Biogas as a Sustainable Alternative for Current Energy Need of India

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Abstract: Per capita energy consumption of India is declining with increasing its population, which has direct impact on national economy. Biogas technology seems promising to attain sustainable energy yields without damaging the environment. Waste management, manure creation, health care and employment foundation are the benefits of biogas system. Use of biogas assures renewable energy supply and balance of green house gases. India is traditionally using biogas since long time but there is need to improve the technology, applications and deployment strategies. Bioenergy centralization in urban and decentralization in rural can help government to minimize both the import of fuel derivatives and solid waste processing cost. The aim is to highlight potential of the technology to bring social and economical sustainability to India. In this review, demand of energy sources, drivers for bioenergy use, economical, social and environmental benefits of biogas regularization in India are described with emphasizing biogas as an ideal sustainable energy source with its potential applications.

Keywords: Energy, environment, bioenergy, biogas, sustainable.

1. Introduction

Worldwide energy consumption and demand are growing up since past 50 years [1]. Most of the resources used like petroleum, natural gas, coal are not sustainable sources of energy. Numbers of countries in the world including India are currently passing through the critical phase of population explosion and the growing population demands more energy inputs. In March, 2011 India had 17% of world's population and ranked first for high population density of 371 people per Km^2 [2]. Indian per capita energy consumption is as low as 700 kWh while the world's average is 2,500 kWh and for many of the developed countries the figure is 15,000 kWh [3]. In India there is deficiency of energy in required form to meet national developmental needs.

Biofuels are capable of minimizing the oil import and pollution; therefore these can be the best alternatives in securing the energy needs of India [4]. Though conventionally Indian population is dependent on biofuels such as cow-dung cake, wood etc but there are problem associated such as ease of use, availability throughout the year, health problems, operating issues, energy gain, by-products or waste generated and pollution. For example in rural India, due to use of fuel wood adverse health impacts on women are observed [5]. Inefficient cooking is seen due to use of traditional cook stoves, with efficiency range of 10-14% [6]. Therefore there is a requirement of energy in India to satisfy the energy demand and which is environment friendly. To fulfill energy demand of Indian population, the strategy must focus on basic seven goals which are cost minimization, efficiency maximization, employment generation, system reliability, minimization of petroleum product, maximization use of local resource, and minimization of emissions [7].

Biogas is the gas produced after anaerobic digestion of organic matter by microorganisms. The biogas is in use since long time in India but the technology improvement is necessary in order to improve energy outputs. Indian energy scenario and drivers for bioenergy regularization in India are discussed in the review. General benefits of biogas technology and applications are mentioned.

2. Need of sustainable energy source in India

Promising sustainable energy is needed for development and future security of India. Nation's wealth, growth, status and population's needs are power dependent. In India, no electricity is accessed by more than 300 million people in December-2011 [8]. There is a shortage of electricity though India is the 4^{th} largest electricity producer in the world. India had installed capacity of 210.951 GW [9] and about 92,000 MW capacity additions are required in the next 10 years as annually the electricity demand grows at 8% [10]. Government of India plans to maintain its gross domestic product (GDP) average growth rate of about 8% in the next 15 years. But India's economy is expected to grow at a rate of 7% per annum over the next 5 years, meaning its demand for energy will also increase [11]. Hence future energy requirements and capable energy sources should be balanced for satisfying the power demands.

2.1 Statistical comparison of coal and petroleum reserves of India

The statistical information available from US Energy Information Administration [12] in, it is proved that India has the fifth largest (7%) coal reserves in the world, but India's proven assets for oil and natural gas are only 0.3% and 0.6% respectively. Although being fifth largest coal revering country, India still imports coal for total demand-supply gap. India's power sector is the largest consumer of coal followed by the iron, steel and cements segments [13]. The oil and natural gas demand availability gap always pushes India to import the same. The reliance on other countries for fuel pressurizes growth and maintenance of Indian GDP.

The worldwide price of conventional energy sources such as crude oil, natural gas etc is increasing as the sources are limited. Therefore there is a need of cheaper and permanent solution.

2.2 Import and production of crude oil in India

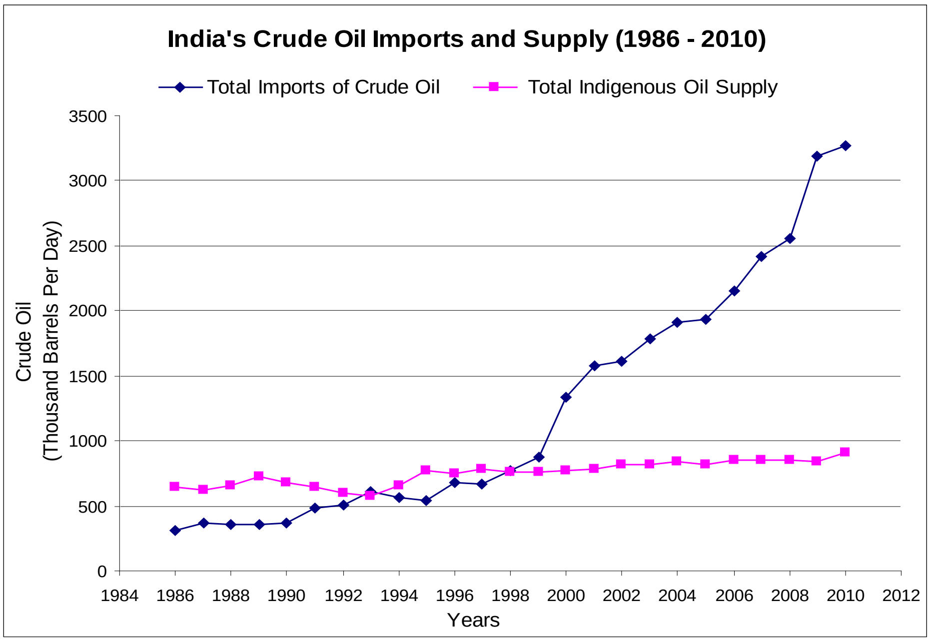
Oil importing countries hope to cut off energy dependency on oil exporting countries and still to be safe energy wise. In the year 2011-12 production of total petroleum products increased by 3.37% including fractioners comparing with production in the year 2010-11. But the indigenous consumption also increased by 4.93% during 2011-12 at 147.995 million metric tons (MMT) comparing with the previous year at 141.04 MMT in India [14]. Therefore India imports to satisfy the petroleum demand. Before 1998 India's crude oil production was lesser than its imports, but in 1998 import increased by nearly 12,000 barrels per day. From year 1998 to 2010 India's average crude oil importing rate increased by 10.8% each year. India's crude oil imports went to 72.13% than the production in the year 2010 and are continuously growing (Fig. 1). The growth of the Indian economy has always fallen sharply in the wake of each major run-up in oil prices as the consumption of net importing countries that lose from higher prices is generally higher than that of the exporting countries [15]. Rising crude oil prices with high rate increasing quantity is putting burden on Indian government and may cause inflation if government passes that burden to consumers. The petroleum prices are growing and will continue to grow in near future leading to the urgent need of alternate sustainable energy sources.

2.3 Natural Gas Production and consumption in India

In the year 2005 India's natural gas consumption increased than production by 2.24 billion cubic meter and is increasing by rate of 11.18% per year. In the year 2010 India's natural gas production and consumption was 1883.35 billion cubic feet and 64.49 billion cubic meter respectively, which states consumption is 17.30% more than the production (Fig. 2). For matching up the production with consumption India has to find and utilize different sources of energy fuel gases.

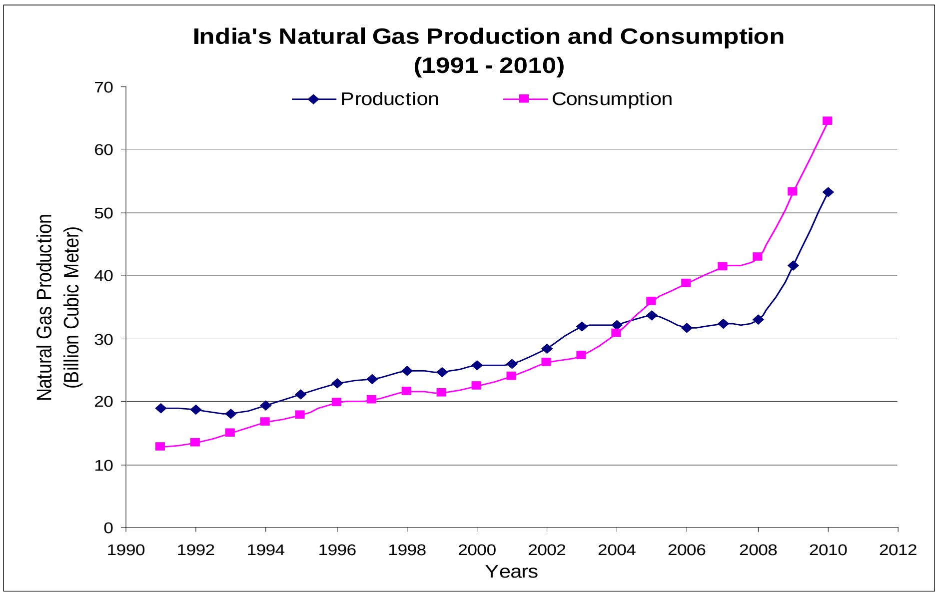
2.4 Total energy production and consumption in India

India is trying to meet the economical progress to become a developed country therefore the energy creation should be improved by non-renewable and renewable means. The energy balance of India (Table 1) interprets that total primary energy supply by diverse energy sources and sector wise final energy consumption in India. Also the same data indicates that the consumption and eventually the demand of exhaustible fossil fuels both are remarkably growing. This situation will lead to fuels exhaust for future generations and immense energy crisis.



Source: US Energy Information Administration: International Energy Statistics [16].

Figure 1. Increasing difference between import and production of crude oil in India from year 1986 to 2010.



Source: US Energy Information Administration: International Energy Statistics [17].

Figure 2. India's increasing consumption of natural gas than production from year 1991 to 2010.

Table 1. Energy balance of India for 2010-11 (ktoe)* [18].

	Coal	Crude Oil	Oil Products	Natural Gas	Nuclear	Hydro	Solar-Wind & Others	Biofuels & Waste	Electricity	Total
Total primary energy supply	292,649	205973	-546,51.5	53,921.5	4856.7	9194.2	1846.7	165,422	487.8	679,699
Final consumption	844,76.9		16,1092.9	21,198.6			302.2	164,278	6,2735.9	494,085
Industry Sector	76,525.6		31,271.4	6,517.1				28,540	20,428.4	163,282
Transport			50,640.7	1,992.3				163.9	5,206.7	58,003.5
Residential	1,594.1		22,799.9	22.3				129,300	13,492.9	167,210
Non-energy use industry/ transformation			20,577.3	12,528.7						33,105.9
Elect. output in GWh	615,454		26,099	111,206	18,636	106,909	17,960	1,995		898,259

* ktoe: Kilotonne of Oil Equivalent.

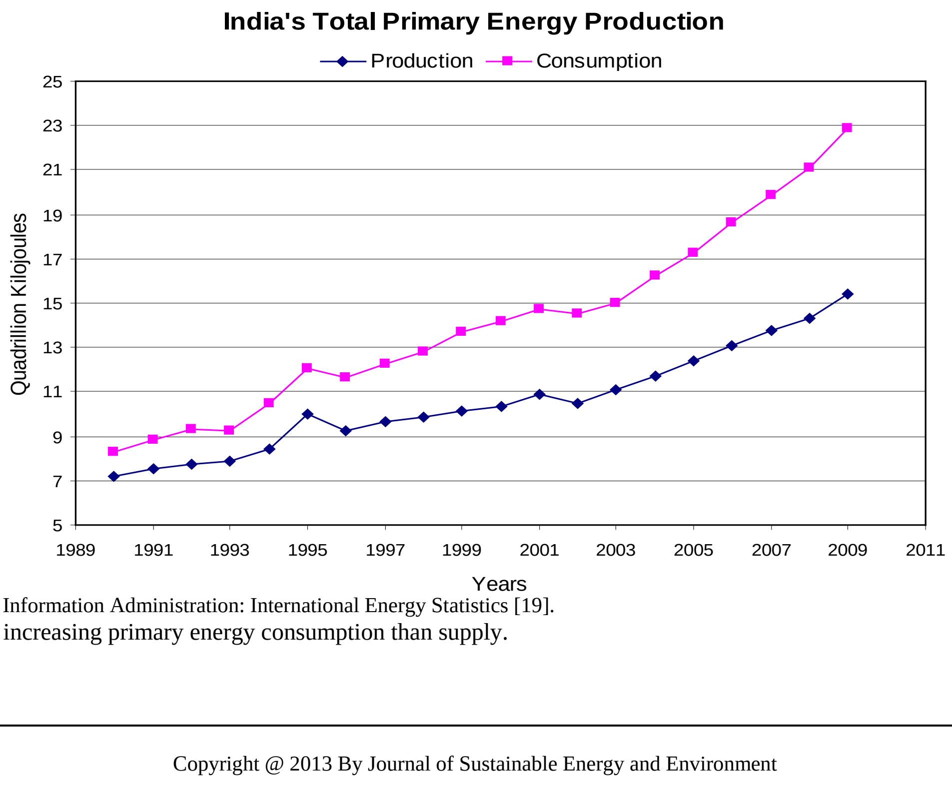
There is an imbalance between two major components of the energy balance statistics. The components are total primary energy supply and total final consumption of energy commodity. Data of the year 1990 to 2009 (Fig. 3) reflects that within 20 years India consumed more primary energy than it produced. The gap between production and consumption has consistently increased which is critical condition for India and only the sustainable energy solution can change this picture.

2.5 Increasing population of India

India, second most populous country, contributes 17.13% to the world population and occupies 2.4% of the world's land area. 69% of the total Indian population lives in villages [2] and is suffering from both economical [18] and energy poverty [20]. Although Indian population growth rate in the year 2010 (1.41%) was comparatively low, India ranked 102nd out of 201 countries in the world [21]. The Indian population in 2008 was 1140 million, which was drastically increased from 894 millions in 1990 and it is projected that it will be 1398 million in 2025 [22]. This growing population needs added resources such as food, land, power etc which may be difficult to be identified and fulfilled by the government. Hence there should be continuous energy supply for rising population.

2.6 Per capita energy consumption in India

Estimated per capita energy consumption of OECD (Organization for Economic Co-operation and Development) countries is around 4.7 tons of oil equivalent (TOE), while world's average per capita energy consumption is 1.8 TOE. India's per capita energy consumption is 0.51 TOE and is dropping down drastically with increasing population resulting in poor energy availability. India needs to increase its per capita TOE significantly for national betterment as the estimated per capita energy consumption was 4,816 KWh in the year 2010-11 [22], which was lower in rural areas than the urban. In the case of electricity, even if all towns were supplied with electricity, 16.3% villages were devoid of electricity [23]. Though 45% rural India uses electricity the power supply in electrified villages is inadequate and unreliable. Rural people are devoid of power for even basic needs such as lighting houses and cooking etc therefore nearly 77 million households use kerosene for lighting [24]. Indian energy production and consumption have raised due to the sector wise energy demands. The power sector is facing problems of fuel scarcity such as coal shortage, government policies, average losses of power transmission, distribution rise, insufficient or poor infrastructure and connectivity in distribution lines etc. The US Energy Information Administration (EIA) projects that the electricity consumption in India will grow at an average rate of 3.3% per year till the year 2035 and to meet up with consumption growth India will have to expand its current power generation capacity by 234 GW [25]. Peak demand in the year 2012 was about 150 GW with corresponding installed capacity requirement about 220 GW and in the year 2017 the peak demand will be more than 200 GW with respective installed capacity requirement more than 300 GW [26].



Source: US Energy Information Administration: International Energy Statistics [19].

Figure 3. India's increasing primary energy consumption than supply.

Looking at all circumstances India needs renewable and sustainable sources of energy. Biofuels, solar, wind, hydropower and Geothermal are sustainable alternatives and renewable energy sources that could possibly be used to help alleviate the serious energy crisis. Comparing with the urban India the rural India is getting deprived access to the electricity (Table 2). Not only electricity but villages get minor supply of all energy sources and as are mainly dependent on kerosene, fire wood and dung etc for cooking and lightening [20]. From overall world population without electricity, 21.86% population contributed by India (Table 4), which shows higher energy requirement to fulfill present and future need of electricity.

2.7 Stress on Indian Government

India was the fourth largest importer of oil and petroleum products in the year 2011 as it imports kerosene and liquefied petroleum gas (LPG) products for domestic use [28]. Indian government is not delivering secure supplies to meet demand because of the fuel subsidies, increasing import and inconsistent energy sector reform [28]. Government development planning has been on concern related to human and inclusive developments with emphasis on poverty alleviation, employment generation, education, health and skill development in India over the years [29]. Factors such as population, inflation, imports, subsidies, employments and resources play a major role in developmental planning. Inflation measured by variations in the wholesale price index (WPI) on a year-on-year basis was 9.1% in November-2011 against 8.2% in November-2010. India's imports registered a five to six fold increase in the last decade from US$ 51.6 billion in the year 2000, to US$ 329 billion in year 2010 [29]. To plan energy policy and development the government has to ensure effective targeting without putting burden on the government itself. Otherwise to minimize this burden (Fig. 4) implementation of decentralized sustainable energy sources with full concentration is needed.

Table 2. Electricity access in the year 2009: India and other re gional aggregates.

Country	Population without electricity (millions)	Electrification rate (%)	Urban electrification rate (%)	Rural electrification rate (%)
Africa	587	41.8	68.8	25.0
North Africa	*2*	*99.0*	*99.6*	*98.4*
Sub-Saharan Africa	*585*	*30.5*	*59.9*	*14.2*
Developing Asia	675	81.0	94.0	73.2
China & East Asia	*182*	*90.8*	*96.4*	*86.4*
South Asia	*493*	*68.5*	*89.5*	*59.9*
India	*288*	*75.0*	*94.0*	*67.0*
Latin America	31	93.2	98.8	73.6
Middle East	21	89.0	98.5	71.8
Developing countries	**1,314**	**74.7**	**90.6**	**63.2**
World*	**1,317**	**80.5**	**93.7**	**68.0**

* World includes OECD and Eastern Europe / Eurasia.
Source: US Energy Information Administration, World Energy Outlook 2011 [27].

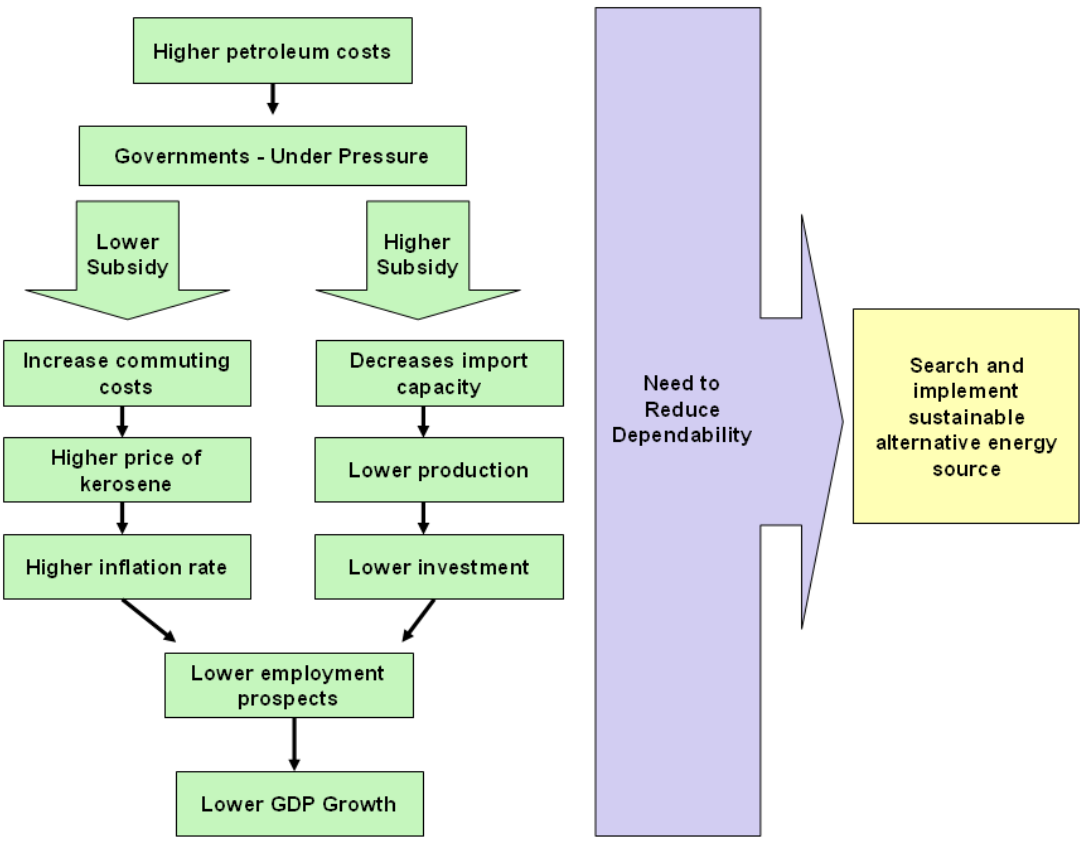


Figure 4. Strategy for possible government stress reduction.

Revolutionary strategies to increase national sustainable energy production by biomass waste management and reusing it in systematic form may help to reduce dependability of India on other countries. Biogas technology is a good option of sustainable biomass energy and can be easily implemented in a country like India.

3. Drivers for sustainable bioenergy use in India

Rise in fossil fuels demand, import cost, population explosion and energy wise unsecured future give signal to find, develop and execute energy solutions. Bioenergy is the energy derived from biological sources and seems one of the promising renewable energies. Out of world's total primary energy 13% is renewable energy and bioenergy is contributing 77% of all renewable energies [30]. The share and potential of bioenergy is higher among all the renewable energies in India (Table 3).

Table 3. Source wise estimated potential of renewable power in India as on 31-03-2011.

Total potential for renewable power generation (MW)	89,762
Wind power potential (MW)	49,132
SHP (small-hydro power) potential (MW)	15,385
Biomass power potential (MW)	17,538
Bagasse-based cogeneration (MW)	5,000
Waste to energy (MW)	2,707

Source: Ministry of New and Renewable Energy Biomass, India [31].

Rising fuel prices is a major concern for India therefore alternative energy sources are to be found out and bioenergy shows potential in contributing future global energy supply [32]. Next to the energy crisis global climatic change or global warming is issue to be surely solved [33]. Bioenergy can be a good and sustainable option to minimize greenhouse gases (GHGs) emissions [34]. Global temperature was forecasted to rise by 1.4–5.8°C during 21st century and bioenergy has the prospective to mitigate global warming [35]. Maximum energy can be generated while saving the carbon dioxide (CO_2) emission. For India bioenergy will be a better way out for un-served rural areas energy wise [36]. Agriculture is a foremost pillar to Indian economy and country's welfare. It is the major profession of Indians hence both the circumstances and topography are suitable for bioenergy generation-utilization. Abundant bio wastes such as agriculture residues are generated (Table 4) by Indian population. Also municipal waste is being used for energy generation conventionally and can be used for future.

Table 4. Households by primary fuel used for cooking in 2011.

Fuel Type	Total % Share	Rural % Share	Urban % Share
Firewood	49	62.5	20.1
Crop residue	8.9	12.3	1.4
Cowdung cake	7.9	10.9	1.7
Coal, Lignite, Charcoal	1.4	0.8	2.9
Kerosene	2.9	0.7	7.5
LPG/PNG	28.5	11.4	65
Electricity	0.1	0.1	0.1
Bio-gas	0.4	0.4	0.4
Any other	0.5	0.6	0.2
No cooking	0.3	0.2	0.5
Total	100	100	100

Note: LPG = Liquefied Petroleum Gases; PNG = Piped Natural Ga
Source: India Census 2011 [37].

62.5% of Indian rural households still use firewood as a primary fuel for cooking (Table 4) with inefficient energy extraction and other health-environmental hazards. Some of these bio-wastes and biomass can be utilized efficiently by introducing technologies like biomass gasifiers [38], biogas [39], liquid biofuels (ethanol etc.) [40], pellet fuel [41] and bio-power generation [42] to improve energy yields. Climate changes due to anthropogenic reasons causes adverse effects on environment and living beings. Along with excess fossil fuel usage, industrial pollution and undue agricultural activities are creating negative climatic changes by emitting GHGs. This climatic change affects agriculture drastically [41] which may subsequently upset national economy as in India out of the total share of 14.5% that agriculture and allied sectors had in GDP in the year 2010-11, agriculture alone accounted for 12.3% [43]. Renewable and sustainable energy sources can be functional here which can play a main role for India to be a global leader in renewable energy production. Extraction, transportation and utilization of fossil fuels have created environmental disturbances such as pollution, land degradation, ash generation and increased GHGs emissions. Whereas biomass utilization for electricity generation does not lead to build up net CO_2 levels in the atmosphere because CO_2 released in combustion is compensated for that withdrawn from the atmosphere for the carbon synthesis and biomass accumulation [44]. India's strategy for sustainable development has to explore all options to reduce energy needs, enhance the efficiency of conventional energy resources and develop new and renewable sources [45].

4. Comparative sustainability of biogas as an energy source

Biogas has been produced since the second half of the 19th century. India was one of the pioneering countries which were generating biogas from manure and kitchen waste for household purposes. Biogas is the gas generated from anaerobic digestion (AD) of organic matter which includes animal-human excreta, kitchen-agricultural residues, municipal wastes and algal-plant biomass etc. with balanced carbon cycle (Fig. 5). Biogas is a source of renewable energy like solar, wind and geothermal etc [46].

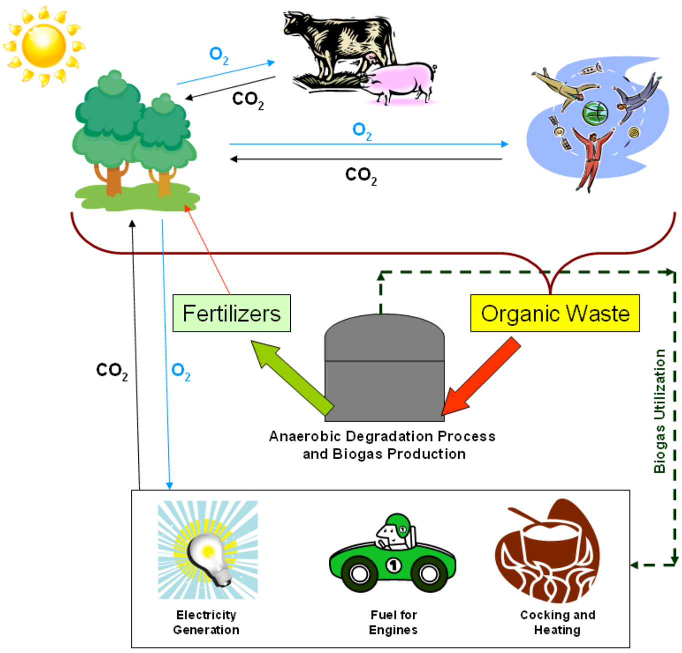


Figure 5. Energy harvesting from sustainable biogas cycle.

Biogas utilization is mainly for cooking, lightening and pumping at individual levels as well as for electricity, heat, power generation and fuel for vehicles (Fig. 5) at industrial levels. Biogas technology is reviewed as a promising sustainable solution for village households and industries both [30,47-50]. Biogas also solves major environmental problems such as soil degradation, deforestation, desertification, CO_2 emission, indoor air pollution,

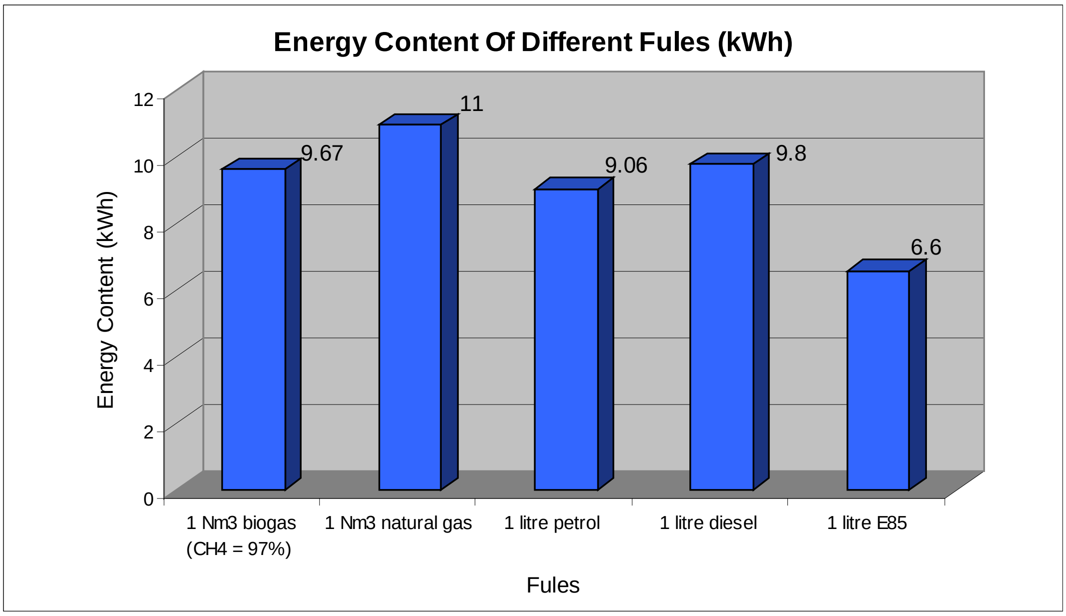


Figure 6. Energy content of different fuels [41-42].

organic pollution and social problems such as women occupation [50] etc. by replacing wood and fossil fuels. Data (Fig. 6) comparing energy content of different fuels with that of biogas illustrates that the biogas technology can be possible option to replace petroleum for vehicular and other applications. From energy content graph (Fig. 6) 1 Nm^3 biogas is equivalent to approx 1.1 liters of petrol.

Comparing with the fossil fuels and other biomass technologies for energy generation, there is no or low emission of air polluting gases during biogas production and storage [50]. GHGs emission is reduced during biogas consumption [51]. For biogas generation there's no competition for food crops or energy crops and fertilizer a byproduct of this technology is Nitrogen-Phosphorous-Potassium (NPK) rich [52-53]. Other common benefits of biogas are - natural habitats are protected, there is no negative effect on social, economical and environmental levels of the area as well as of nation [54]. In case of environmental sustainability, a study indicates that a kg of *Acacia* wood burned in a traditional mud stove generates 318 gm of Carbon (g-C) equivalent of Carbon emission [55]. Bates et al. confirmed that the use of solid fuel in indoor stoves is associated with an increased risk of cataracts in women [56].

An additional problem with the traditional biomass use is the social costs associated with excessive pollution. The incomplete combustion of biomass in traditional stoves releases pollutants like Carbon monoxide, methane, nitrogen oxides, benzene, formaldehyde, benzopyrene, aromatics and respirable particulate matter. These pollutants cause considerable damage to the health, especially of women and children who are exposed to indoor pollution for long duration [15,57-59]. Hence the twin problems of traditional biomass use are the energy inefficiency and excessive pollution.

4.1 Biogas from different sources

In India, the key biomass feed-stocks available include rice husk-straw, bagasses, sugarcane tops, leaves-trash, groundnut shells, cotton stalk, coconut residues, mustard stalk and wastes from agricultural products. Possible feed sources reported for biogas reactor available in India are shown in Fig. 7.

Different methods are used to improve biogas production and methane yield such as use of additives with organic matter as substrate, slurry recycling, operational parameter optimization for process, change in type of reactor and other configuration of biofilm [51]. Biogas is being generated form cattle dung and kitchen waste since long but for highest yield the reactors are being optimized not only in size and types but also the substrates are studied. (Table 5).

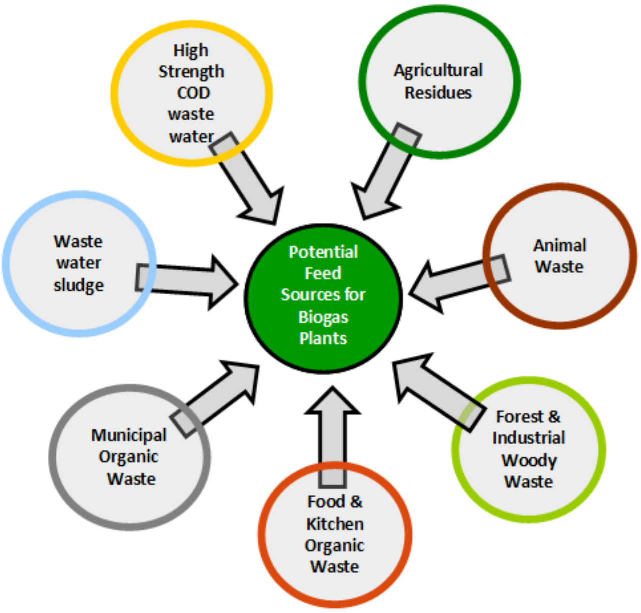


Figure 7. Potential biogas feed sources.

Table 5. List of substrate used for biogas production.

Substrates	References
Biological additives	[60-63]
Powdered leaves of some plants and legumes	[64-65]
Agricultural Residue	[66-67]
From Grains and crops	[68]
From Diary manure	[67,69]
From Algal biomass	[70]
Food waste	[69,71-72]
Animal waste	[67,73-74]
Municipal Waste	[61,75-77]
Fruit and vegetable waste	[78-79]
Cellulose containing substrates	[80-81]

Substrates are consumed anaerobically to produce biogas and residue can be used as superior fertilizer which is nutrient rich and odorless [53,82-83]. Indian biomass power technology capacity demand is likely to be constrained by food security and the issue of high power generation cost, compared to the cheaper cost of generating electricity from coal. Therefore improved technologies for energy generation from biomass in feasible cost and methane capture from anaerobic wastewater treatment makes economic sense to follow the waste to energy prospect. According to the EPA, it is possible to produce electricity for as little as $0.038 per kWh [84] assuming a 20 years capital repayment scope. This can be compared favorably to national electricity rates that range from $0.057 to $0.228 per kWh [85].

4.2 Potential biogas applications in India

Biogas production is considered CO_2 neutral and therefore does not add GHGs to atmosphere. However if biogas is not recovered properly it will contribute to GHGs and the effect will be 24 times worse than if methane is simply combusted (24 CO_2 equivalent, 24 CO_2e) [86]. Therefore the real challenge is to transfer biogas combustion energy into heat and/or electricity. Additional advantage of treating organic waste anaerobically is to reduce the adverse impact of these wastes. Biogas plants contribute to a better image of the farming community due to the reduction in odor, pathogens and weeds from the manure along with generation of improved fertilizer easily assimilated by plants. Biogas not only generates energy but also plays important role in waste management, environment cleaning and gives surety of continuous fuel supply in future i.e. it is renewable and sustainable as well [46,87-90]. Conventionally biogas is consumed for cooking in India [91] but with increasing faith in renewable energies the biogas application area is widening. General applications of biogas technology are described in Fig. 8.

Crude biogas needs to be scrubbed and upgraded according to its application. Primarily biogas use is for direct combustion and heat production but farmers utilize biogas as well for cooking, heating, farm level electricity generation, organic waste recycling, efficient fertilizer production, waste disposal, veterinary sanitation, odor removal and GHGs reduction. All this eventually improves farmers' economically [92-93]. Biogas creates energy from municipal organic waste and solves the concern of waste disposal and hygiene [61,75-77]. Biogas generated heat is useful for industrial processes, agriculture and for space heating [94-96]. Use of biogas in internal combustion engines is reliable which does not affect engine performance but needs minor modifications [97]. In biogas driven micro-turbines electric capacity is typically below 200 kWe but the cost of biogas micro-turbines is quiet high. The calorific value of biogas is about 21.6 MJ/m^3 (net calorific value depends on the efficiency of the burners or appliances) which is about half a liter of diesel oil (Calorific value of diesel 35.86 MJ/L) hence can be used as transportation fuel [98].

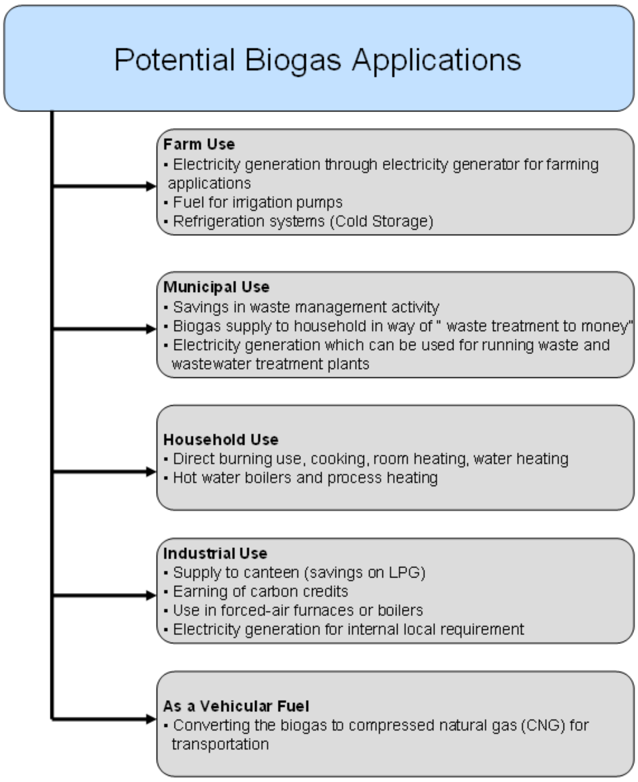


Figure 8. Potential biogas applications.

4.3 Potential economical benefits

Research is going on worldwide in the biogas sector to achieve energy targets with the policies created by government and public bodies. Slurry from 1 kg of digested dung can yield up to extra 0.5 kg Nitrogen compared to fresh manure [99]. Considering economic value of the bio-slurry as manure the investment in process can be gained back in three to four years [100]. It is estimated that the use of bio-slurry annually saves 39 kg of Nitrogen, 19 kg Phosphorus and 39 kg Potassium per household [101]. Bioslurry use can solve problems of soil degradation in areas where dung has been used as a burning fuel and implies that less artificial fertilizer has to be bought which bring revenue to the household [102]. Regularization of biogas technology and utilization will be beneficial in capacity building of rural economics, which includes development of village level institutions, capacity building of village communities, NGOs, entrepreneurs, researchers and evolution of appropriate bioenergy policy [103].

Various economically benefits of biogas technology can be absorbed at local and national levels. Economical and health impacts of biogas application at local level can improve national economy (Fig. 9).

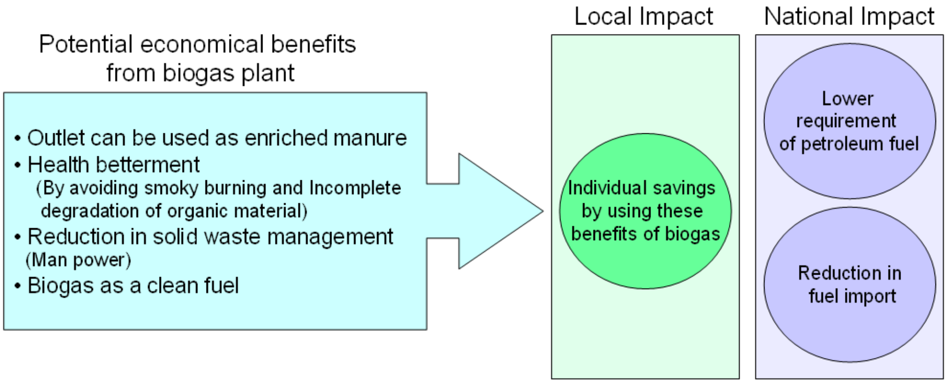


Figure 9. Future possible economic impacts of biogas use.

4.4 Potential social benefits

In the year 2000 World Health Organization (WHO) estimated about 420 thousand premature deaths per year in India because of the household fuel air pollution [104]. Use of biomass directly for burning causes negative health impacts such as pneumonia, low birth weight in children, chronic lung disease, cataracts and heart disease etc. Biogas is a smokeless fuel hence offers an excellent substitute for kerosene oil, cattle dung cake, agricultural residues and firewood being used as fuel in most of the developing countries. Even if the family biogas program is considered most effective in terms of targets achieved, the community biogas program has been said to have made slower progress. Socio-economic benefits (Fig. 10) can be listed as

a) Illumination and safe drinking water availability for 2,500 households

b) Cooking fuel (biogas) supply to all the households

c) Irrigation to at least half an acre for each household

d) Establishment of agro-industry units, generation of employment and incomes

e) Empowerment and

f) Reduction in women and children drudgery [103].

4.5 Potential environmental benefits

Biomass combustion plays an important role in creating outdoor air pollution in rural India. In case of the Ganga river basin; average air pollution level is substantially above Indian and WHO health-based norms [105]. Due to the products formed out of incomplete combustion, significant GHGs emission occurs by traditional biomass stoves [106]. Analysis of data for the years 1901 to 2005 shows the annual mean temperature of India has gone up by 0.51°C over the period. However since year 1990 minimum temperature is steadily rising and rate of rise is slightly more than that of the maximum temperature [107]. The per capita GHGs emission of India (average across the five studies) is estimated to be 2.1 tons of CO_2e in the year 2020 and 3.5 tons of CO_2e in the year 2030 [108]. Börjesson has stated that the reduction in the contribution to the global warming potential (GWP) will be between 70% and 85% if biogas replaces petrol as a transportation fuel in light-duty vehicles [109]. Already earth's temperature has increased by 0.74°C in the last century and is predicted to rise by 1.1°C to 6.4°C by the end of this century [110]. About 8 million tons of GHGs are emitted into the atmosphere annually of which developed countries emit 70% and the rest is shared by developing countries [111]. GHGs emission from field based biogas plants reported was about 21 to 36% of the emission from fossil petrol or diesel use [112]. Food industry or community bio-waste based biogas GHGs emission was only about 13 to 23% of those from fossil fuels [113]. Development, cleaner energy source use, reduction in energy wastage, energy conservation, consumption patterns change and the use of carbon sinks-carbon credits-carbon taxes are the most popular means of climate change mitigation [113].

Not only climate change but also biogas has the potential to combat environmental problems such as eutrophication, acidification and air pollution [109]. Indirectly environment adversely gets affected by ammonia, nitrates and nitrite filed emissions generated due to the waste composting and manure usage contributing to the eutrophication and acidification. Börjesson has shown a significant reduction in these contributions up to 97% by using biogas technology [109]. For cooking efficiency of combustion is more in case of biogas stoves than the traditional biomass or fossil fuel stoves (kerosene / LPG stoves) and biogas stoves will contribute the lowest to GHGs [55].

Some of environmental benefits are listed down;

- CO_2 reduction via fossil fuel substitution
- Land reclamation via forestry (development of biomass generating forest), community and farm lands.
- Biomass conservation to reduce pressure on trees and forests

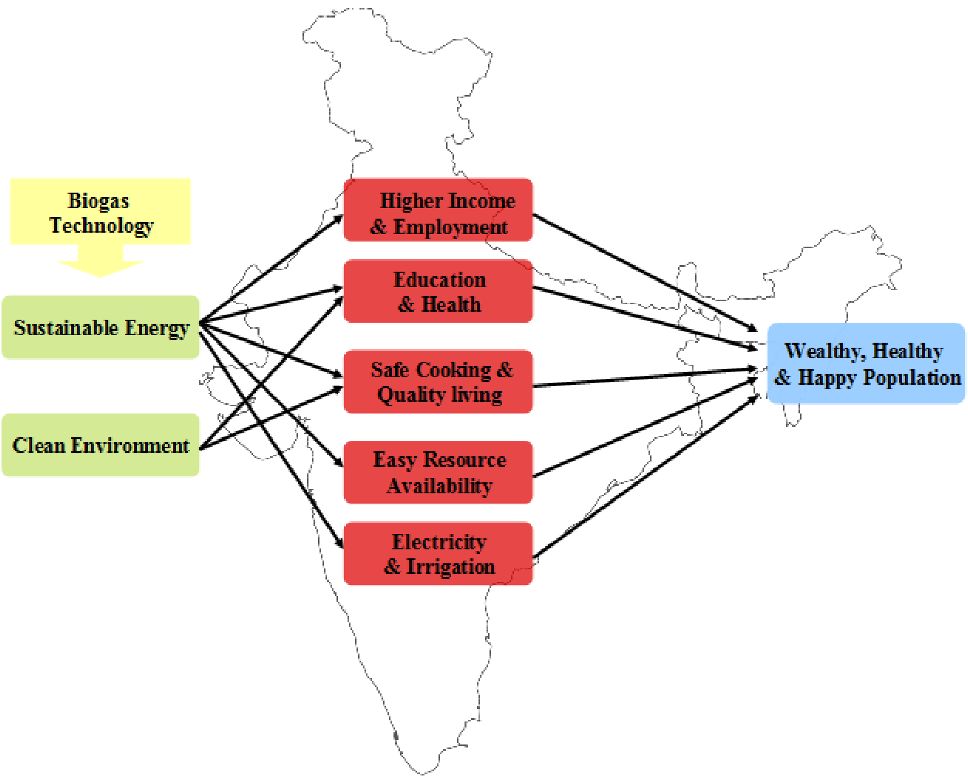


Figure 10. Potential Social Impacts of Biogas Technology on Indian Population.

5. Conclusion

Energy being one of the driving forces in the nation's growth India should produce it adequately. There is a need of sustainable energy sources in India to fulfill the power demands of growing population. Along with the energy solution environment should be balanced well. To achieve social-economical stability India should start developing energy from renewable sources such as bioenergy. Biogas, a traditional energy generating technology seems promising satisfying the energy needs of both urban and rural population. There are many advantages of biogas system such as waste to energy conversion, NPK rich manure, ease in operation for urban as well as for rural people. Biogas is supportive to agriculture hence can improve the status of farmers. The technology may lack somewhere but new adaptations in technology can solve the problems. Future aspirations of biogas technology are in transportation fuel, fuel cells, industrial level electricity generation and heat generation etc. Biogas can bring progress economically, socially as well as environmentally. Conditions Available in India such as climate, biomass availability and hands on operation etc are encouraging for biogas generation and utilization. Different designs, construction strategies and government policies are developing and some are to be developed to produce more methane yields with low investments, higher paybacks and sturdiness of system. Biogas market creation and scientific breakthroughs are needed to meet biogas technology challenges which India is facing currently. Otherwise there is a huge potential for biogas technology in the country. There is need to utilize biogas technology and/or other renewable energy sources in combinations for Indian as well as global bright energy future.

References

[1] OpenStax College, World Energy Use, *College Physics* (2012) Available online: https://www.inkling.com/read/college-physics-openstax-college-1st/chapter-7/7-9-world-energy-use [accessed 26 February 2014].

[2] 2011 Census, *Census of India* (2011) Available online: http://www.censusindia.gov.in/2011-prov-results/indiaatglance.html [accessed 22 May 2012].

[3] Srikumar Banerjee (said), First Commercial fast Reactor Nearly Ready, *A Hindu Report* 29 June 2012: p-07, Available online: http://www.thehindu.com/todays-paper/tp-national/first-commercial-fast-reactor-nearly-ready/article3582922.ece [accessed 10 December 2012].

[4] Kumar L, Mohan MR, Biofuels: the key to India's sustainable energy needs, *Proceedings of the RISO International Energy Conference* (2005) 423-438.

[5] Smith KR, Fuel combustion, air pollution exposure and health: the situation in developing countries, *Annual Review of Energy and the Environment* 18 (1993) 529-556.

[6] Ravindranath NH, Hall DO, Biomass, Energy and Environment: a developing country perspective from India, *Oxford: Oxford University Press* (1995).

[7] Rajendran K, Aslanzadeh S, Taherzadeh MJ, Household Biogas Digesters-A Review, *Energies* 5/8 (2012) 2911-2942.

[8] International Energy Agency (IEA), *Energy access database-the World Energy Outlook (WEO)*, Available online: http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/ [accessed 24 February 2014].

[9] Central Electricity Aithority, Ministry of Power, Government of India, *All India region wise generating installed capacity of power utilities including allocated shares in joint and central sector utilities*, Available online: www.cea.nic.in/reports/monthly/executive_rep/dec12/8.pdf‛[accessed 12 February 2013].

[10] The Delhi International Renewable Energy Conference (DIREC) 2010 – Knowledge Center, *India's Renewable Energy Sector Potential and Investment Opportunities* (2010) available online: http://direc2010.gov.in/pdf/India's-RE-Sector-Potential-and-Investment-opportunites-SSM.pdf [accessed 12 February 2013].

[11] Centre for Global Energy Studies, India's demand for oil increases, *Quarterly Oil Demand* (2011).

[12] US Energy Information Administration, *Countries*, Available online: http://www.eia.gov/countries/index.cfm?view=reserves [accessed 25 February 2014].

[13] Indian Chamber of Commerce, *The Indian coal sector: Challenges and future outlook* (2012) Available online: http://www.pwc.in/en_IN/in/assets/pdfs/industries/power-mining/icc-coal-report.pdf [accessed 21 November 2012].

[14] Ministry of Petroleum & Natural Gas, Government of India, *Indian Petroleum & Natural Gas Statistics 2012-13* (2013) Available online: http://petroleum.nic.in/pngstat.pdf [Accessed 21 November 2012].

[15] Smith KR, Household Fuels and Health, *Urja Bharati* 3/3 (1993) 31-32.

[16] US Energy Information Administration, *International Energy Statistic: Petroleum: Production*, Available online: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=50&pid=57&aid=1&cid=IN,&syid=1994&eyid=2012&freq=M&unit=TBPD [accessed 25 February 2014].

[17] US Energy Information Administration, *International Energy Statistic: Natural Gas: Production*, Available online: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=26&aid=1&cid=IN,&syid=2008&eyid=2012&unit=BCF [accessed 25 February 2014].

[18] Kapur Mehta, A, Shah A, Chronic poverty in India: Incidence, causes and policies. *World Development* 31/3 (2003) 491-511.

[19] US Energy Information Administration, *International Energy Statistic: Total Energy: Total Primary Energy Production*, Available online: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=44&pid=44&aid=1&cid=IN,&syid=2008&eyid=2012&unit=QBTU [accessed 25 February 2014].

[20] Bhattacharyya SC, Energy access problem of the poor in India: Is rural electrification a remedy? *Energy Policy* 34/18 (2006) 3387-3397.

[21] The World Bank, *World Bank Indicators Databank, by topic*, Available online: http://data.worldbank.org/indicator [accessed 15 January 2013].

[22] Rural Energy- Present status of energy use in India. Available online: http://www.indg.in/rural-energy/rural-energy/re-basics-whatis [accessed 02 March, 2014].

[23] Centre for Science and Environment, *Renewable Energy* (2013) Available online: http://www.cseindia.org/userfiles/04Renewable%20energy.pdf [accessed 02 March 2014].

[24] Dhussa A, Biogas in India Methane to Markets Partnership- Meeting of Agr. Sub-Committee April 22 2004, *Ministry of New and Renewable Energy, India* (2004).

[25] US Energy Information Administration, *India* (2013) Available online: http://www.eia.gov/countries/cab.cfm?fips=IN [accessed 25 February 2014].

[26] WEC-IMC and Power Grid Corporation of India Limited, *Transmission and Distribution in India, A Report* Available online:

http://www.indiaworldenergy.org/pdf/T&D%20Report_PGCIL.pdf [accessed: 19 October 2012].

[27] US Energy Information Administration, *World Energy Outlook 2011: Access to Electricity* (2012) Available online: http://www.iea.org/publications/worldenergyoutlook/resources/energydevelopment/accesstoelectricity/ [accessed 26 February 2014].

[28] Independent Statistics and Analysis, Energy Information Administration (EIA), *India* (2013) Available online: http://www.eia.gov/countries/analysisbriefs/India/india.pdf [accessed 18 April 2013].

[29] Ministry of Finance, Government of India, *Annual Report 2011-2012*, Available online: http://finmin.nic.in/reports/AnnualReport2011-12.pdf [accessed: 19 October 2012].

[30] Wise DL, Leuschner AP, Levy PF, Sharaf MA, A practical village biogas system for wastes and agricultural residues, *Resources and Conservation* 13/1 (1986) 23-36.

[31] Central Statistics Office, Ministry of Statistics and Programme Implementation, Government of India, Available online: http://mospi.nic.in/mospi_new/upload/Energy_Statistics_2012_28mar.pdf [accessed 26 February 2014].

[32] Berndes G, Hoogwijk M, van den Broek R, The contribution of biomass in the future global energy supply: a review of 17 studies, *Biomass and Bioenergy* 25/1 (2003) 1-28.

[33] Tu W, Zhang L, Zhou Z, Liu X, Fu Z, The development of renewable energy in resource-rich region: A case in China, *Renewable and Sustainable Energy Reviews* 15/1 (2011) 856-860.

[34] Bilgen S, Keleş S, Kaygusuz A, Sarı A, Kaygusuz K, Global warming and renewable energy sources for sustainable development: a case study in Turkey, *Renewable and Sustainable Energy Reviews* 12/2 (2008) 372-396.

[35] Dhillon RS, von Wuehlisch G. Mitigation of global warming through renewable biomass, *Biomass and Bioenergy* 48 (2013) 75-89.

[36] Jagadish KS, Bioenergy for India: prospects, problems and tasks, *Energy for Sustainable Development* 7/1 (2003) 28-34.

[37] Ministry of Affairs, Government of India, *India Census 2011: Chapter 5 Cooking fuel and lighting* (2011) 329-378, Available online: http://censusmp.nic.in/censusmp/All-PDF/7.%20Chapter-5%20%20Cooking%20fuel%20and%20lighting.pdf [accessed 27 February 2014].

[38] Somashekhar HI, Dasappa S, Ravindranath NH, Rural bioenergy centres based on biomass gasifiers for decentralized power generation: case study of two villages in southern India, *Energy for Sustainable Development* 4/3 (2000) 55-63.

[39] Coulibaly L, Ouattara JMP, Agathos S, Biogas potential of the agro-pastoral residues and human excrement in the Comoé river catchment (Côte d'Ivoire), *Journal of Sustainable Development in Africa* 14/4 (2012) 18-31.

[40] Reijnders L, Ethanol production from crop residues and soil organic carbon, *Resources, Conservation and Recycling* 52/4 (2008) 653-658.

[41] Stelte W, Holm JK, Sanadi AR, Barsberg S, Ahrenfeldt J, Henriksen UB, Fuel pellets from biomass: the importance of the palletizing pressure and its dependency on the processing conditions, *Fuel* 11 (2011) 3285-3290.

[42] Kumar A, Flynn P, Sokhansanj S, Biopower generation from mountain pine infested wood in Canada: An economical opportunity for greenhouse gas mitigation, *Renewable Energy* 33/6 (2008) 1354-1363.

[43] Ministry of Finance, Government of India, *Economic Survey 2011–12, Chapter 8: Agriculture and Food* (2012) Available online: http://indiabudget.nic.in/budget2012-2013/es2011-12/echap-08.pdf [accessed 22 February 2013].

[44] Hall DO, Mynick HE, Williams RH, Cooling the greenhouse with bioenergy, *Nature* 353 (1991) 11-2.

[45] Parikh K, Sustainable development and low carbon growth strategy for India, *Energy* 40/1 (2012) 31-38.

[46] Arthur R, Baidoo MF, Antwi E, Biogas as a potential renewable energy source: A Ghanaian case study, *Renewable Energy* 36/5 (2011) 1510-1516.

[47] Jash T, Basu S, Development of a mini-biogas digester for lighting in India, *Energy* 24/5 (1999) 409-411.

[48] Acumentrics Corporation, Westwood, Massachusetts, USA, Acumentrics produces power from biogas-An Article, *Fuel* Cell Bulletin (2007) 5-6, Available online: http://www.sciencedirect.com/science/article/pii/S1464285907704169 [accessed 20 January 2013].

[49] Mohseni F, Magnusson M, Görling M, Alvfors P, Biogas from renewable electricity–Increasing a climate neutral fuel supply, *Applied Energy* 90/1 (2012) 11-16.

[50] Ansari A, Biomass: Energy and Environmental Concerns in Developing Country, *Research Journal of Environment Sciences* 1/1 (2012) 54-57.

[51] Sreekrishnan TR, Kohli S, Rana V, Enhancement of biogas production from solid substrates using different techniques-a review, *Bioresource Technology* 95/1 (2004) 1-10.

[52] Suthar S, Potential of domestic biogas digester slurry in vermitechnology, *Bioresource Technology* 101/14 (2010) 5419-5425.

[53] Abubaker J, Risberg K, Pell M, Biogas residues as fertilizers–Effects on wheat growth and soil microbial activities, *Applied Energy* (2012).

[54] Brown VJ, Biogas: A Bright Idea for Africa, *Environ Health Perspect.* 114/5 (2006) A300-A303, Available online: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1459950/ [accessed 22 December 2012].

[55] Smith KR, Uma R, Kishore VVN, Joshi V, Zhavg J, Joshi V, Khalil MAK, Greenhouse Implications of Household Stoves: *An Analysis for India* 25 (2000) 741-763.

[56] Bates MN, Pokhrel AK, Smith KR, Khalakdina A, Deuja A, Case-Control Study of Indoor cooking smoke exposure and cataracts in Nepal and India (2005).

[57] Smith KR. Biofuels, Air Pollution and Health: A Global Review, New Delhi, *Plenum Publishing Corporation* (1987).

[58] Bruce N, Perez-Padilla R, Albalak R, Indoor air pollution in developing countries: a major environmental and public health challenge, *Bulletin of the World Health Organization* 78/9 (2000) 1078-1092.

[59] Patel T, Raiyani CV, Indoor Air Quality: Problems and Perspectives, in Energy Strategy and Greenhouse Gas Mitigation. Eds. Shukla PR, *Allied Publishers*, New Delhi, India (1997).

[60] Nallathambi Gunaseelan V, *Parthenium* as an additive with cattle manure in biogas production. *Biological Wastes* 21/3 (1987) 195-202.

[61] Singh R, Mandal SK, Jain VK, Development of mixed inoculum for methane enriched biogas production, *Indian Journal of Microbiology* 50/1 (2010) 26-33.

[62] Mateescu C, Constantinescu I, Comparative analysisof inoculum biomass for biogas potential in the anaerobic digestion, *UPB Sci. Bull.* 73 (2011) 99-104.

[63] Weiß S, Tauber M, Somitsch W, Meincke R, Müller H, Berg G, Guebitz GM, Enhancement of biogas production by addition of hemicellulolytic bacteria immobilized on activated zeolite, *Water Research* (*Oxford*) 44/6 (2010) 1970-1980.

[64] Magdum SS, More SM, Nadaf AA, Biochemical conversion of acid-pretreated water hyacinth (*Eichhornia crassipes*) to alcohol using *Pichia stipitis* NCIM3497, *International Journal of Advanced Biotechnology and Research* 3/2 (2012) 585-590.

[65] Satyanarayan S, Murkute P, Biogas production enhancement by *Brassica compestries* amendment in cattle dung digesters, *Biomass and Bioenergy* 32/3 (2008) 210-215.

[66] Dubrovskis V, Kotelenecs V, Zabarovskis E , Celms A , Plume I , Rivža P , Rivža S , Biogas production potential from agricultural biomass and organic residues in Latvia, *Proceedings of the International Scientific Conference Renewable Energy and Energy Efficiency* (2012) 115-120, Latvia University of Agriculture, Jelgava, Latvia.

[67] Amon T, Amon B, Kryvoruchko V, Zollitsch W, Mayer K, Gruber L, Biogas production from maize and dairy cattle manure- influence of biomass composition on the methane yield, *Agriculture, Ecosystems & Environment* 118/1 (2007) 173-182.

[68] Mursec B, Vindis P, Janzekovic M, Brus M, Cus F, Analysis of different substrates for processing into biogas. *Journal of Achievements in Materials and Manufacturing Engineering* 37/2 (2009) 652-659.

[69] El-Mashad HM, Zhang R, Biogas production from co-digestion of dairy manure and food waste, *Bioresource technology* 101/11 (2010) 4021-4028.

[70] Salerno M, Nurdogan Y, Lundquist TJ, Biogas production from algae biomass harvested at wastewater treatment ponds, In Proceedings of the *Bioenergy Engineering Conference* (2009).

[71] El-Shimi SA, El-Housseini M, Ali BE, El-Shinnawi MM, Biogas generation from food-processing wastes. Resources, *Conservation and Recycling* 6/4 (1992) 315-327.

[72] Curry N, Pillay P, Biogas prediction and design of a food waste to energy system for the urban environment, *Renewable Energy* 41 (2012) 200-209.

[73] Navickas K , Anciūnas A , Janušauskas R , Content and biogas yield evaluation of pig manure , Žemės Ūkio Inžinerija, *Mokslo Darbai* 31/1 (1998) 47-58.

[74] Alvarez R, Villca S, Liden G, Biogas production from llama and cow manure at high altitude, *Biomass and Bioenergy* 30/1 (2006) 66-75.

[75] Hilkiah Igoni A, Ayotamuno MJ, Eze CL, Ogaji SOT, Probert S. D, Designs of anaerobic digesters for producing biogas from municipal solid-waste, *Applied energy* 85/6 (2008) 430-438.

[76] Elango D, Pulikesi M, Baskaralingam P, Ramamurthi V, Sivanesan S, Production of biogas from municipal solid waste with domestic sewage, Journal of hazardous materials 141/1 (2007) 301-304.

[77] Kalloum S, Bouabdessalem H, Touzi A, Iddou A, Ouali MS, Biogas production from the sludge of the municipal wastewater treatment plant of Adrar city (southwest of Algeria), *Biomass and Bioenergy* 35/7 (2011) 2554-2560.

[78] Ranade DR, Yeole TY, Godbole SH, Production of biogas from market waste, *Biomass* 13/3 (1987) 147-153.

[79] Bouallagui H, Ben Cheikh R, Marouani L, Hamdi M, Mesophilic biogas production from fruit and vegetable waste in a tubular digester, *Bioresource Technology* 86/1 (2003) 85-89.

[80] Jeihanipour A, Karimi K, Niklasson C, Taherzadeh MJ, A novel process for ethanol or biogas production from cellulose in blended-fibers waste textiles, *Waste Management* 30/12 (2010) 2504-2509.

[81] Keating C, Cysneiros D, Mahony T, O'Flaherty V, The hydrolysis and biogas production of complex cellulosic substrates using three anaerobic biomass sources, *Water Science and Technology* 67/2 (2012) 293-298.

[82] Dahiya AK, Vasudevan P, Biogas plant slurry as an alternative to chemical fertilizers, *Biomass* 9/1 (1986) 67-74.

[83] Balasubramanian PR, Bai RK, Biogas plant-effluent as an organic fertilizer in monosex, monoculture of fish *Oreochromis mossambicus*, *Bioresource Technology* 55/2 (1996) 119-124.

[84] Environmental Protection Agency, 'Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities.' *EPA Combined Heat and Power Partnership* (2007) Available online: http://www.epa.gov/chp/documents/wwtf_opportunities.pdf [accessed 27 December 2012].

[85] Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, *Energy Information Administration* (2009) Available online: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html [accessed 22 December 2012].

[86] North Yorkshire Waste Action Group, *Objection to Allert on Waste Recovery Park: Climate Change* (2011) Available online: http://www.nywag.org/wp-content/uploads/2012/02/NYWAG-Climate-Change.pdf [accessed 28 February 2014].

[87] Katuwal H, Bohara AK, Biogas: A promising renewable technology and its impact on rural households in Nepal, *Renewable and Sustainable Energy Reviews* 13/9 (2009) 2668-2674.

[88] Budzianowski WM, Sustainable biogas energy in Poland: Prospects and challenges, *Renewable and Sustainable Energy Reviews* 16/1 (2012) 342-349.

[89] Gosens J, Lu Y, He G, Bluemling B, Beckers TA, Sustainability effects of household-scale biogas in rural China, *Energy Policy* (2012).

[90] Weiland P, Biogas production: current state and perspectives, *Applied Microbiology and Biotechnology* 85/4 (2010) 849-860.

[91] Vijay VK, Prasad R, Singh JP, Sorayan VPS, A case for biogas energy application for rural industries in India, *Renewable Energy* 9/1 (1996) 993-996.

[92] Massé DI, Talbot G, Gilbert Y, On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations, Animal Feed Science and Technology 166 (2011) 436-445.

[93] Lansing S, Botero RB, Martin JF, Waste treatment and biogas quality in small-scale agricultural digesters, *Bioresource Technology* 99/13 (2008) 5881-5890.

[94] Axaopoulos P, Panagakis P, Energy and economic analysis of biogas heated livestock buildings, *Biomass and Bioenergy* 24/3 (2003) 239-248.

[95] Jiang Z, Steinsberger SC, Shih JC, *In situ* utilization of biogas on a poultry farm: Heating, drying and animal brooding, *Biomass* 14/4 (1987) 269-281.

[96] Taşdemiroğlu E, Economics of biogas space heating systems in rural Turkey, *Bioresource Technology* 36/2 (1991) 147-155.

[97] Maizonnasse M, Plante JS, Oh D, Laflamme CB, Investigation of the degradation of a low-cost untreated biogas engine using preheated biogas with phase

separation for electric power generation, *Renewable Energy* 55 (2013) 501-513.

[98] Uusitalo V, Soukka R, Horttanainen M, Niskanen A, Havukainen J, Economics and greenhouse gas balance of biogas use systems in the Finnish transportation sector, *Renewable Energy* 51 (2013) 132-140.

[99] Sasse LV, Biogas Plants; A Publication of the Deutsches Zentrum fuer Entwicklungstechnologein GATE in: *Deutsche Geselleschaft fuer Technische Zusammenarbeit* (GTZ) GmbH (1998).

[100] Devkota GP, Biogas Technology in Nepal- A Sustainable Source of Energy Rural People (2001) 101.

[101] East Consult: Biogas Users Survey of 2003/2004, *Alternative Energy Promotion Centre* (2004).

[102] Li Z, Tang R, Xia C, Luo H, Zhong H, Towards green rural energy in Yunnan, China, *Renewable Energy* 30 (2005) 99-108.

[103] Biomass Energy For Rural India Society, *Bioenergy Potential Benefits*, Available online: http://bioenergyindia.kar.nic.in/pro_benefits.htm [accessed 25 January 2013].

[104] Ezzati M, Lopez AD, Rodgers A, Murray CJ, Comparative quantification of health risks: the global and regional burden of disease attributable to selected major risk factors, Geneva, *World Health Organization* (2004).

[105] Venkataraman C, Sagar AD, Habib G, Lam N, Smith KR, The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion, *Energy for Sustainable Development* 14/2 (2010) 63-72.

[106] Bansal M, Saini RP, Khatod DK, Development of cooking sector in rural areas in India—A review, *Renewable and Sustainable Energy Reviews* 17 (2013) 44-53.

[107] National Climate Center India Meteorological Department, Pune, *Climate change Scenario in India*, Available online: http://www.imdpune.gov.in/research/ncc/climatereserch/climateresearch.html [accessed 2 March 2013].

[108] India's GHG Emissions Profile Results of Five Climate Modeling Studies Ministry of Environment and Forests Government of India, September (2009).

[109] Borjesson P, Biogas from waste materials as transportation fuel-benefits from an environmental point of view, *Water Science and Technology* 57/2 (2008) 271-276.

[110] IPCC, an Assessment of the Intergovernmental Panel on Climate Change (2007).

[111] Shakya SR, Application of Renewable energy Technology for greenhouse gas Emission in Nepalese context: A case study, *The Nepalese Journal of Engineering* 1/1 (2005) 92-101.

[112] Tuomisto HL, Helenius J, Comparison of energy and greenhouse gas balances of biogas with other transport biofuel options based on domestic agricultural biomass in Finland, *Agricultural and Food Science* 17/3 (2008) 240-251.

[113] Börjesson P, Berglund M, Environmental systems analysis of biogas systems-Part II: The environmental impact of replacing various reference systems, *Biomass and Bioenergy* 31/5 (2007) 326-344.