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Innovations for Sustainability: A Case of Mainstreaming Energy Access in Rural India

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Abstract India faces a formidable challenge in ensuring security of access to modern energy carriers to majority of its population. The fossil-fuel dominated centralized energy system has proved to be ineffective in creating sustainable access to energy, which suggests need for a radical and innovative approach. We present such an approach. First, the need for innovations given the implications of lack of energy access on sustainable development is assessed. Next, possible innovations with respect to technologies, policies, institutions, markets, financial instruments and business models are discussed. Finally, an economic and financial feasibility of implementing such innovations are analyzed. The results indicate that such a proposal needs an investment of US$ 26.2 billion over a period of 20 years for a GHG mitigation potential of 213Tg CO_{2e}. The proposition is profitable for the enterprises with IRRs in the range of 39%-66%. The households will get lifeline access to electricity and gas for cooking at an affordable monthly cost of about US$ 5.7.

Keywords Energy access, sustainability, innovations, bioenergy technologies

I. Introduction

Poverty and climate change are the two greatest challenges being faced by the humanity. Climate change is expected to intensify the sufferings of the poor by impacting the meagre resources and assets owned by them. Poor with limited access to income as well as to other resources, goods and services are typically vulnerable to unpredictable events and disasters. Energy is at the center of the two - extent of its access determines the poverty levels and it contributes to climate change by emitting greenhouse gases (GHGs). Energy, more specifically the modern energy, is the driver of technology and technologies are expected to facilitate improvement in living standards, promotion of efficient use of resources, adaptation to local conditions and needs, and integration with other existing technologies.

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India's energy challenges are accentuated by the presence of majority energy poor lacking access to modern energy services. The presence of 365 million people without access to electricity and 715 million relying on solid fuels for cooking out of a total rural population of 826 million in 2011 (Chandramouli, 2012) indicate the seriousness of challenge. This suggests the need for expanding the energy system both to bridge this access gap as well as to meet the requirements of fast growing economy and imperative of partnering with global economies in climate change mitigation. The desired outcome would be to achieve all the three objectives without compromising on any one. In this context, the challenge is to expand access to basic energy services for the large number of energy poor while contributing to climate change mitigation. This leads to questions such as can climate change mitigation become a stimulus for expanding rural energy access in India and can bioenergy technologies make significant contribution to meeting both the objectives. This study makes an attempt to answer these questions.

Lack of energy access has implications for economic, social and environmental sustainability (Saghir, 2005; UNDP, 2007; Ezzati and Kammen 2002; Kanagawa and Nakata 2008; Johnson and Lambe, 2009). Experiences and the literature point to the widening gap that exists between recognition of the need for expanding energy access and action towards this (Balachandra, 2014; Balachandra, 2011a; UNDP, 2007). Partly, this is because energy governance often been biased towards "supply-side" and suggested solutions almost always revolve around "hardware" aspects (Balachandra, 2011a; Srivastava and Rehman, 2006). The "demand-side" aspects of energy have been grossly neglected. This is an outcome of ineffective government policies and programs implemented over the past several years (Balachandra, 2012; Balachandra, 2011a; Reddy et al., 2009; Srivastava and Rehman 2006; Planning Commission, 2002; Bhattacharya and Srivastava, 2009; Bhattacharya, 2006; Modi, 2005; Neudoerffer et al., 2001). The fossil-fuel dominated centralized energy supply system has proved to be ineffective in creating physical access to modern energy carriers for the majority of rural population as well as ensuring adequate and reliable energy supply to those who have at least physical access. These suggest that India needs a radical approach to bridge energy access gaps. In this paper, we attempt to discuss the following in the context of mainstreaming sustainable energy access - (i) Need for innovations given the challenges of energy deprivations and imperative of sustainable development; (ii) Modern bioenergy technologies as innovative solutions for providing affordable, reliable and adequate access to both electrical and heat (cooking) energy for all rural households by 2030; and (iii) An innovative implementation mechanism for effective rural energy governance with specific proposals for effective institutions, rural energy policies, regulatory practices, multi-stakeholder partnerships, financial instruments and entrepreneurial models for energy service delivery. In the next step, this approach is subjected through three-pronged evaluation for its effectiveness by assessing - (i) the implications for energy resources, energy needs and environment, (ii) the economic cost-benefit analysis at the macro level, and (iii) financial cost-benefit analysis at the energy enterprise level.

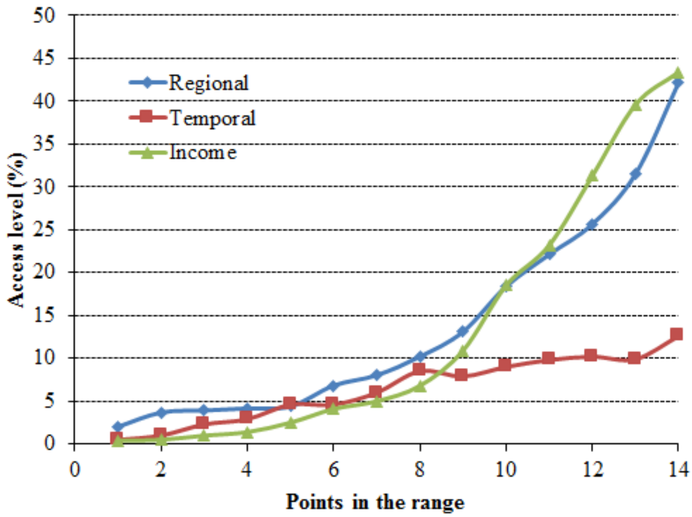
II. Need for Mainstreaming Rural Energy Access in India

Energy security, fulfilling one's energy needs in a sustainable manner, is an important issue both from the perspective of economic development aiming at eradication of prevailing extreme poverty and climate change which is threatening the existence of humanity. Energy, development and climate change are correlated and the causation is both ways. Majority of the households in the developing world, can neither afford to have modern energy carriers nor reconcile to have standard of living below poverty line because of energy starvation. Energy poverty defined in terms of lack of access to modern energy services is a direct outcome of income poverty. The poor cannot afford modern energy carriers and live in houses, which are unfit to be connected to the modern energy systems, for example, to the electricity grid or to a gas network. Similarly, a poor nation is constrained by inadequate access to energy and capital resources, and therefore cannot build adequate infrastructure to create connectivity to modern energy carriers. Thus, "un-affordability" due to poverty and "inaccessibility" due to inadequate infrastructure are the root causes of lack of access to modern energy. India faces a very significant challenge in this regard, especially in the rural regions.

1. Dynamics of Rural Energy Access: Indicators of Deprivations

The rural cooking energy scenario in India is characterized by inadequate, poor and unreliable supply of energy services and large dependence on biomass fuels (Balachandra, 2014; Balachandra, 2012; Chandramouli, 2012; Krishnaswamy, 2010; Reddy, et al., 2009). Figures 1 and 2 attempt to capture dynamic changes in rural cooking energy and electricity access over a time period of 30 years, across income classes and across regions represented by major states in India using the National Sample Survey (NSS) results of 1997-2010 and Census of 1981-2011 (NSSO, 1997; NSSO, 2001; NSSO, 2007; NSSO, 2008; NSSO, 2012; Census 2005; NHB, 2004; Chandramouli, 2012). The analysis is limited to two indicators, namely, access to electricity for lighting and modern fuels for cooking in the residential sector. The modern fuels for cooking include liquefied petroleum gas (LPG), biogas, kerosene and electricity.

In Figures 1 and 2, the y-axis indicates the energy access levels whereas the x-axis indicates various points in the range given by 14 yearly data points during 1981 to 2011, 14 income classes represented by per capita monthly expenditure (PCME) classes in 2007-2010 and 14 major states[1] in the order of highest to lowest level of access.



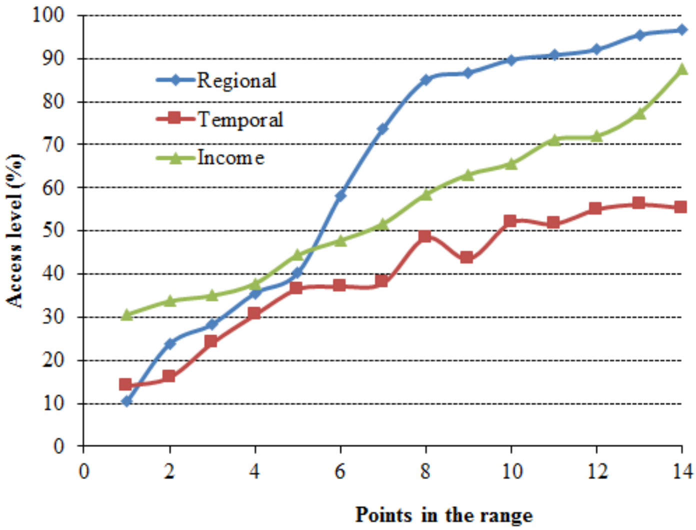
Source: Adapted from Balachandra (2012)

Figure 1 Dynamic changes in rural cooking energy access

Figure 1 indicates the unfavourable trends in cooking energy access. The temporal trends should have had the highest slope indicating high growth in cooking energy access levels, which is not the case, access level has increased from 0.5% to just 12.6% in about 30 years during 1981-2011. The analysis of the trend shows that the household access level was growing at a rate of 19.2% annually during the first decade (1981-1991) came down to 10.5% during the second decade (1991-2001) and drastically reduced to 4.8% in the recent decade (2001-2011). However, the slopes are high for both the graphs showing changes in access levels with respect to per capita income and regions represented by

[1] 14 major states in the ascending order of rural electricity access levels are Bihar, Uttar Pradesh, Assam, Odisha, West Bengal, Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh, Tamil Nadu, Kerala, Punjab and Himachal Pradesh. Similarly, 14 major states in the ascending order of rural cooking energy access levels are Chhattisgarh, Odisha, Bihar, Madhya Pradesh, West Bengal, Uttar Pradesh, Rajasthan, Assam, Karnataka, Gujarat, Andhra Pradesh, Kerala, Tamil Nadu, Punjab and Himachal Pradesh

different states. One could observe significant variations in access to modern fuels with respect to income levels. The access levels are close to zero at low income levels and they increase to 43% for the highest income level. The regional variations in cooking access levels are again high, which ranges between 2% and 42.2% for major states. This suggests that the pro-poor energy access policies (Balachandra, 2012; Balachandra, 2011a), especially with respect to access to modern fuels for cooking, of government have failed to achieve the desired results. The temporal trends also suggest lack of any new initiatives by the government to address these challenges in the recent years. Similarly, the regional variations in access levels suggest the need for states with lower access levels learning from successful states.



Source: Adapted from Balachandra (2012)

Figure 2 Dynamic changes in rural electricity access

Compared to cooking energy access, the lighting access situation appears far better (Figure 2). Unlike cooking energy access, the governments both at the national and state level have initiated many programmes (Balachandra, 2012, Balachandra, 2011a) for expanding rural electricity access. The lowest and highest electricity access levels among the major states are significantly high at 10.4% to 96.6% compared to those for cooking energy access. As in the case of cooking energy access, the temporal variations in electricity access levels are lower than income and regional variations. The access level has increased from 14% to about 55.3% in about 30 years during 1981-2011. The analysis of the trend shows that the household electricity access level was growing at a rate of 8.1% annually during the first decade (1981-1991) came down to 3.6% during the second (1991-2001) and further reduced to 2.4% in the recent decade (2001-2011). This suggests that the government programmes on rural electrification, especially the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), have failed to achieve the desired impacts on expanding electricity access. Further, one could observe a significant increase in access with the rise in income levels indicating that income poverty may be one of the reasons for lack of access. Similarly, increase in electricity access levels can also be seen with respect to states. Some states are more successful than others. The inadequacies at the state level with respect to policies, programmes, implementation, etc., appear to be the reasons for such a situation.

2. Energy Access and Implications for Sustainable Development and Livelihoods

The strong relationship between energy access and economic development is a proven fact. Here an attempt is made to validate this hypothesis in the Indian context. The data for all the relevant indicators have been obtained for the major states of India from secondary sources. A total of 13 states with varying energy access levels are included for the analysis. This is a list of states based on performance related to cooking and electricity access levels (Figures 1 and 2). Rural household energy access indicators, cooking energy and electricity access, are compared with per capita state income, head count ratio of poverty (HCR) and index of infrastructure. The per capita state income is in terms of per capita net state domestic product at factor cost (at current prices) obtained from the Reserve Bank of India (RBI, 2010). The incidence of poverty is measured in terms of HCR of poverty and index of infrastructure is developed using economic, social, and administrative infrastructure indicators (Planning Commission, 2008). The indicators used for developing index of infrastructure are based on agriculture, banking, electricity, transport, communication, health, and civil administration. Since indicator values use different scales and vary with huge margins, a normalization procedure is used. A Z-transform normalization procedure is used to normalize all the indicator values so that their overall distribution has an average of “zero” and a standard deviation of “one”. This procedure helps in determination of each state’s standing in relation to other states on the basis of a given index. The equation used for this purpose is as follows:

$$Z(I_S) = \frac{I_S - I_{avg}}{\sigma_I}$$

Where,

Z(Is) = Transformed indicator value for the state **"S"**

Is = Actual indicator value for the State **"S"** for a given indicator **"I"**

Iavg = Average of actual values of each State obtained for a given indicator

σI = Standard deviation of all the actual values.

The five indicators with normalized values for all the chosen states are plotted as shown in Figure 3.

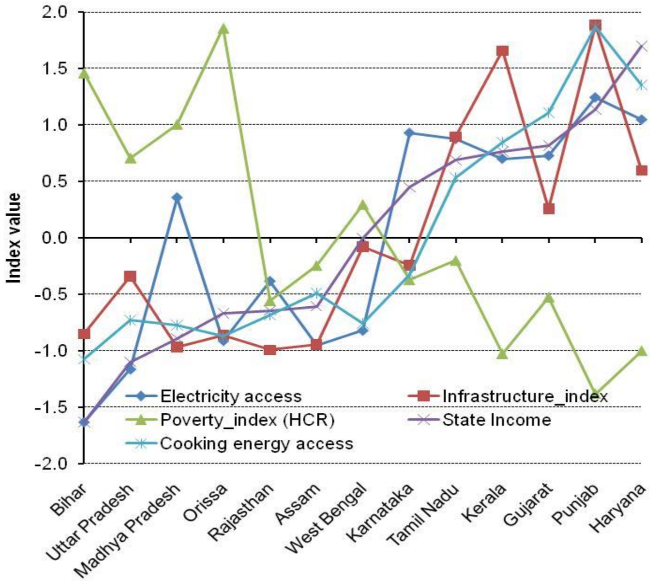


Figure 3 Rural household energy access and development

Figure 3 suggests a strong relationship between energy access and overall development. The states are arranged in the ascending order based on per capita state income. With zero being the mid-point for the range of normalized values for the index on state income, the performance of states on different indices can be compared. West Bengal is on the mid-point having obtained zero value for the index state income. It is a state with low access levels in both cooking and electricity. Therefore West Bengal and the states ordered before it can be classified as low income states where as the states after West Bengal as high income states. Thus, we have seven low income and six high income states. The low income states have invariably obtained values less than zero for the three indicators on infrastructure, electricity and cooking energy access and above zero for HCR with few exceptions. Similar is the case with high income states obtaining below zero value for HCR and above zero for the remaining three indicators, again with few exceptions. Madhya Pradesh is less successful in providing cooking energy access to rural households whereas it has done well with respect to electricity access. Karnataka, though a high income state, has failed in providing cooking energy access and fares badly with respect to infrastructure index. Rajasthan and Orissa though categorized as low income states have done fairly well in reducing the poverty levels. They have normalized HCR levels which are below zero. The trickledown effect appears to be strong in these two states. However, similar good performance is not visible with respect to energy access and infrastructure index. Overall it could be stated that the states with better rural infrastructure and energy access levels have lower incidence of poverty and higher per capita income levels.

III. Modern Bioenergy Technologies as Low-Carbon Solution

Biomass is typically classified into two types, woody and non-woody. Woody biomass is derived from forests, plantations and forestry residues. Non-woody biomass comprises agricultural and agro-industrial residues, and animal, municipal and industrial wastes. The proposal is to use woody biomass for electricity generation through biomass gasification route and soft-biomass (including cattle dung) for biogas production through bio-methanation route. There are two distinct advantages of using biomass. First, India has adequate biomass resource potential to produce adequate quantum of modern energy carriers to meet the energy needs. Second, advanced biomass energy technologies, which are versatile and robust enough to perform at various scales and in rural regions have reached near commercialization.

1. Biomass for Power Generation through Biomass Gasifier

India’s biomass resource base for power generation is substantial. There are large tracts of degraded lands that can be used for growing biomass. An area of about 107 million hectares has been estimated to be degraded with 64 million hectares categorized as wasteland (GOI, 2005). As per the estimates, the minimum waste-land area that might be available for biomass production is about 35 million hectares. Agro-forestry can also be promoted through contract farming whereby corporate bodies can organize groups of farmers to produce the required biomass under contract through development of wastelands. The potential for additional production of woody biomass in the country has been estimated at 255 MT. Out of this, forests wastelands are estimated to contribute 171 MT and the marginal cropland to contribute the rest of 84 MT (Ravindranath and Balachandra, 2009).

Woody biomass can be converted to producer gas for use in internal combustion engines/alternators for electricity generation. Biomass gasifiers are devices performing thermo chemical conversion of biomass through the process of oxidation and reduction under sub-stoichiometric conditions. These systems are used to meet both power generation using reciprocating engines or for direct usage in heat application. Among the biomass power options, small-scale gasifiers (of 20 to 500 kW) have the potential to meet all the rural electricity needs and leave a surplus to feed into the national grid. Indigenously developed technologies for biomass gasifiers have been demonstrated successfully for their rural electrification potential, though on a relatively smaller scale.

2. Biomass for Biogas Production through Biomethanation

Currently, biogas is produced in India only through cattle dung as the feedstock. India has the highest bovine population of about 273 million (Kishore, et al, 2007) that produces a total dung of 1,190 MT/year. Even if the total recoverable dung of 458 MT per year (Vijay, 2006) is used for biogas, it is possible to produce 16 billion m3 of biogas per year, which can generate 336 PJ of energy. The biogas generated will be adequate to meet the cooking energy requirements of about 250 million people. Another alternative is to use soft-biomass as feedstock to produce biogas. The non-fodder soft biomass available in India is estimated to be between 300-600MT (dry) per year (Ravindranath, et al., 2005). Even if we assume that only 300 MT of dry soft-biomass is available per year for biogas production that can produce about 90 billion m3 of biogas per year at 0.30 m3 of biogas per kg of dry biomass.

Biogas, a mixture of about 60% methane and 40% carbon dioxide, is a combustible gas, which is the product of anaerobic fermentation of cellulosic materials such as animal dung, plant leaves and waste from food processing and households. Biogas can be combusted directly as a source of heat for cooking. In India, several types of biogas plant designs are being promoted, which use either cattle dung or soft-biomass as feedstock.

3. Climate Change Mitigation Imperatives and Benefits of Biomass Energy

The global climate change regime requires India’s contributions in mitigating GHGs. India cannot avoid participating in this global initiative for long time by insisting on the need for development. Non-participation might result in economic consequences. There is a danger of isolation in the global community. The wise strategy for India is to look for solutions which can contribute to climate change mitigation as well as sustainable economic development. There are a large number of options popularly known as “low hanging fruits” or “no regrets options” and expanding rural energy access with a major share from climate friendly renewable energy sources integrated with energy efficiency is one such option available for India.

The common belief is that the GHG emissions from the rural household energy consumption in India are negligible. The underlying assumption is that most of energy consumed is for cooking or heating and this is mostly derived from renewably harvested fuel wood or agricultural waste, which are considered carbon neutral. This is not entirely true. It is agreeable that all the cattle dung, crop waste and a large share of fuel wood is harvested on a sustainable basis and the carbon is recycled within a short period compared with climate change processes (Smith et al., 2000). Earlier studies have reported that on an average, in India, 40% of the fuel wood is typically obtained from unsustainable means in the sense that it is not from renewable biomass source (Parikh and Reddy, 1997). The situation might have worsened now considering that biomass use for cooking has consistently remained at same level in rural India and availability of firewood is declining. The CO_2 emissions from this 40% of the firewood use cannot be ignored and need to be included in the GHG emissions. It has also been shown that inefficient combustion of traditional biomass fuels in cookstoves yields significant gaseous products of incomplete combustion (PICs) that are GHGs (Smith et al., 2000). This incomplete combustion results in emission of black carbon, which is a potent GHG. Residential sector in India is considered as one of the major contributors of black carbon (BC). It has been estimated that the global warming effect of black carbon is equal to 20 to 50% of the effect of CO_2 (Wallack and Ramanathan, 2009). In other words, it is in general agreed that about 10-20% of the gross warming is due to black carbon (Baron et al, 2009) compared to about 40% by CO_2. Approximately, the residential sector is contributing 18% to 25% of the black carbon in the world (Baron et al, 2009, Smith, 2009). In the Indian context, the total BC emissions range between a high of 600 Gg/year to a low of 416 Gg/year (Venkataraman, 2004). Even the BC contributions of the biofuel used by the household sector in India too show similar variations ranging from 167-420 Gg/year. In addition to all these, the biomass combustion in cook stoves emits other GHGs like CH_4 and N_2O.

In India, cattle dung is first converted into cakes (mixing the wet dung and loose biomass from crop waste) and dried sufficiently before being used in conventional stoves for cooking. This open exposure of cattle dung results in release of CH_4 to the atmosphere. The experiments reveal that from one tonne of dung about 26% of gas potential is released when it is stored untreated in pits for a week to 10 days and when drying is slow. Thus, out of the gas potential of 45m3 /tonne dung, 25.73% = 11.58 m3 of biogas with 60% methane (6.95 m3 or 4.96 kg of CH_4) is wasted to the atmosphere. This is equal to about 104 kg CO_2 equivalent per tonne of cattle dung (Chanakya and Balachandra, 2012). In addition to biomass, the rural households in India also use LPG, kerosene and coal for meeting their cooking and heating needs. Similarly, these households use electricity and kerosene for lighting purpose. Thus, total emissions of GHG from all these energy carriers are likely to be significant.

IV. Scenarios of Universal Rural Energy Access in India

The proposal targets at universal access to modern energy carriers for cooking and lighting services by 2030, i.e., in 20 years starting from 2010, the base year used for scenario construction. The energy requirements are proposed to be met with a judicious mix of energy supply from centralized energy system (electricity grid and LPG) and decentralized bioenergy-based system (electricity and biogas from distributed energy systems). The modern energy carrier considered for lighting is electricity and that for cooking is either LPG or biogas. In the case of lighting, the energy efficient lighting technologies like compact fluorescent lamps, LEDs are proposed to be used. It is proposed that the programme of expanding rural energy access through decentralized energy systems would be based on market principles by adopting a public-private-people partnership (PPPP) driven business model approach. The approach adopted here is to construct scenarios of rural cooking and lighting energy access with an a priori target of 100% access by 2030.

The 2010 access levels for modern energy carriers are estimated using growth rates obtained from the household energy dependency shares during 2004-05, 2009-10 and 2011 (NSSO, 2007; NSSO, 2012; Chandramouli, 2012). The number of rural households in 2010 is estimated using data from Census, 2001; United Nations Population Division (UNPD) and Census, 2011 (Census, 2005; UNPD, 2008; MORD, 2012). Having derived 2010 status and decided about the 2030 status of rural household energy access, the next step is to determine the trajectory of the path of the growth in energy access till 2030. Only two aspects become important for this, speed at which the target is to be achieved and willingness to make the investments by the government, public and private sectors. The objective of developing these scenarios is to ascertain the implications for energy resources, investments, operating costs and carbon emissions.

Table 1 Rural household energy scenario in 2030

	Cooking		Lighting	
Characteristic	LPG	Biogas	Grid	Biomass gasifier
Total households in 2030 (Million)	188.2			
Households with access as on 2010 (Million)	24.7	0.3	105.5	0.0
Households provided with access during 2010-2030 (Million)	48.4	114.8	49.7	33.1
Annual fuel/electricity usage per household (kg or M^3 or kWh)	128	292	65.0	65.0
Annual energy requirements (Million Tonne or billion M^3 or GWh)	9.4	33.6	20,627	2,152
CO_2 emission factor (kg/GJ or kg/kWh)	67.4	0	0.83	0.0
Baseline CO_2 emissions per year (Million Tonne)	61.3	122.2	23.4	6.0
Alternative CO_2 emissions per year (Million Tonne)	29.0	0	17.1	0.0
CO_2 emissions mitigation potential per year (Million Tonne)	32.3	159.2	6.4	6.0
Annual recurring cost (Rs. Billion)	131.0	95.5	3.8	7.0
Installed capacity required (MW)	---	---	4,022	2,500
Initial investment for generation capacity (Rs. Billion)	---	---	175.8	81.2
Initial investment for transmission system (Rs. Billion)	---	---	128.7	0
Initial investment for stoves (Rs. Billion)	130.6	114.8	---	---
Initial investment for biogas plant (Rs. Billion)	0	356.8	---	---
Initial investment for distribution system (Rs. Billion)	0	265.2	64.4	40.0
Initial investment for final connection (Rs. Billion)	---	---	109.2	72.8
Initial investment for CFLs (Rs. Billion)	---	---	14.9	9.9
Total investment (Rs. Billion)	130.6	736.8	493	204

The summary of scenario results of cooking and lighting energy needs in 2030 is given in Table 1. Results for two alternatives, LPG-based and biogas-based cooking energy services for all households, are presented. In 2030, there are expected to be about 188.2 million rural households in India. Out of these, about 25 million have access to modern energy carriers for cooking in 2010 and the remaining 163 million requires to be provided access in the next 20 years. Out of these, about 48 million are estimated to have LPG connections whereas the remaining 115 million biogas connections. The total annual biogas requirement is about 33.6 billion M3 and to meet this, the estimated soft biomass (dry) requirement is about 67 million tonne, and the wet dung requirement is about 355 million tonne. The demand for LPG would be about 9.4 million tonne by 2030. Such a transformation from biomass to modern energy carriers for cooking has significant cost implications (Table 1). All the cost estimates are in 2010 Indian Rupees (Rs.). The cooking energy access scenario has an annual cost implication of about Rs. 336 billion by 2030 including the annualized capital cost discounted using a discount rate of 10%. The total investment over a period of 20 years is about Rs. 867 billion.

The GHG mitigation benefits of the proposed cooking energy access scenarios are significant. The baseline scenario for 2030 representing no interventions is expected to contribute nearly 184 million tCO_{2e} annually. The proposed scenario will have emission levels of just 29 million tCO_{2e} per year. There is an additional benefit of mitigation of CH_4 emissions equivalent of 37 million tCO_{2e} per year by avoiding open exposure of cattle dung. Thus, the proposed scenario, if adopted, can contribute to GHG mitigation of nearly 192 million tCO_{2e} annually. The GHG abatement cost of Rs. 1,756/tonne (US$ 29.3/tonne)[2] is attractive considering related development benefits.

Similar scenario results for 100% electricity-based lighting access are presented in Table 1. As per the projections made about 105.5 million households are estimated to have access to electricity for lighting in 2010 and the remaining 82.8 million households need to be given access in the next 20 years. Out of these rural households, about 49.7 million are expected to have grid-based electricity connections whereas the remaining 33.1 million households are to be connected to the biomass-based distributed electricity systems. The results indicate that by 2030, the centralized grid is expected to supply about 90% of the electricity needs of the rural households for lighting and the remaining 10% to be contributed by the distributed electricity. The installed capacity required to provide lighting access for the incremental households is about 6,500 MW with 4,000 MW from the grid and 2,500 MW from distributed biomass power. From Table 1, it may be observed that the total investment over a period of 20 years is about Rs. 697 billion with grid supply accounting for Rs. 493 billion and biomass gasifier power for Rs. 204 billion. On the other hand, the total annual cost (including annualized capital cost and recurring cost) of biomass gasifier-based electricity access is at Rs. 22.9 billion compared to grid-based access at Rs. 29.6 billion. The annual GHG mitigation

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[2] Rs. 60 per US $

potential is expected to be 12.4 million tonne. The GHG abatement cost of about Rs. 4,233/tonne (US$ 70.6/tonne) is relatively high in the present context.

The overall annual cost implication of providing access to modern energy services is about Rs. 389 billion (US$ 6.5 billion). In addition, the proposed programme contributes to annual GHG mitigation of 213 million tonne at an abatement cost of Rs. 1,826/tCO2e (US$ 30.4/tCO2e).The whole programme needs an overall investment of Rs. 1,571 billion (US$ 26.2 billion) over a period of 20 years. Out of this, the major shares are accounted by the investments required for establishment of the distribution systems to supply biogas and electricity to the households at 24%, construction of biogas plants at 23%, and purchase of end-use devices and addition of new generation capacity at 17% each.

V. Enabling Sustainable Energy for All

The proposed approach is a public-private-people partnership driven ‘business model’ with innovative institutional, regulatory, financing, and delivery mechanisms. Some of the innovations recommended for adoption are (Balachandra, 2011b) - i) Multi-stakeholder and multi-level implementation programme, (ii) Enacting an exclusive integrated rural energy policy, (iii) Creation of exclusive rural energy access authorities (REAAs) within the government system as leadership institutions, (iv) Establishment of energy access funds (EAFs) to enable transitions from the regime of investment/fuel subsidies to incentive-linked delivery of energy services, (v) Integration of business principles to facilitate affordable and equitable energy sales to households and carbon trade, and (vi) Treatment of entrepreneurs as implementation targets and not millions of rural households.

An earlier paper by the author describes the proposed implementation framework in detail (Balachandra, 2011b). The framework represents a top-down approach with the government/s represented by the appropriate ministries at the top and the rural households, at the other end reaping the benefits. The framework entails establishment of the rural energy access authorities (REAAs) both at the national and regional levels to be empowered with enabling regulatory policies and supported by the multi-stakeholder partnership. The national REAA is expected to establish the national energy access fund (EAF), support the creation of and coordinate with the regional REAAs, and develop a comprehensive entrepreneurship development programme with inputs from stakeholders. The regional REAAs are expected to manage the regional EAFs and facilitate the conduct of intensive capacity building programmes for the prospective entrepreneurs. At the other end, the trained entrepreneurs are envisaged to establish village-level energy micro-enterprises to produce and distribute energy carriers to rural households at affordable cost. The energy service companies (ESCOs) will function as intermediaries between these enterprises and the international carbon market in aggregating certified emission reductions (CERs) and trading them under clean development mechanism (CDM) or similar mechanisms. As per the proposal, the ESCOs would share carbon trade proceeds with energy enterprises at pre-determined rates.

1. Integrated Rural Energy Policy

The proposal recommends introduction of an integrated rural energy policy (IREP). The advantage is that most of the components of this proposed policy framework already exist in various energy policy documents developed by Indian government at different times. Therefore the recommendation is to extract relevant policies from these documents and include them in the proposed IREP. In addition, IREP also needs to include some new policy guidelines to facilitate establishment of new institutions and to expand the scope of currently pursued initiatives on expanding energy access (Balachandra, 2011b). It is proposed to include policies to enable setting-up of exclusive REAAs both at the national and state levels as nodal agencies. These authorities need to be empowered with exclusive powers to initiate, establish, manage, support and supervise programmes for expanding energy access. It is also required to establish EAFs both at the national and regional levels to support implementation and sustainable operation of the programme. The EAF should be established with contributions from the re-targeted fossil fuel subsidies, budgetary allocations, plan grants and donor funding. The proposed IREP should have policy guidelines to facilitate establishment of a large number of rural energy enterprises. They should be enabled to carry out the business of all-inclusive energy service providers including production of energy carriers. The scope of these enterprises should be enlarged to include electricity generation from distributed power generation systems, performing transactions between the distributing utilities and the rural households, LPG distribution, usage of the infrastructure created by the government and establishment of biogas supply systems for supplying cooking gas.

2. Rural Energy Access Authorities

Second critical recommendation is to establish rural energy access authorities (REAAs) both at the national and regional levels. The national REAA could be established on the lines of Central Electricity Authority (CEA) including the bureaucratic structure. Empowered group of ministers (EGoM) from all the relevant ministries under the chairmanship of the Prime Minister could perform the leadership roles and take crucial policy level decisions. In addition, there could be an advisory group with representatives from relevant stakeholders providing technical as well as expert inputs. The role of REAA is to design implementable programmes, support its actual implementation along with regional REAAs and other stakeholders, and monitor its progress. The regional REAAs also could be structured on similar lines keeping the state-level administrative system in mind. They are the ones who would be implementing the programmes, conducting entrepreneurship development programmes, interacting with the entrepreneurs, and providing incentives.

3. Energy Access Funds

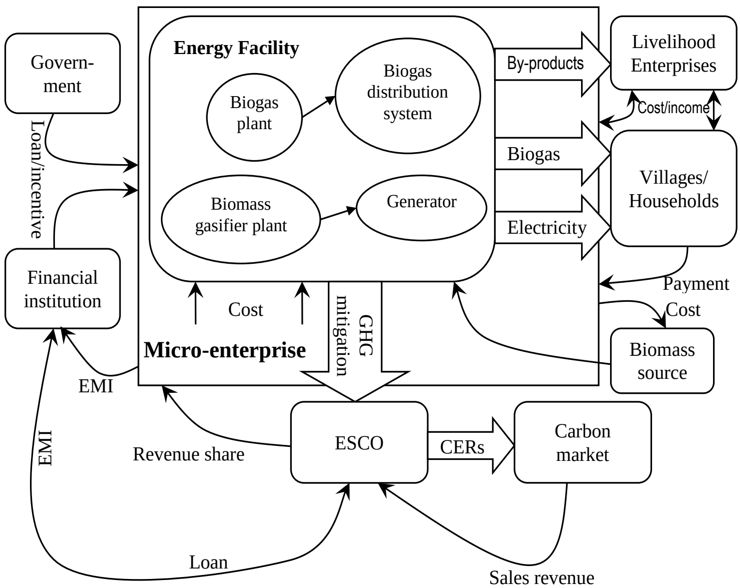
Third most important proposal is to establish energy access funds (EAFs) at the national as well as state levels. The past efforts in expanding energy access have shown that providing capital subsidies do not ensure success of the initiatives. Just establishing energy infrastructure at free of cost cannot guarantee their continuous operation because energy benefits alone may not motivate individuals to use these assets continuously. Surplus revenue streams or cash incentives are likely to be better motivators for sustained performance of energy systems. The need is to convert "capital subsidies" into "operational incentives". Further, the entrepreneur would be more responsible towards the asset provided he has invested into the asset either through a loan from a financial institution or equity contribution or both. Thus, "burden of investment" and "operational incentives" can be expected to be more effective. It is proposed that the EAFs will contribute to the payment of operational incentives to the entrepreneurs. These incentives should be linked to the performance levels of the energy enterprises in terms of quantity of energy carriers sold to the rural consumers.

4. Multi-Stakeholder Partnerships

These kinds of innovative processes aiming at universalization of energy access through bioenergy, in addition to centralized access through grid connection and LPG supply, have to pass through a number of hurdles. These barriers are created by various stakeholders of energy systems and their involvement is absolutely necessary to overcome them. Government/policy makers, energy organizations/utilities, technical institutions and R&D organizations, industries, entrepreneurs, financial institutions, donor agencies, NGOs and rural households need to join together to achieve the objective of universal rural energy access.

5. Micro-Enterprise for Rural Energy Services

The final delivery of energy services to the rural households is to be performed by the micro-enterprises. The overall structure of the micro-enterprise would be as shown in Figure 4 (Balachandra, 2011b). The enterprise would own an energy facility consisting of biogas plants, either based on biomass or cattle dung or both types, for producing biogas and biomass gasifier plants for generating electricity. The energy infrastructure would also include biogas distribution system connecting every household in the village/s. This would ensure piped biogas supply to the households. For electricity access, the existing electricity distribution infrastructure would be used under lease from the government utilities at pre-determined leasing rates. The entrepreneurs are also can directly purchase electricity from the grid and perform only the distribution of it to the rural customers. Similarly, LPG can also be procured from the government agencies and distributed to the households. A mixed strategy with purchased quantity complementing own production, especially for electricity, could be the preferred choice.



Source: Adapted from Balachandra (2011b)

Figure 4 Micro-enterprise for rural energy services

The financial institutions are expected to support the enterprise with loans at favorable terms and government entities to support with incentives to enhance profitability and reduce risks. In addition, the entrepreneur is expected to invest in the enterprise as his or her equity contribution. For the entrepreneur, the financial inflow is in the form of payments received from the households, revenue share from the ESCO due to CER sales and operational incentives from the government. The enterprise could enhance its revenue by selling the surplus energy carriers at higher prices to other sectors of the rural economy and to households for other than basic end-uses (lighting and cooking). The financial outflow for the entrepreneur would be for equated monthly installments (EMI) for loan repayment, and expenses related to O&M and purchase of biomass.

An ESCO would bundle many such enterprises and present a single potential CDM project to the international carbon market. It will transform the GHG emissions mitigated into CERs and trade them in the carbon market. In this process, the ESCO need to bear both the fixed and variable transaction costs and again it would seek loans from the financial institutions. The revenue from CER sales would be shared with the entrepreneurs. Thus, financial inflow for the ESCO would be revenue from CER sales and the outflow would be the EMI for loan repayment and the revenue shared with the entrepreneurs.

6. Support Mechanisms for Micro-Enterprises

A micro-enterprise establishes the energy facility to provide access to modern carriers to the households of a village or a number of villages depending on the availability of biomass resources, financial feasibility, size of the villages, geographical clustering, etc., (Figure 5). As stated earlier, the government (including national and state government entities) provides regulatory, incentive and infrastructural support to the entrepreneurs to establish and run the energy enterprises. As regulated by the government, the financial institutions provide soft loans to the entrepreneurs under priority lending schemes to establish the energy enterprises. The responsibility of the R&D/technical organizations / manufacturer is to provide the necessary support under agreed terms for installation and operation of the energy facilities. They also could be involved in providing the required training to the entrepreneurs (or staff) in operating, maintaining and repairing the systems. Village committees or local governments (Panchayat raj institutions) should function as local enabler and ensure that the enterprise meets the social demands of rational distribution of benefits of energy access. The ESCO would facilitate the access to carbon market and provide other support if desired on payment basis. The households are expected to pay the agreed upon nominal monthly charges for the energy access they are provided with.

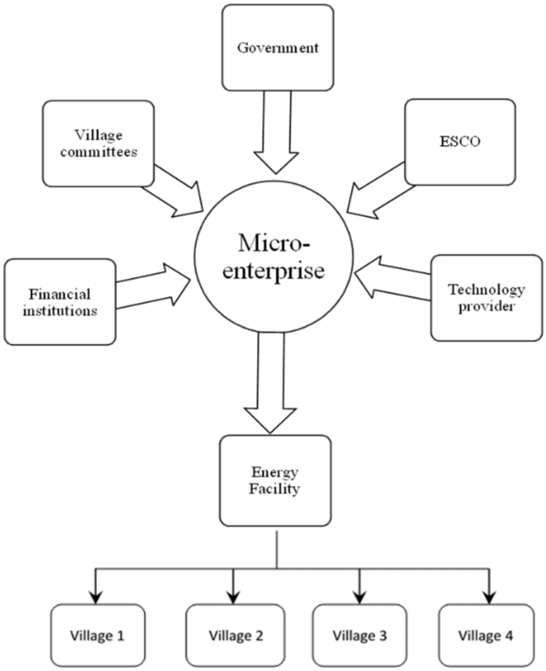


Figure 5 Support mechanisms for micro-enterprises

Ⅵ. Micro-Enterprises for Expanding Rural Energy Access

The success of any business is dependent on the level of profits it could earn. Thus, a financial feasibility analysis of a business proposition is very much critical to assess its profitability potential. The estimates of net present value (NPV) and internal rate of return (IRR) are excellent indicators of profitability of a business. The financial feasibility assessment of two possible rural energy enterprises is performed (Balachandra, 2014). The first one is adopting biomethanation technology for producing biogas for cooking by using cattle dung and biomass gasifier technology for generating electricity for lighting and other end-uses. The second enterprise uses soft biomass for producing biogas and biomass gasifier for generating electricity. For ease of understanding, the first enterprise is named as Biomass-Dung-Energy-Enterprise (BDEE) and the second one as Biomass-Biomass-Energy-Enterprise (BBEE). In both the enterprises, energy efficiency is integrated with the inclusion of compact fluorescent lamps (CFL) for household lighting. While performing the financial feasibility study of energy enterprises, the following assumptions (Balachandra, 2014) have been used - (i) The number of households per enterprise is assumed to be equal to 1000, (ii) an equity contribution of 20% of the investment will be contributed by the entrepreneur. Remaining 80% will be obtained as a loan at a subsidized interest rate of 6% with a repayment period of 5 years, (iii) a discount rate of 10% is used for estimating the present values of cash flows happening in different years, (iv) a price for Certified Emissions Reduction (CER) of US $20/tCO2 and a conversion rate of Rs. 60/US$, and (v) the benefits for households are on account of cost and efforts saved due to non-use of biomass, and the cost is the monthly payment to be made to the entrepreneur. All the costs related to distribution infrastructure, operations and maintenance (O&M) and end-use devices are to be borne by the entrepreneur.

Table 2 Financial feasibility of energy enterprise from entrepreneur's perspective

Characteristic	BDEE	BBEE
Contribution by entrepreneur @ 20% equity (Rs. million)	2.50	2.50
Loan amount (Rs. million)	10.0	10.0
Equated monthly installment, EMI (Rs.)	197,977	197,977
O&M cost (Rs./month)	221,577	221,577
Annual CO_2 emissions reduction (tonne)	2,688	1,682
CDM revenue from intermediary (Rs./month)	199,685	121,868
Household repayment (Rs./month)	340,944	340,944
Profit per month for the first 5 years (Rs.)	121,075	43,258
Profit per month for the remaining 20 years (Rs.)	319,052	241,235
Internal rate of return (IRR) - %	66%	39%
Net present value (Rs.)	21,131,724	13,426,090

The results show that the NPV for the entrepreneur from BDEE model is about Rs. 21.1 million and that for BBEE model is about Rs. 13.4 million and this is significantly higher than the original equity contribution of Rs. 2.5 million (Table 2). The IRRs of 66% and 39% respectively for the two types of enterprises show the benefits are significantly higher than the costs. These numbers suggest that both the enterprises are attractive as potential investment propositions even without government incentives. The avoided methane emissions are mainly responsible for higher returns in the case of BDEE. For a bundling intermediary (an ESCO), a bundle of either 20 BDEEs or 30 BBEEs would be feasible from the point of view of cost implications, and the need for retaining the status of small-scale CDM project. The results suggest that the financial returns with NPVs of about Rs. 8.6 million and Rs. 8.4 million respectively for the two project cases seem to be very attractive (Table 3). Again the IRRs of 107% and 88% further prove the profitability nature of these CDM projects for the ESCOs.

Table 3 Financial feasibility of energy enterprises from ESCOs perspective

Characteristic	BDEE	BBEE
No. of enterprises	20	30
Annual CERs available for sale	53,759	50,460
Revenue from CERs (Rs. million)	53.76	50.46
Transaction cost (Rs. million) - One time	3.5	4.0
Transaction cost (Rs. million) - Annual	3.	3
Intermediary's contribution @ 20% equity (Rs. million)	0.7	0.8
Loan amount (Rs.)	2.8	3.2
Equated monthly installment, EMI (Rs.)	55,392	63,306
O&M cost (Rs./month)	120,000	180,000
Net profit from CER sales (Rs. million)	48.65	44.54
Share of profits @1.5% for the first 5 years (Rs. Million)	0.7	0.7
Share of profits for the remaining 20 years (Rs. Million)	1.4	1.4
Share of profit for entrepreneurs (Rs. million)	47.92	43.87
Internal rate of return (IRR) - %	107%	88%
Net present value (Rs)	8,580,346	8,436,599

VII. Conclusions

This paper communicates an innovative approach, which proposes incremental innovations with regard to technology, policy, financing, institutions and implementation to concurrently address the challenges of sustainable access to modern energy carriers for rural households of India and mitigation of greenhouse gases. The results establish the fact that such an innovative approach if implemented can result in a win-win situation for all the participating stakeholders. The rural households can benefit from access to modern energy carriers at affordable cost; the entrepreneurs can run profitable rural energy enterprises; carbon markets can have access to carbon credits; the Indian government can secure energy access to a large section of rural population; and globally, there is a benefit of climate change mitigation. Further, the recommended bioenergy technologies provide various types of by-products, and micro or household enterprises could be established to produce and market value added products. These energy and by-products based enterprises when managed and run locally create enormous value addition with a high potential for sustainable development. The outcomes of the approach falsify the notion that the social enterprises are always bound to make losses. It has been proved in this study that the enterprises created to maximize social benefits can also maximize private benefits. By adopting a proper business model integrated with efficient incentive schemes can simultaneously provide economic/livelihood benefits to the rural population while earning handsome profits to the entrepreneurs.

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