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Mini-Review

Energy efficiency: scope, benefits, synergies and pitfalls for the developing world

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Abstract

Energy Efficiency (EE) has many meanings and contexts. It is sometimes taken to be solely the reduction of end use power by the use of more efficient electric appliances, especially lighting. It does, however, have other connotations, with these being efficiency of converting raw energy into power (or other end use energy form), efficient transmission and distribution and having as low as possible carbon footprint. In developing nations with restricted indigenous raw energy resources, it also means finding local sources of raw energy as import replacements.

Creating, maintaining and promoting EE needs to be looked upon as an ongoing activity. It must be examined in all its facets to produce the greatest benefit. In developing economies it cannot be seen as a limiting factor to economic development and social well-being. Mature and developed economies, such as many of those of the EC, will have different EE agendas compared to those of the developing world, whose leaders must find the most applicable form of EE for their economies.

Keywords: Energy Efficiency, Developing World, DSM, CDM

Introduction

Defining energy efficiency

Energy Efficiency (EE) has numerous meanings and contexts. For some it means the application of Demand Side Management (DSM) in electric power use; for others it is the mileage achieved per unit of liquid fuel supplied to a vehicle, whilst others would include such factors as continuity of supply and the carbon footprint of energy generation (production), transmission and use.

CDM (Clean(er) Development Mechanism) has a lot to do with EE. The production of a specific item using less energy and with lower total carbon emissions is the theme of CDM. The substitution of a renewable energy source for a fossil fuel energy source also has a significant relationship to EE. The reduction of the carbon footprint of the manufacture, distribution and waste management of a specific product also has great relevance to EE.

In the developing world the need for energy to assist in escaping poverty and to accelerate development is apparent. The increase in the import price of fossil fuels during the 1990s and early and mid 2000s has seen the foreign exchange situation of some developing nations (e.g. the Philippines and Pakistan) challenged with electricity and transport fuel costs cutting into the living budget of the populace.

The internationalisation of raw energy prices (i.e. oil, coal and natural gas prices being set by the international market with minimal reference to local capacity to pay) has increased the relative cost of energy to developing economies, whilst the steep increase in the price of steel and other fabrication materials, plus the high cost of international expertise required for the design of major energy infrastructure, have been additional impediments to developing economies. At the same time, the transfer of consumer goods and capital plant manufacturing from developed economies (essentially through de-industrialisation) to developing economies with cheap labour has increased their energy need and thus the need for EE.

In the developing world, EE has also come to mean reducing the dependence on imported fuel and the substitution of imported raw energy with indigenous raw energy, preferably renewable energy. This desire for energy independence again is partially related to the internationalisation of raw energy.

EE in the developing world thus means reducing energy input per unit of manufacture, reducing energy wastage in commercial and domestic use, improving generation efficiencies at all levels of production, substituting imported raw energy with indigenous raw energy, complementing imported raw fossil fuel energy with indigenous fossil fuel and/or renewable energy, improving transmission and distribution systems, and generally creating systems that will allow for economic growth and development with long-term sustainable energy input.

Scope of EE in the Developing World

The energy need (the measured and estimated requirement for energy) and demand (the willingness and ability to pay for meeting the need) are flexible and will be partially determined by how well EE is applied. EE in effect is in part a mechanism to help get needs to match demands. There can however be pitfalls in EE, these being for example unexpected consequences of substituting one fuel for another (as in increased plant maintenance), or using a renewable energy resource, where the raw energy may be ‘free’ but the CAPEX and OPEX are not sustainable in the context where it is to be utilised. Two specific applications of EE are examined in this paper, these being Electrical Power and Transport Fuels.

EE and Electrical Power

In terms of electricity supply, opportunities and responsibilities for EE can be defined in terms of generation, transmission, distribution and use, as illustrated in Figure 1.

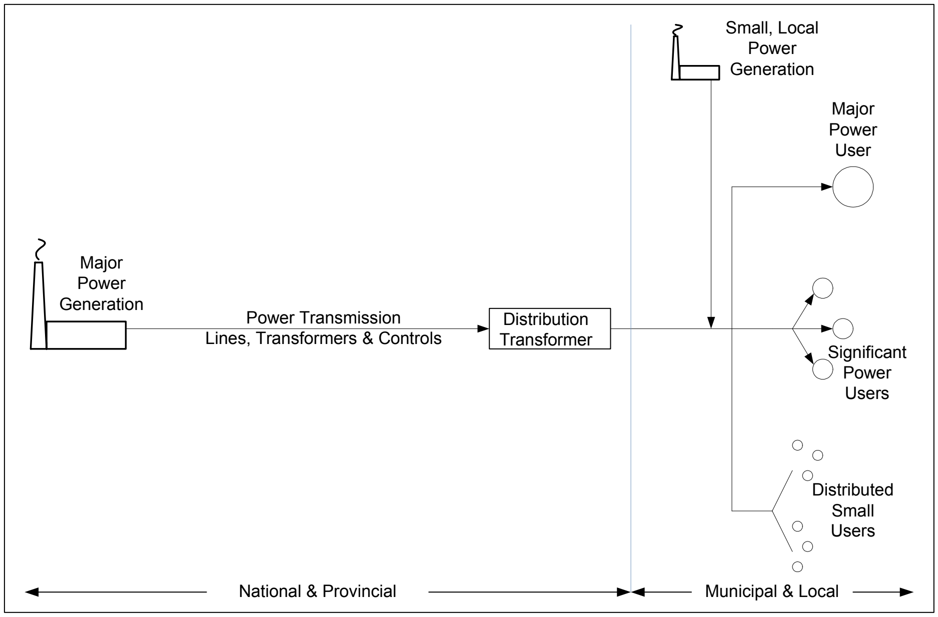

Figure 1. The Power Grid

A relatively new and growing feature of the grid is the occurrence of significant small (distributed) local generation. This will often be from renewable sources, such as, biomass, mini-hydro, solar voltaic and wind. The advent of the household mini-solar photovoltaic can make an urban dwelling a power generator with some jurisdictions offering incentives through feed-in tariffs to households. The advent of regional wind-farms has created the opportunities for rural property holders to become significant 'small' generators with outputs in the tens of megawatts. Where this home and locally generated electricity is to be fed into the national grid questions of power quality (frequency and voltage stability, and availability) plus feeder (transmission) capacity and reliability arise. For example, biomass can have very significant seasonal supply variations and may require fossil fuel supplementation. If through the lack of supply or through high moisture content, the supply of raw energy cannot be met, the reliability of electricity supply cannot be guaranteed.

Biomass with fossil fuel supplementation (e.g. local lignite or lower black coal) can assist in developing both seasonally available biomass and marginal fossil fuel resources.

Non-grid connected power generation and use also have major ramifications in terms of EE. Specific industrial and commercial power loads can be met with dedicated generation, generation capacity that may be connected to the grid on occasion, but is primarily meant to supply a specific need. Oil refineries, paper mills and aluminium refineries often have significant dedicated generation capacity. Dedicated, ring-fenced generation can also supplement grid power in situations where meeting peak loads is required. In this case avoiding peak power tariffs as well as insuring key supply, come together as solid reasons for installing dedicated peak power capacity.

EE may also have very significant influences in the selection of co-generation and combined heat and power systems. This will be explored later in this paper.

Specific factors in electrical EE application

Generation and transmission efficiencies, the efficiency of converting raw energy to a desired form, i.e. AC electricity and reticulating that electricity

For a super-critical coal fired power station, the fuel use and electricity output could look like the following:

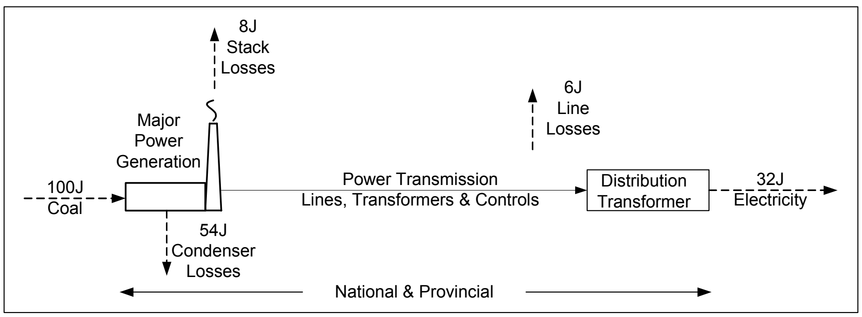

Figure 2. Fuel Input and Electricity Output, Conversion Energy Flows for a Major Coal Fired Plant.

The features of the system described in Figure 2 are that it is big (say greater than 300 MWe), it uses current technology in terms of generation and transmission and the output power is reliable with the whole system having around an 85% capacity factor. The system can however be improved, with new generation plant (an Integrated Gasification Combined Cycle with a total efficiency of say 45%), a strengthened power grid (with the increase of carrying voltage from say 275 kV to 500 kV, thus reducing the line losses), and improvements in power management producing an output of say 41J, a significant improvement but one that is costly in terms of capital investment required.

In terms of generation, base-load (i.e. the amount of power required to meet minimum demands based on reasonable expectations of customer requirements [1]) is supplied by a big plant operating at or near maximum capacity. It is a national or major provincial responsibility. Nuclear power using new Light Water Reactors (LWR) has an efficiency of around 35%, and Figure 2 thus becomes:

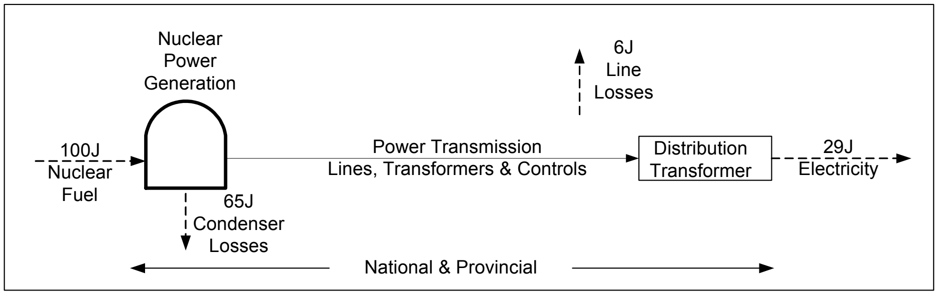

Figure 3. Fuel Input and Electricity Output, Conversion Energy Flows for a Nuclear LWR Plant.

Figures 2 and 3 are schematics of two power generation and transmission systems with similar outputs and efficiencies; however, the nuclear plant has a much smaller operational carbon footprint. It can be noted that present day coal fired plants have carbon emissions (as CO_2 equivalents) of around 900kg/MWh whilst nuclear ranges from 20 – 40 kg/MWh [2].

The minimisation of the overall carbon footprint of the total electricity supply will need careful consideration regarding what are the best choices of large base-load generation plant. Although choices based on carbon footprint may be available with respect to distributed generation (small plant situated in municipal and local areas), the base-load generation carbon footprint will not provide that many choices. In many situations the choice will be between coal, natural gas and/or nuclear.

Distribution efficiencies, the efficiency of directing energy to end-users, e.g. electricity to end users from a major node.

Electrical distribution efficiencies are partially dependant on the nature of the final end use. Significant factors in determining efficiency are Power Factor (PF), transformer adequacy and the quality of the conductors. Power factor is defined as, 'the ratio of real power to apparent power and is related to the phase angle between voltage and current'[3]. A power factor of less than one equates to wasted current and an inefficient power delivery system. To overcome low power factor (in some areas as low as 0.6) power factor correction is applied, as shown in Figure 4.

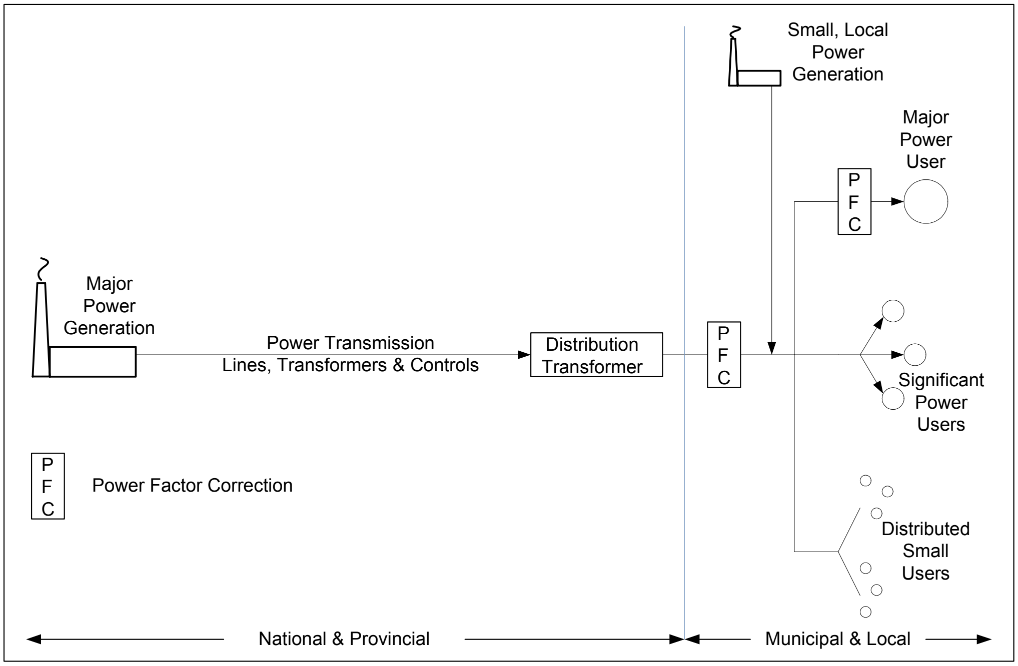

Figure 4. Power Factor Correction Applied to the Distribution System and User Loads.

It can be noted that poor power factor also increases losses in transformers and in distributive conductors, where unnecessary heat is generated.

The other problem in transmission and distribution in the developing world is the inadequacy of conductors (powerlines) and anciliary plant such as transformers and monitoring and switching devices. These inadequacies lead to excessive energy loss again through the generation of wasted heat and poor load following.

End-user efficiencies, the efficiency of what the end-user applies the power/energy or fuel to.

End-users of energy should be mindful of wastage, since for the majority of such users that wastage is costing money. There are however societal and economic reasons why end-users do not improve efficiency of their energy usage to the maximum extent, these being:

- Efficient appliances such as airconditioners with reverse cycle and inverter technology are capital expensive and are therefore unattractive for communities that have limited capital,
- Luminaires such as standard Compact Flourescent Lamps (CFLs) produce a different range of frequencies to traditional Incandescent Lamps (ILs),
- Although CFLs are claimed to have a longer lifetime than ILs, their light output does significantly decrease over their rated service life [4] [5],
- There are environmental questions regarding the disposal of CFLs that have not been fully resolved, and there is controversy regarding the amount of embodied energy in such lighting,

- Some electricity utilities only charge for Watts (not kVA) and have no or little penalty for poor Power Factor, and
- There are those users that are not aware of the loss or who could not care.

Other energy inefficiencies in total power grid systems

Some other examples of energy wastage at the generation end are:

- Fugitive emissions of methane from natural gas production and coal mining,
- The disgarding of mined lower quality coal without consideration of applicable uses for that coal,
- The use of single (simple) cycle gas turbine operation for base-load power generation,
- The use of inadequate cooling on steam cycle plants (fossil fuel and nuclear) causing loss of generating efficiency,
- Poor management of biomass, where degradation is allowed to remove significant energy values before use, and
- The non-use of energy storage (specifically pumped storage) to better utilise intermittant renewable energy and reserve spinning capacity.

EE and Transport Fuels

EE and its relationship to transport fuels has many facets, some of these being:

- The efficiency of end-use applications in terms of the efficiency of engines, transmissions and rotating parts is important. The age of vehicles is related to their efficiency and developing economies with a high proportion of vehicles that are 'old' have lower aggregated transport efficiency than those with more modern vehicles.
- The distribution of transport fuels is a major consumer of transport fuels, and economies with poor distribution systems will be less efficient in terms of the percentage of energy reaching the end-users.
- Transport fuels are refined products and the refining process has in itself an inefficiency and a significant carbon footprint. The more refined the fuel the greater are the energy losses, and transport that relies on highly refined fuels, that have a narrow quality window, has an inherent fuel inefficiency.
- The production, refining, transport and use of fuels all incur energy losses as spills and leaks (and sometimes theft – e.g. oil theft in Nigeria). In developing countries poor distribution systems will have greater losses.

EE and indigenous and renewable transport fuels

The desire of developing economies to be energy self-sufficient is understandable, especially where those economies are industrialising with high energy demand production technologies. The development of bio-diesel, wood derived ethanol and biomass derived dimethyl ether are all looked upon as being replacements or supplements to traditional transport fuels. They however do come at a 'price' with this price being the loss of arable land and in some cases the lowering of operational efficiency of transport units and increased maintenance [6].

Transport fuels derived from true wastes, such as Municipal Solid Waste (MSW), are possible but until now the processing of those wastes into useable fuel streams has not been adequately demonstrated. The honing of the acidification and fermentation technologies may make such processes technically and economically viable in the future.

There is a window, however, that in some cases makes the production of indigenous and renewable transport fuels viable in both an economic and agricultural resource conservation sense, this being the use of wastes such as field trash in mobile gasifier systems. These technologies are being re-examined in Australia [7], have been sought in Pakistan and have been demonstrated in Thailand. There is also the possibility of ethanol production from such wastes in moderately sized plants.

Stretching the Available Energy Supply and Energy Infrastructure

Co-generation, 'the simultaneous generation of electrical and thermal energy where both forms of energy are put to productive use' [1], and its technical cousin, Combined Heat and Power (CHP) can stretch available raw energy resources. The concepts of generating power from waste heat or producing useful thermal energy are well understood, but require planning to accomplish. In developing economies the co-location of power generation and industrial production units can produce significant synergies and total energy savings.

The second stretching is related to electrical energy in the balance between base load and peak load. Keeping the growth in base and peak load in proportion will avoid the necessity for having seldomly used peak generation and transmission capacity. The use of economic penalties/incentives in the form heavy peak power tariffs and attractive base load tariffs is one means of keeping peak demand in check. Another way is to work with users and offer power planning. In some instances the installation of off-grid peak capacity may be the best solution of meeting high peak loads.

EE and Economic Development

Mature technological economies are in many cases exporting energy demanding manufacture (de-industrialising [8]) to developing regions, with examples being the transfer of electronics and white-goods manufacturing to the developing economies such as Eastern Europe, China, India, Thailand and the Philippines. The developing economies receive employment opportunities, but also must be able to supply energy for manufacturing, population relocation, labour transport, materials and product transport, services provision and waste management.

As the price of energy becomes further internationalised, as in the case of oil, traded coal, uranium, cross-boundary electricity and natural gas (either piped or as LNG), EE in manufacturing will gain additional importance. One advantage for developing economies is that they will be able to utilise the most advanced EE technologies in their development, if the additional CAPEX can be met and technology licencors are willing to share/trade their intellectual property.

Conclusion

Energy Efficiency (EE) has been defined by some proponents in a very narrow sense that has often meant little more than replacing incandescent lighting with Compact Flourescent Lighting (CFL) [9]. The total scope of EE is however very broad and includes raw energy sourcing, conversion (e.g. power generation), transmission and distribution, as well as all forms of energy use. It requires national direction followed up by regional and local implementation.

The way forward in the application of EE in the developing world will be partnerships between technology developers and owners, technology users (such as manufacturers) and financiers. To make the partnerships work there must be equity for all stakeholders, including local labour.

In the developing world implementing EE will be one of the key factors governing economic development. EE requires requires public understanding and support to be effective in promoting development. Energy Efficiency is important to all levels of society.

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