structures and their success in rural electrification.

Five models of institutional structure for rural electrification are apparent. All the models are characterised by a key role for central government. Recognizing the need for rural electricity, central government must provide the enabling legislation and regulations towards developing a national electricity network and supporting those who can move rural electrification forward.

*Public monopoly*

Many countries adopt a public monopoly for rural electrification. It can focus on the needs of the sector and offers decision-making autonomy. National standards and tariffs can be imposed or regional variation can be allowed. For this model to be effective, close coordination with local governments is essential, providing support for licensing, tariff implementation, and access to greater levels of financing.

*Local electricity utilities*

With advantages similar to the public monopoly, smaller public utilities under the control of local government are particularly well suited for rural areas, where a local government can act as a champion to the community by bringing together the necessary participants, provide an institutional environment that protects the interest of the community, and set tariffs at a level suitable to local cost. Furthermore, local government can leverage its position as a successful facilitator, coordinating investment in other public facilities and projects. An advantage of local utilities is that comparison of comparative indices assists the regulation of the sector on a national scale.

*Multi-service utilities*

Local government is well placed to establish and operate multi-service utilities, focusing on the broad needs of customers, instead of on a technology. Some recent studies have shown that multi-service utilities have attractive economies of scale and function that allow lower cost operation than single service utilities.

*Co-operatives*

The strength of the cooperatives lies in their ability to work closely with members to develop services that suit local needs. However, cooperatives often lack the necessary technical skills for developing and running power systems. This can be resolved through national assistance (as in the USA) or by the competitive procurement of a specialized power service provider.

*Private sector participation*

The participation of the private sector in rural electrification is usually proposed with the idea of attracting private capital, efficient operation and new technologies for rural electrification. Problems can arise from the definition of subsidies, ownership of the systems and the continued responsibility for them, and consistent government policy.

Where electricity supply is carried out as a profitable commercial enterprise, the focus will be on economic electrification, which is how electricity utilities started in most countries. Only later, when utilities were required to contribute to socio-economic or social objectives, subsidies were introduced and some utilities nationalised. Recent changes, to force utilities to become financially viable businesses, were initiated in developed countries where electricity supply is predominantly economic.

In developing countries, where extensive electrification is still needed to support socio-economic and social objectives, it can be difficult to regulate competitive, market-based utilities to meet those objectives. All subsidies must be clearly identified, and preferably be allocated from outside the utility. Therefore, public ownership and operation may be preferable to privatization and market competition for rural electrification in most countries. Regulation will still be necessary, but competition by comparison between diverse utilities can be introduced if a single monopolistic utility is avoided. The performance of utilities in all categories of economic, socio-economic and social development, as well as technology, operational performance and finance, can be compared. Successful utilities should be encouraged and supported. Those failing in their responsibilities need to change or be taken over by others, transferring the assets along with the obligations.

Local community involvement is one of the cornerstones of a successful rural electrification programme, local equipment and qualified workers should be sourced whenever economical. Already at the planning stage, the local community needs to be informed and consulted as an appropriate and clear definition of service requirements underlies the investment and operating costs in rural electricity supplies and affects affordability as well as sustainability of the programme. Training programmes including demonstration and hands-on training in using electricity are needed.

### *4.6.* ***Environmental issues***

Concern about the environment and climate change is changing the electricity industry in Europe and North America. Natural gas is preferred to oil and coal because of the up to 30% lower carbon dioxide emissions per unit of electrical energy generated. Most developed countries have introduced environmental policies and subsidies or taxes that create financially viable opportunities for small scale dispersed generation (DG) from renewable sources. DG and renewable energy technologies significantly affect the planning and operation of electricity systems in these countries, requiring new grid codes and leading to the emergence of active distribution networks.

In developing countries, intrinsically viable renewable energy projects, such as from sugar cane bagasse or hydro power stations, may additionally need support from new grid codes. Conversely, those “environmental” programmes that are not financially and economically viable only divert resources and subsidies that might be used for electrification in better ways. Externally funded grants for such environmental projects could be acceptable, provided they do not impose conditions (such as on equipment standards) or obligations (such as maintenance) that contradict electricity utility and national policies.

Low capacity grid connections can supply substantially more energy than wind and PV systems for a similar or lower cost. Further, the limited reliable energy capacity of isolated wind and PV systems can represent a poverty trap for customers despite the initial advantages of a limited supply. With development and growth, the need will arise to move to the next level of energy consumption by duplicating the basic unit, adopting a different technology for the isolated supply, or obtaining a grid connection, for which the total investment (initial and improvement) will be too high. Until costs change, most renewable energy and non-grid supplies are not optimal economic solutions to large-scale rural electrification.

Household energy consumption is still a small part of national energy consumption in developing countries, so an increase in emissions from electricity production to supply newly electrified households will have negligible impact on global carbon dioxide ($CO_2$) emissions, even if electrification results in more household use of energy or does not replace fossil fuel combustion. Electrification of larger enterprises, such as industry, only rarely replaces renewable energy, so will not be associated with emissions increases.

The protection of vegetation through electricity use can have benefits for erosion, water supply and land use that are difficult to quantify or compare with CO2 emissions. Accordingly, the broader environmental impact of electrification requires rigorous analysis of the whole process of electricity supply and of the fuels replaced by electricity.

*Health and safety*

Although there are benefits associated with combustion fuels (kerosene can be purchased in small quantities and used in cheap appliances, and wood and other biomass are available at low cost or collected for free), these fuels do not provide the same indoor health and safety benefits of electricity.

Several studies show that indoor air pollution, particularly from combustion fuels, is an important contributor to respiratory disease, especially lower respiratory infections, and may be implicated in tuberculosis and eye infections.

In some cases, the subsidies needed to support household electrification could be less than or similar to the associated reduction of the costs of treating lower respiratory infection. Under these circumstances, electrification's justification is that it meets socio-economic objectives, and is not only a social imperative. Where health services are so deficient that only small savings are achieved in treating illnesses, then the electrification has a social perspective and a choice might be needed between committing resources to reducing the cause of the illness (by implementing electrification) or treating the effects of the pollution (by providing better health services, which might have a wider impact on community health).

The success of household electrification in reducing indoor air pollution depends largely on the extent to which electricity replaces combustion fuels in the households, not on the access to electricity. To have a real impact, full electrification (i.e. for lighting, cooking and heating) is desirable. This means that assistance with obtaining low cost, efficient and safe appliances, and the adoption of subsidized tariffs for poor people, may be required.

### *4.7. Issues of project development and decision making.*

Electrification alone cannot achieve all the development objectives, which are the result of many different factors. Similarly, electrification does not have a direct effect on the environment. Table 2 indicates some of the activities needed to supplement the effects often stated as expected from electrification.

Table 2: Supplementary actions needed to achieve the intent of electrification.

| *Intent* | *Nature of objective* | *Supplementary actions needed* |
|---|---|---|
| Create employment | Economic | Support growth so that increased productivity from electrification does not reduce employment. |
| Stimulate rural industrialization | Economic | Provide other factors of production and access to markets, particularly roads. |
| Raise household income | Socio-economic | Support productive use in households in addition to consumption. |
| Improve health service delivery | Socio-economic | Provide and manage clinic services. |
| Promote home study | Socio-economic | Improve schooling and adult literacy programmes. Provide resources from which to study at home. |
| Reduce migration from rural to urban areas | Socio-economic or social | Counter perception of better life (opportunities and services) in urban areas. |
| Poverty alleviation | Social | Supply basic quantity of energy at subsidized tariffs with conditions that target the poor. |
| Reduce biomass (fuel wood, dung) consumption | Environmental | Address "free" availability of collected biomass compared with electricity. |
| Promote energy efficiency | Environmental | Assist the procurement of efficient electrical appliances. |

Most decisions about electrification are based on models that assume electrification contributes to economic and socio-economic development. A model of social electrification leads instead to decisions different from those taken in economic electrification programmes. The different approaches are illustrated in Table 3. Identifying and understanding the differences between economic and social objectives, and their effect on electrification, environment, electricity tariffs and subsidies, electricity distribution industry operations, and regulation, can contribute to better decision-making and greater effectiveness.

Table 3: Comparison of approaches to economic and social household electrification.

| | *Economic and socio-economic electrification* | *Social electrification* |
|---|---|---|
| *Inputs* | Investment, materials, skills, integrated development plans. | Grants, materials, expertise, needs identification. |
| *Project Activities* | Selective electrification based on financial or economic viability.<br>Technology choice based on lifetime financial projection.<br>Cost-reflective tariffs. | Blanket electrification (also called area coverage).<br>Minimum capital investment.<br>Capital subsidies, free or low-cost connections. |
| *Project Outputs* | Households and businesses connected for acceptable cost. | Numbers of households connected.<br>Completion within budget. |
| *Operation and Use* | Focus on revenue collection.<br>‘Normal’ appliance purchasing and use.<br>Efficient, profitable utility operation.<br>Regulate financial and technical performance. | Focus on electricity (kWh) sales.<br>Poor households use subsidized electricity with available appliances.<br>Utilities supply adequate quality.<br>Regulate social performance. |
| *Programme Outcomes* | Lower household energy costs.<br>New businesses.<br>Viable utilities. | Basic use of electricity in homes.<br>Environmental improvement.<br>Sustainable utilities. |
| *Assimilation and change* | Stimulated business development.<br>Increase in economic activities.<br>Health and education supported. | Better lighting supports education.<br>Less indoor pollution promotes better health. |
| *Overall Impacts* | Households in modern energy economy contributes to wealth creation. | Poverty alleviation.<br>Improved quality of life.<br>Political demonstration of service delivery. |

The success of any project is directly related to the quality of the decisions underlying the project. Quality decisions are well considered, justifiable and explainable. Since rural electrification has economic, environmental, social and institutional effects, and the social benefits often outweigh financial benefits, traditional cost-benefit analysis which reduces all the impacts to a single financial criterion is inadequate. For instance, impacts such as poverty alleviation are difficult to convert into financial terms, and are usually excluded from financial analysis. Multi-criteria (MC) analysis, using a family of criteria or attributes throughout the decision process, is more appropriate for RE decision-making.

The logical framework approach is one of several used to guide the implementation, monitoring and evaluation phases of projects, enhancing the justifiability and explainability of the project decision process. Informing the approach with MC analysis helps to make more apparent a wide range of possible uncertainties that often lead to later project failures. In essence MC analysis encourages a multi-dimensional perspective on the framework approach (instead of focusing mainly on the financial dimension), and provides a structure and a common terminology for discussion throughout the decision process.

Three examples indicate how new tools in MC analysis can be used to inform the decision makers:

- An Uncertainty Checklist (Figure 2) can be created from lessons learned from failures and problems on previous electrification projects. This checklist helps to make explicit the project uncertainties.

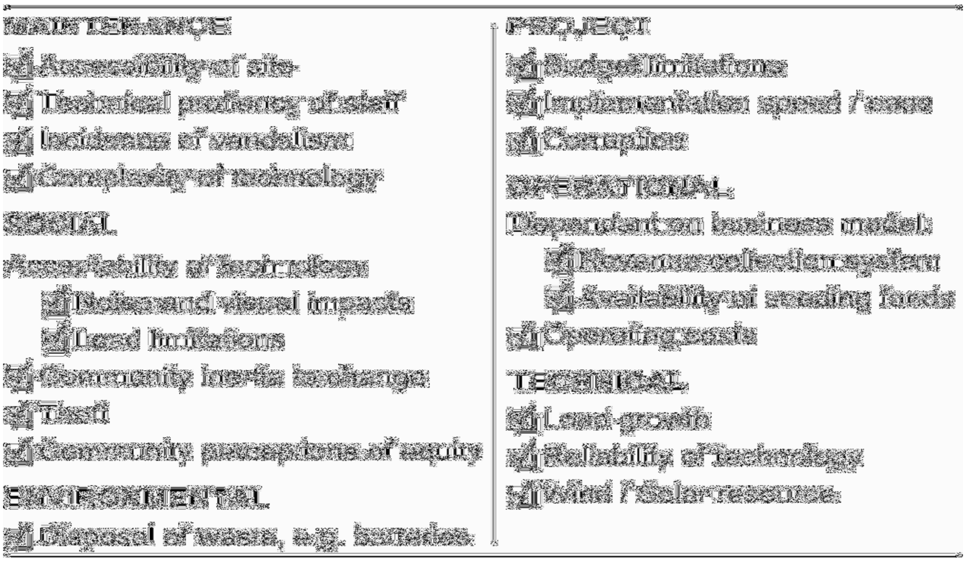


Figure 2. An example of uncertainties included in a checklist for a rural electrification project, showing each item has been considered [Bekker].

- The minimum set of attributes should model all the significant impacts in order to balance the measures of investment, performance, and risk. Each criterion (attribute) can be rated with an integer value between –3 (very negative) to 3 (very positive). If a specific criterion has sub-criteria (eg. financial impact), the combination of the sub-criteria ratings into a final rating for the criterion is subjective for each respondent.

| Rating | Number |
|---|---|
| Very positive | 3 |
| Positive | 2 |
| Slightly positive | 1 |
| Neutral | 0 |
| Slightly negative | -1 |
| Negative | -2 |
| Very negative | -3 |

Colours as shown in Fig 3 can be used to assist the visual interpretation of a large table of options. The different criteria are not combined into a single composite value in order to rank alternatives; however, they form a part of the decision process regarding the investment.

Figure 3: Attribute Rating.

- An Outcomes Structure (Figure 4) can be useful for informing decision makers of a wide range of possible outcomes of electrification projects.

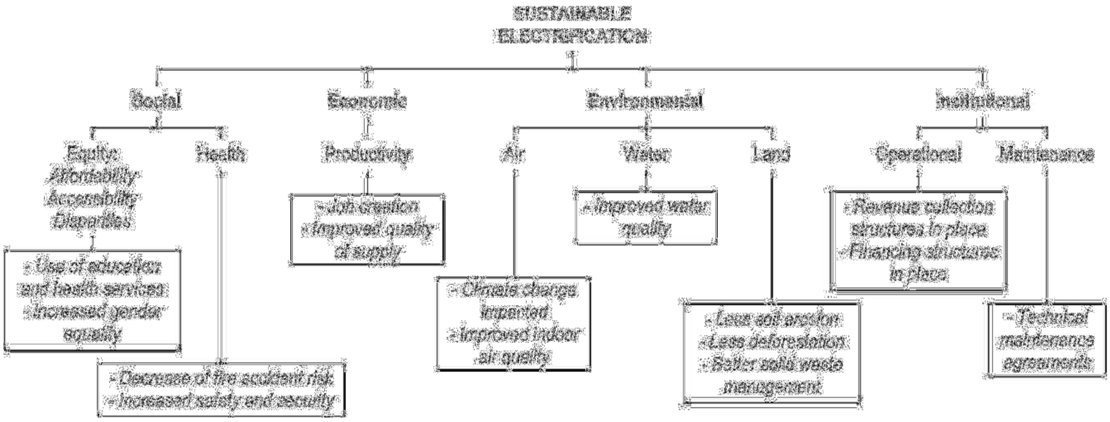


Figure 4. Outcomes Structure with examples of outcomes groups derived from IAEA energy indicators [Bekker].

## 5. Conclusion and recommendations

National governments, utilities, donor agencies, multi-lateral development banks, NGOs, private companies and local entrepreneurs are developing and implementing programmes to improve access to modern energy services, reduce energy poverty, support local socio-economic development and improve the living conditions of people in rural areas. Limited government resources, limited ability of customers to pay for electricity and unfavourable technical conditions (long distances, low load densities, low average loads) continue to characterize rural electrification. Many countries have shown that rural electrification can be achieved provided that subsidies on the investments and proper institutional arrangements are made available.

Bangladesh, one of the poorest countries in the world, has provided access to many rural villages through a system of innovative cooperatives, a strong, constitutionally-backed, national commitment, and support from the international community. Thailand and Vietnam have provided access in excess of 80% through incentives, international support and the utilization of technical expertise by their national utilities. In Mexico, a combination of centralized planning and decentralized implementation has led to a near 95% electrification rate. Tunisia provides 88% of its scattered rural population and 100% of the urban population with access to electricity by using a 3-pillar integrated planning solution structured around education, health and rural electrification. Brazil and South Africa have implemented large scale electrification programmes. China, the most populous nation in the world, has achieved electrification through its firm resolve towards public sector leadership in planning and effective on-the-ground implementation at a decentralized level.

Common among these and other countries is the recognition that purposeful arrangements are needed, and that the only way to provide electricity for the poor is through a socially, technically and financially sustainable solution as part of a development process.

Though the links between energy and poverty reduction have not yet been fully understood, it is clear that there is a strong correlation between economic poverty, food poverty and energy poverty. Against this background electrification seeks to address the problems of energy poverty. However, because of economic poverty, the affordable tariffs for the delivery of services do not provide electricity utilities with sufficient revenue for achieving long-term financial sustainability. Where tariff income provides only limited cost recovery, the impetus to engage in socially responsible electrification is constrained by commercial feasibility and the resultant limited access to capital for investment. Therefore, alternative solutions are required, depending on the extent of the need and the resources available.

The technology for the electrification of rural and slum areas is not yet mature but still evolving. It also comprises more than technology. Important observations from the colloquia and the deliberations in the working group are that the electrification of these areas needs a multi-disciplinary approach, and also that decision makers need appropriate information, structures and tools as a basis for consistent and appropriate decision-making.

International experience clearly suggests that rural electrification programmes require a strong public sector initiative, especially during the early stages. In several cases institutional changes and re-regulation of the power sector are needed.

For rural electrification a process orientation would seem appropriate: from idea to the use of electricity, and from design to operation and maintenance. Both central grid-based and decentralised systems are needed to meet the needs of the large number of presently unconnected dwellings.

Scattered PV and micro-hydro schemes can be economically attractive when it becomes cost-prohibitive to expand network systems to sparsely populated rural areas. These conditions also offer opportunities to deploy locally available energy sources. For these small-scale supply schemes it can be easier to obtain funding, despite, in many instances, these options having significantly higher unit costs due to a lack of economies of scale. Hybrid power generation systems that combine one or more renewable energy sources with other technologies such as batteries and conventional diesel generators offer improved off-grid generation systems with appropriate operational performance.

Though substantial progress has been made, much remains to be addressed in more detail. The Working Group recommends consideration of the following subjects for further study by Cigré:

- The practical experience and lessons learnt with prepaid meters need to be collected on a wider scale and assessed in more detail, not only from the technical side but also from the system of implementation side.
- The wide variety of technical and quality standards, for both grid-based (medium and low voltage) and off-grid systems, need to be investigated in more detail.
- The cost comparison of grid-based and off-grid electrification based on actual projects and figures.
- Hybrid systems, both small and large capacity (several MWs): feasibility and limits in terms of capacity, benefits, practical experiences, standards.
- Opportunities and limits for consumptive and productive use of stand alone PV systems.
- Service interruption costs for rural consumptive and productive uses: preliminary results given but further study needed.
- Business models for both grid-based and off-grid systems, also in a liberalized environment.
- The need for building relevant local capacity.

## 6. Reference documents

This report draws on many source documents, most of which have not been formally published, and the Working Group acknowledges the following contributions.

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MA Van Harte, CT Gaunt: “Challenges for reliability regulation in a developing country”.

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CK Loo, H Osman: “Issues associated with connections of DG in remote rural areas”.

A Manglick: “Transgrids experience and initiatives on demand side response”.

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