Renewable and Sustainable Energy Reviews 15 (2011) 1513–1524

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Role of renewable energy sources in environmental protection: A review

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ARTICLE INFO

Article history:
Received 12 August 2010
Accepted 12 November 2010
Available online 12 January 2011

Keywords:
Greenhouse gases
CO_2 mitigation
Sustainable development
Renewable energy sources

ABSTRACT

Renewable technologies are considered as clean sources of energy and optimal use of these resources minimize environmental impacts, produce minimum secondary wastes and are sustainable based on current and future economic and social societal needs. Sun is the source of all energies. The primary forms of solar energy are heat and light. Sunlight and heat are transformed and absorbed by the environment in a multitude of ways. Some of these transformations result in renewable energy flows such as biomass and wind energy. Renewable energy technologies provide an excellent opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources. In this article a review has been done on scope of CO_2 mitigation through solar cooker, water heater, dryer, biofuel, improved cookstoves and by hydrogen.

Contents

1. Introduction

Renewable energy sources (RES) supply 14% of the total world energy demand [1]. RES includes biomass, hydropower, geothermal, solar, wind and marine energies. The renewable are the primary, domestic and clean or inexhaustible energy resources [2,3]. Large-scale hydropower supplies 20 percent of global electricity. Wind power in coastal and other windy regions is promising source of energy [1,4]. Main renewable energy sources and their usage forms are given in Table 1. RESs are also called alternative energy sources. The share of RESs is expected to increase very significantly (30–80% in 2100) [4]. The global renewable energy scenario by 2040 is presented in Table 2.

Sustainable development requires methods and tools to measure and compare the environmental impacts of human activities for various products [7]. At present, consumption of fossil fuels

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doi:10.1016/j.rser.2010.11.037

Table 1
Main renewable energy sources and their usage form [5].

Energy source	Energy conversion and usage options
Hydropower	Power generation
Modern biomass	Heat and power generation, pyrolysis, gasification, digestion
Geothermal	Urban heating, power generation, hydrothermal, hot dry rock
Solar	Solar home system, solar dryers, solar cookers
Direct solar	Photovoltaic, thermal power generation, water heaters
Wind	Power generation, wind generators, windmills, water pumps
Wave	Numerous designs
Tidal	Barrage, tidal stream

is dramatically increasing along with improvements in the quality of life, industrialization of developing nations, and increase of the world population. It has long been recognized that this excessive fossil fuel consumption not only leads to an increase in the rate of diminishing fossil fuel reserves, but it also has a significant adverse impact on the environment, resulting in increased health risks and the threat of global climate change [8]. Changes towards environmental improvements are becoming more politically acceptable globally, especially in developed countries. Society is slowly moving towards seeking more sustainable production methods, waste minimization, reduced air pollution from vehicles, distributed energy generation, conservation of native forests, and reduction of greenhouse gas emissions [9].

Increasing consumption of fossil fuel to meet out current energy demands alarm over the energy crisis has generated a resurgence of interest in promoting renewable alternatives to meet the developing world's growing energy needs [10,11]. Excessive use of fossil fuels has caused global warming by carbon dioxide; therefore, renewable promotion of clean energy is eagerly required [12]. To monitor emission of these greenhouse emissions an agreement was made with the overall pollution prevention targets, the objectives of the Kyoto Protocol agreement [13]. In this paper, attempt has been made to find out the scope of renewable energy gadgets to meet out energy needs and mitigation potential of greenhouse gases mainly carbon dioxide.

2. Renewable energy sources

Renewable energy resources will play an important role in the world's future. The energy resources have been split into three categories: fossil fuels, renewable resources and nuclear resources [14]. Renewable energy sources are those resources which can be used to produce energy again and again, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc. and are also often called alternative sources of energy [15]. Renewable energy sources that meet domestic energy requirements have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Renewable energy system development will make it possible to resolve the presently most crucial tasks like improving energy supply reliability and organic fuel economy; solving problems of local energy and water supply; increasing the standard of living and level of employment of the local population; ensuring sustainable development of the remote regions in the desert and mountain zones; implementation of the obligations of the countries with regard to fulfilling the international agreements relating to environmental protection [16]. Development and implementations of renewable energy project in rural areas can create job opportunities and thus minimizing migration towards urban areas [17]. Harvesting the renewable energy in decentralized manner is one of the options to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way [18,19].

3. Climate change scenario

Climate change is one of the primary concerns for humanity in the 21st century [20]. It may affect health through a range of pathways, for example as a result of increased frequency and intensity of heat waves, reduction in cold related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases and effects on the risk of disasters and malnutrition. The overall balance of effects on health is likely to be negative and populations in low income countries are likely to be particularly vulnerable to the adverse effects. The experience of the 2003 heat wave in Europe showed that high-income countries may also be adversely affected [21]. The potentially most important environmental problem relating to energy is global climate change (global warming or the greenhouse effect). The increasing concentration of greenhouse gases such as CO_2, CH_4, CFCs, halons, N_2O, ozone, and peroxyacetylnitrate in the atmosphere is acting to trap heat radiated from Earth's surface and is raising the surface temperature of Earth [22]. A schematic representation of this global climate change problem is illustrated in Fig. 1.

Table 3 reveals Humankind is contributing with a great many economic activities to the increase atmospheric concentration of various greenhouse gases. Current situation and the role of various greenhouse gases are given in Table 3.

Many scientific studies reveal that overall CO_2 levels have increased 31% in the past 200 years, 20 Gt of Carbon added to environment since 1800 only due to deforestation and the concentration of methane gas which is responsible for ozone layer depletion has more than doubled since then. The global mean surface temperature has increased by 0.4–0.8 °C in the last century above the baseline of 14 °C. Increasing global temperature ultimately increases global mean sea levels at an average annual rate of 1–2 mm over the last century. Arctic sea ice thinned by 40% and decreased in extent by 10–15% in summer since the 1950s [25].

Table 2
Global renewable energy scenario by 2040 [6].

	2001	2010	2020	2030	2040
Total consumption (million tons oil equivalent)	10,038	10,549	11,425	12,352	13,310
Biomass	1080	1313	1791	2483	3271
Large hydro	22.7	266	309	341	358
Geothermal	43.2	86	186	333	493
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Photovoltaic	0.1	2	24	221	784
Solar thermal electricity	0.1	0.4	3	16	68
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
Total RES	1,365.5	1,745.5	2,964.4	4289	6351
Renewable energy source contribution (%)	13.6	16.6	23.6	34.7	47.7

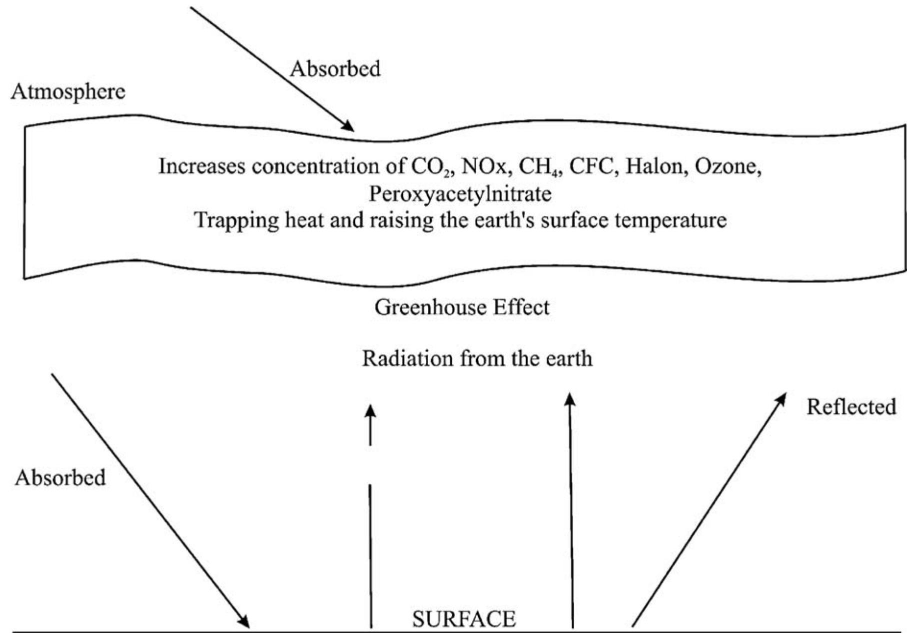

Fig. 1. A schematic illustration of greenhouse effect [23].

Table 3
Role of different substances in the greenhouse effect [24].

Substance	Ability to retain infrared radiations compared to CO_2	Pre industrial concentration	Present concentration	Annual growth rate (%)	Share in the greenhouse effect due to human activity (%)	Share in the greenhouse increase due to human activity (%)
CO_2	1	275	346	0.4	71	50 ± 5
CH_4	25	0.75	1.65	1.0	8	15 ± 5
N_2O	250	0.25	0.35	0.2	18	9 ± 2
R-11	17,500	0	0.00023	5.0	1	13 ± 3
R-12	20,000	0	0.00040	5.0	2	13 ± 3

Table 4
CO_2 emission by region (million tons of CO_2 [28].

	1971	1995	2010	2020
OECD	9031	10,763	13,427	14,476
Transition economic	3029	3135	3852	4465
China	875	3051	5322	7081
Rest of the world	1436	4791	8034	11,163
World	14,732	22,150	31,189	37,848

Industry contributes directly and indirectly (through electricity consumption) about 37% of the global greenhouse gas emissions, of which over 80% is from energy use. Total energy-related emissions, which were 9.9 Gt CO_2 in 2004, have grown by 65% since 1971 [26]. There is ample scope to minimize emission of greenhouse gases if efficient utilization of renewable energy sources in actual energy meeting route is promoted [27].

Table 4 reveals that over the period from 1971 to 1995, CO_2 emissions grew at an average rate of 1.7% per year. The outlook projects a faster growth rate of CO_2 emissions for the period to 2020, at 2.2% per year. By 2020, the developing countries could account for half of global CO_2 emissions.

4. Solar energy

4.1. Solar thermal application

As far as renewable energy sources is concerned solar thermal energy is the most abundant one and is available in both direct as well as indirect forms. The Sun emits energy at a rate of 3.8×10^{23} kW, of which, approximately 1.8×10^{14} kW is intercepted by the earth [29]. There is vast scope to utilize available solar energy for thermal applications such as cooking, water heating, crop drying, etc.

Solar cooking is the most direct and convenient application of solar energy. Solar energy is a promising option capable of being one of the leading energy sources for cooking [30–32]. Various types of solar cookers are available, out of them box type solar cooker (Fig. 2) is widely used all over the world. A study was conducted in Costa Rica and in the world as a whole, and then compared the advantages and limitations of solar ovens with conventional firewood and electric stoves. The payback period of a common hot box type solar oven, even if used 6–8 months a year, is around 12–14 months, roughly 16.8 million tons of firewood can be saved and the emission of 38.4 million tons of carbon dioxide per year can also be prevented [33].

Solar water heater of domestic size, suitable to satisfy most of the hot water needs of a family of four persons, offers significant protection to the environment and should be employed whenever possible in order to achieve a sustainable future [35]. It is estimated that a domestic solar water heating system of 100 l per day capacity can mitigate around 1237 kg of CO_2 emissions in a year at 50% capacity utilization and in hot and sunny region it is about 1410.5 kg [36,37]. A schematic of solar water heater is illustrated in Fig. 3

Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality,

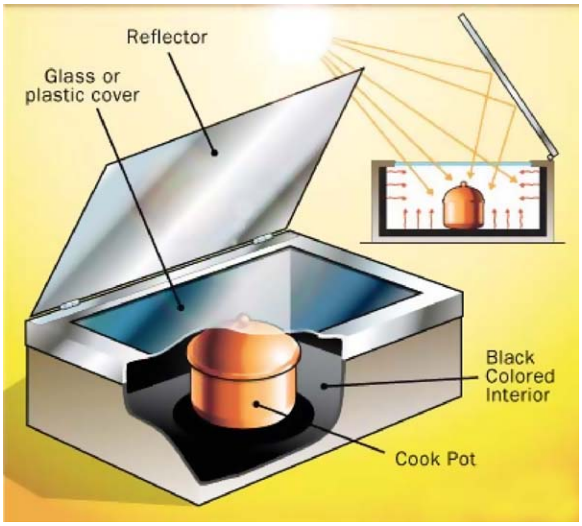

Fig. 2. Box type solar cooker [34].

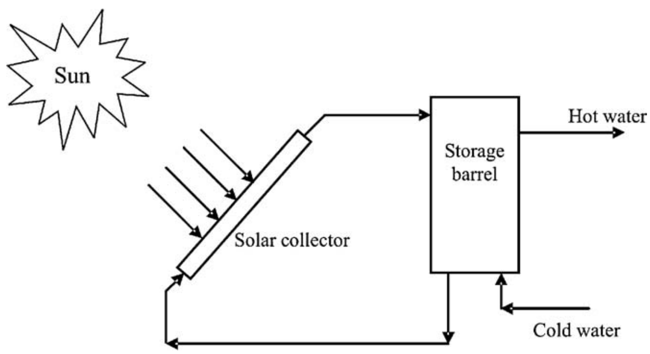

Fig. 3. A typical domestic-scale solar water heater [38].

makes the process more efficient and protects the environment [39].

Piacentini and Mujumdar [40] estimated CO_2 production for a drying system using 100 kWh day^{-1} of electricity, over 25 days per month in 11 months of operation per year. It came to around 14.77 tons of CO_2 year^{-1}. Further study was conducted on solar crop drying and CO_2 emission potential. It was estimated that 1 m^2 aperture area can save 463 kg of carbon dioxide in life cycle embodied [41].

4.2. Solar thermal power

Solar energy is a very important energy source because of its advantages. There are many remote areas in the world where electricity is not available, but solar irradiation is plentiful, thus the utilization of solar energy to produce electricity in these areas is quite possible [42]. Solar thermal electricity power system is a device which utilize the solar radiation for the generation of electricity through the solar thermal conversion; basically collected solar energy is converted to electricity through the use of some sort of heat to electricity conversion device as shown in Fig. 4 [43,44].

The major component of any solar thermal system is the solar collector. Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. A historical introduction into the use of solar energy was attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish, and

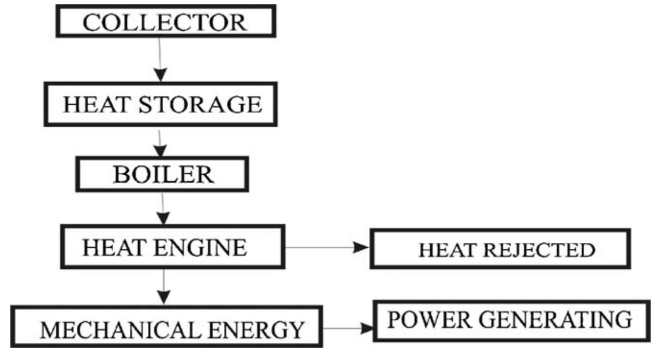

Fig. 4. Schematic diagram of a solar thermal conversion system.

heliostat field collectors [45]. Electricity production cost through solar energy is quite higher than that of conventional power station. As far as carbon emission is concerned solar based power station released almost zero carbon as presented in Table 5.

4.3. Solar photovoltaic system

Electrical energy is the pivot of all developmental efforts in both the developed and the developing nations because conventional energy sources are finite and fast depleting [46]. In the last decades, energy related problems are becoming more and more important and involve the ideal use of resources, the environmental impact due to the emission of pollutants and the consumption of conventional energy resources [47].

Direct solar energy conversion to electricity is conventionally done using photovoltaic cells, which makes use of the photovoltaic (PV) effect. PV effect depends on interaction of photons, with energy equal to, or more than the band-gap of PV materials. Some of the losses due to the band-gap limitations are avoided by cascading semiconductors of different band-gaps. [48]. PV modules generate electricity directly from light without emissions, noise, or vibration. Sunlight is free but power generation cost is exceptionally high, although prices are starting to come down. Solar energy has low energy density: PV modules require a large surface area for small amounts of energy generation [49]. The primary component in grid connected PV systems is the inverter, it convert DC power produced by PV array into AC power consistent with the voltage and power quality requirement of the utility gird as illustrated in Fig. 5.

Silicon solar cells are perhaps the simplest and most widely used for space and terrestrial applications. The PV system is promising source of electricity generation for energy resource saving and CO_2 emission reduction, even if current technologies are applied [50,51]. Further the development in efficiency of solar cells, amount of material used in the solar cell and the system design for maximum use of recycled material will reduce the energy requirement and greenhouse gas emissions [52].

Net annual CO_2 emission mitigation potential from 1.8 kWp solar photovoltaic pump at an average solar radiation of 5.5 kWh m^{-2} is about 2085 kg from diesel operated pumps and about 1860 kg from petrol operated pumps. The CO_2 emissions mitigation potential is higher in the case of diesel substitution as

Table 5
Economics and emissions of conventional technologies compared with solar power generation [42].

Electricity generation technology	Carbon emissions (gC/kWh)	Generation costs (US¢/kWh)
Solar thermal and solar PV systems	0	9–40
Pulverized coal–natural gas turbine	100–230	5–7

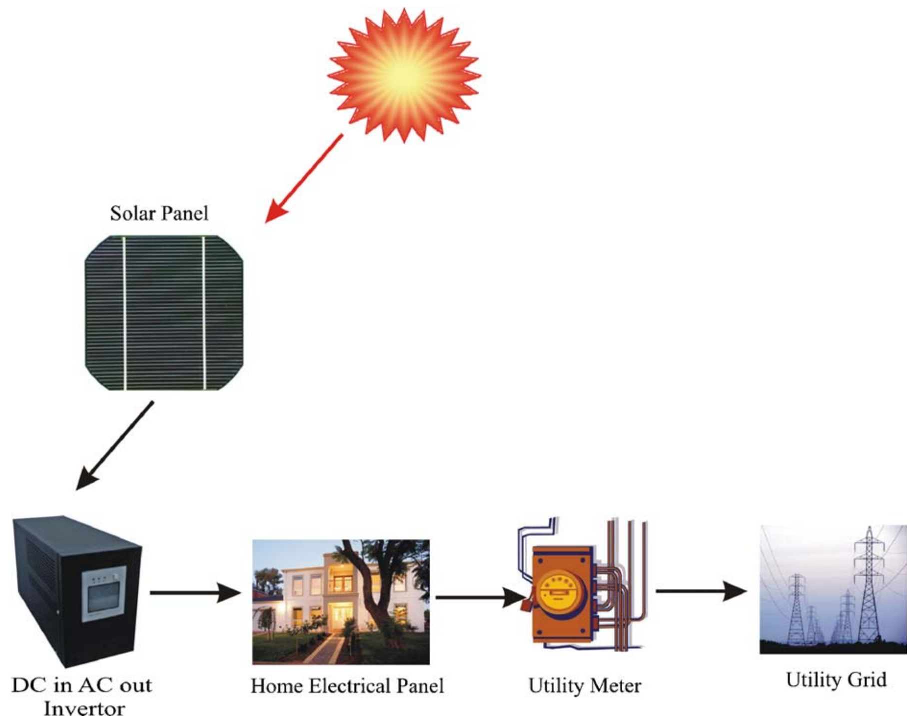

Fig. 5. Grid connected photovoltaic system.

compared to the petrol substitution. This is primarily due to low efficiency of fuel utilization in the diesel engine pump [53].

5. Wind energy

Of the renewable energy technologies applied to electricity generation, wind energy ranks second only to hydroelectric in terms of installed capacity and is experiencing rapid growth. India is one of the most promising countries for wind power development in the world [54]. Expansion of wind energy installed capacity is poised to play a key role in climate change mitigation. However, wind energy is also susceptible to global climate change. Some changes associated with climate evolution will most likely benefit the wind energy industry while other changes may negatively impact wind energy developments, with such 'gains and losses' depending on the region under consideration [55]. Wind power may prove practical for small power needs in isolated sites, but for maximum flexibility, it should be used in conjunction with other methods of power generation to ensure continuity [56]. Wind energy potential studies show that the world-wide wind resources are abundant. The world-wide potential for wind energy is estimated to be 26,000 TWh/yr, while a capacity of 9000 TWh/yr may be utilized due to economical and other reasons [57].

Wind energy for electricity production today is a mature, competitive, and virtually pollution-free technology widely used in many areas of the world [58]. Wind technology converts the energy available in wind to electricity or mechanical power through the use of wind turbines [59]. The function of a wind turbine is to convert the motion of the wind into rotational energy that can be used to drive a generator, as illustrated in Fig. 6. Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it into rotating mechanical power. Wind turbine blades use airfoils to develop mechanical power [60].

In the power-starved developing countries, wind power is the viable source of electricity, which can be installed and transmitted very rapidly, even in remote, inaccessible and hilly areas [61]. Electricity generation from wind never depletes and never increases in price. The electricity produced by these systems could save several billion barrels of oil and avoid many million tons of carbon and other emissions [62].

At a mean wind speed of 4.5 m/s, the estimated value of net annual CO_2 emission mitigation potential is the lowest (2874 kg) for GM-II model and highest (7401 kg) for SICO model in the case of diesel substitution. Similarly, for the case of electricity substitution for the same wind speeds, it is estimated at 2194 kg and 5713 kg, respectively, for the above-mentioned two models [36].

6. Bioenergy

6.1. Biogas

The production of biogas through anaerobic digestion offers significant advantages over other forms of bioenergy production. It has been evaluated as one of the most energy-efficient and environmentally beneficial technology for bioenergy production [63]. For the production of biogas it is possible to use several different raw materials and digestion technologies. This variety and the various fields of application for the biogas and digested product result in great differences in the environmental performance among the potential biogas systems. Among the raw materials are organic waste from households and the food industry, dedicated energy crops, and agricultural waste products, such as crop residues and manure [64].

The large amounts of animal manure and slurries produced today by the animal breeding sector as well as the wet organic waste streams represent a constant pollution risk with a potential negative impact on the environment, if not managed optimally. To prevent emissions of greenhouse gases (GHG) and leaching of nutrients and organic matter to the natural environment it is necessary to close the loops from production to utilization by optimal recycling measures [65] and it is as shown in Fig. 7.

Biogas is a mixture of gases that is composed mainly of CH_4 40–70%, CO_2 30–60%, and other gases 1–5%. The calorific value of biogas is about 16–20 MJ m^{-3} [67]. Methane fermentation is a com-

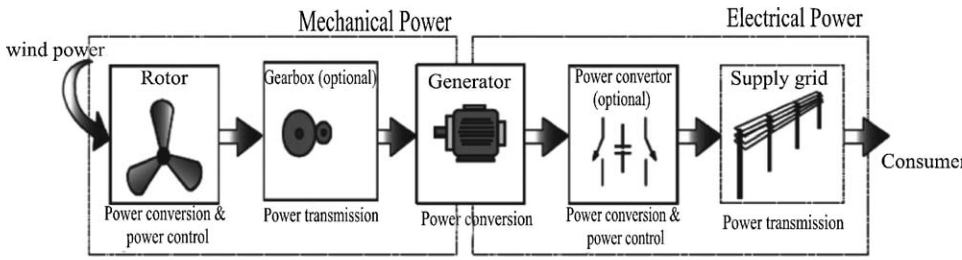

Fig. 6. Conversion from wind power to electrical power in a wind turbine.

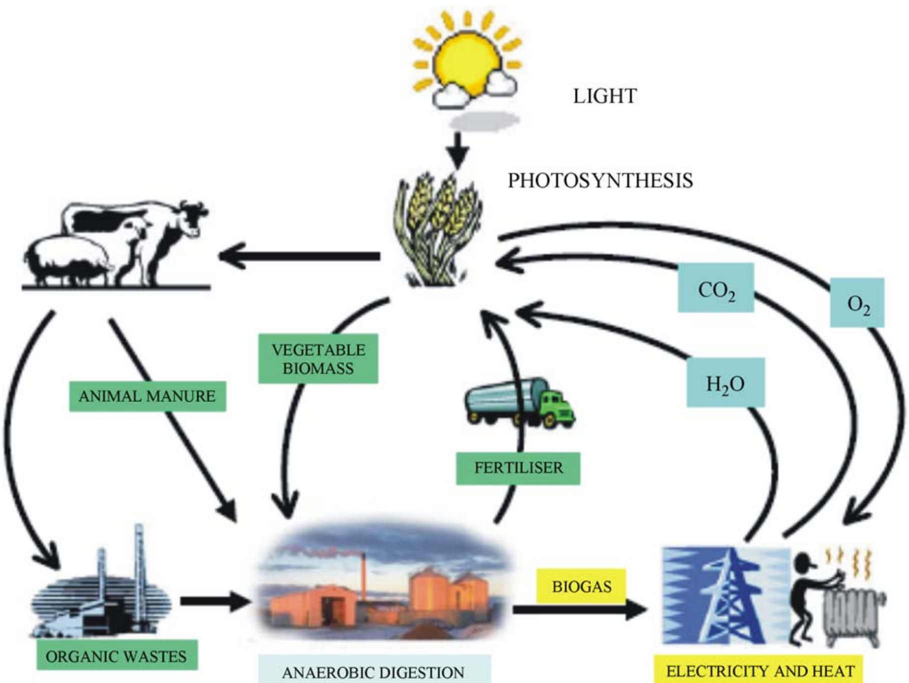

Fig. 7. Schematic representation of the sustainable cycle of anaerobic co-digestion of animal manure and organic wastes [66].

plex process, which can be divided up into four phases: hydrolysis, acidogenesis, acetogenesis/dehydrogenation and methanation as shown in Fig. 8.

Borjesson and Berglund [64] present an overview of biogas systems as shown in Fig. 9. It include emissions from the energy input in the entire biogas production chain; that is, the handling of raw materials, the digestion of the raw materials in farm-scale and large-scale biogas plants, and the final use of the digestates and biogas. Handling of energy crops includes the entire energy input and emissions from the cultivation and harvesting of the crop, since it is assumed to be cultivated primarily for biogas production. These crops are assumed to be cultivated on set-aside arable land, and hence, the analysis does not treat the production of food or fodder replacements. The other raw materials are assumed to be waste products. Consequently, the analysis includes only the additional energy input and emissions associated with the handling and transport of these waste products, and none of the input used in the production of the main product.

Biogas has definite advantages, even if compared to other renewable energy alternatives. It can be produced when needed and can easily be stored. It can be distributed through the existing natural gas infrastructure and used in the same applications like the natural gas [13]. The biogas can directly be used for domestic cooking, transportation fuel or distributed on the natural gas grid for end application [69].

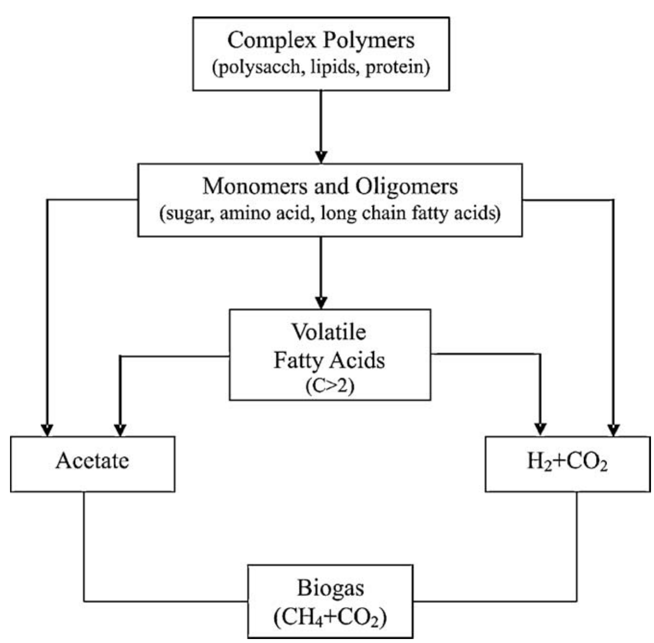

Fig. 8. The stages of the methane fermentation process [68].

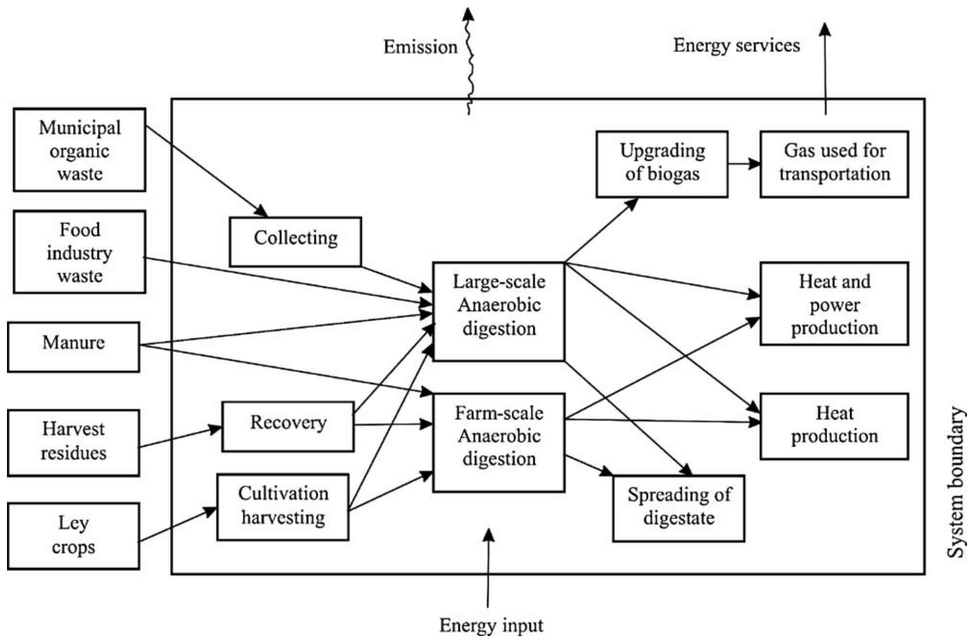

Fig. 9. Overview of the biogas systems analysed. The arrows represent material flows, energy flows, and emissions from the system.

Biogas systems are considered to be strong alternatives to the traditional space heating systems (stoves) in rural Turkey. Biogas systems for heating was found economical viable when compared with traditional heating systems fuelled by wood, coal and wood mixture, and dried animal waste [70]. Power generation from biogas is quite possible in both duel fuel mode and 100 percent biogas run engine. The overall engine performance was improved when scrubbed biogas was used in duel fuel engine as compared to raw gas duel fuel engine [71].

Biogas technology provides an excellent opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting firewood for cooking, kerosene for lighting and cooking and chemical fertilizers. The global warming mitigation potential of a family size biogas plant was 9.7 tons CO_2 equiv. year^{-1} and with the current price of US \$10 tons^{-1} CO_2 equiv., carbon credit of US \$97 year^{-1} could be earned from such reduction in greenhouse gas emission under the clean development mechanism [72].

6.2. Biodiesel

With reference to world energy scenario [73], some 85–90% of world primary energy consumption will continue (until 2030) to be based on fossil fuels. At the same time rising petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated intense international interest in developing alternative non-petroleum fuels for engines. The use of vegetable oil in internal combustion engines is not a recent innovation. Rudolf Diesel (1858–1913), creator of the diesel cycle engines, used peanut vegetable oil to demonstrate his invention in Paris in 1900. In 1912, Diesel said, "The use of vegetable oils as engine fuel may seem negligible today. Nevertheless, such oils may become, in the passing years, as important as oil and coal tar presently." Nowadays, it is known that oil is a finite resource and that its price tends to increase exponentially, as its reserves are fast depleting [74]. Biodiesel is a clean burning fuel that is renewable and biodegradable. Biodiesel is being extracted from Mahua oil [75], rubber seed oil [76], Pongamia pinnata oil [77], palm oil [78], Jatropha curcas [79,80], duck tallow [81] and castor seed oil [82] and its blends showed performance characteristics close to diesel [83].

Straight vegetable oil has higher viscosity and one of the most common methods used to reduce oil viscosity in the biodiesel industry is called transesterification [84]. Transesterification is the process of exchanging the alkoxy group of an ester compound by another alcohol. These reactions are often catalyzed by the addition of a base and acid. Bases can catalyze the reaction by removing a proton from the alcohol, thus making it more reactive, while acids can catalyze the reaction by donating a proton to the carbonyl group, thus making it more reactive [85]. The physical properties of the primary chemical products of transesterification are given in Table 6.

Biodiesel has the potential to reduce emissions from the transport industry, which is the largest producer of greenhouse gases. The use of biodiesel also reduces the particulate matter released into the atmosphere as a result of burning fuels, providing potential benefits to human health [87]. A study was reported in Indian

Table 6
Comparison of physical properties of vegetable oil and their methylester preparation via transesterification [86].

Properties	Oil or fat (refined)			Methyl ester		
	Viscosity (mm^2/s at 311 K)	Cetane number	Flash point (K)	Viscosity (mm^2/s at 311 K)	Cetane number	Flash point (K)
Soyabean (US)	33.1	38.1	548	4.08	46	441
Palm (Malaysia)	42.7	65	576	3.94	62	431
Rapeseed (EU)	37.3	37.5	531	4.60	47	453
Sunflower (EU)	34.4	36.7	535	4.16	49	439
Cottonseed (China)	33.7	37.1	524	3.75	42	433
Tallow (US)	32.3	75	525	4.10	58	436
Tall oil (Scandinavia)	51.0	?	485	5.30	50	461

context that if 10% of total production of castor seed oil is transesterfied into biodiesel, then about 79,782 tons of CO_2 emission can be saved on annual basis. The CO_2 released during combustion of biodiesel can be recycled through next crop production, therefore, no additional burden on environment [88].

6.3. Biomass gasifier

Gasifier is a device which converts solid fuel into gaseous fuel through thermo chemical conversion route. In the gasifier low grade fuel, i.e. biomass gets converted in high grade fuel known as charcoal and further into low calorific gas called producer gas [98,99]. The gas thus produced by gasifier can be utilized to produce process heat for thermal application. To disseminate the gasification technology in actual uses, Ministry of New and Renewable Energy (MNRE) has taken initiative to develop research group within India for technology and man power development, as a consequence Indian premier institute like Indian Institute of Science, Bangalore (IISc) [100]. The Energy and Resource Institute (TERI), Sardar Patel Renewable Energy Research Institute (SPRERI), etc. have been involved in the field of biomass combustion and gasification technology. More than 350 TERI gasifier systems have been successfully installed in the field throughout India with a cumulative installed capacity of over 13 MWth [101]. The gasifier technologies available in India are based on downdraft gasification and designed primarily for woody biomass [102].

Package of practice was developed by IISc, Bangalore to dry marigold flower with open top downdraft gasifier. The developed gasifier is in position to replace 2000 l of diesel or LDO per day completely. The system operates over 140 h per week on a nearly nonstop mode and over 4000 h of operation replacing fossil fuel completely [103]. Work on development of modular throat type down draft gasifier having 1.39 MW thermal capacities was carried out by Pathak et al. [104]. There is huge scope to utilize the gasification technology in small scale industries for low temperature applications. Study was conducted on open core downdraft gasifier in small scale industries to produce process heat in the temperature range of 200–350 °C for backing bakery items. During the study it was found that 6.5 kg of LPG was replaced by 38 kg of woody biomass. Over 3000 h of operation gasifier has resulted in a saving of about 19.5 tons of LPG, implying a saving of about 33 tons of CO_2, thus a promising candidate for clean development mechanism [105].

Fig. 10. Gasifier installed at M/s Phosphate India Pvt. Ltd., Udaipur.

Similar design of gasifier was tested at M/s Phosphate India Pvt. Limited, Udaipur Fig. 10. This industry is working for concentration of about 500 l/day of phosphoric acid. The initial gravity of acid is 20%, which is required to be brought 50%. Required process heat is meeting through combustion of biomass in open furnace. The system is operating for about 6 h every day and consumes approximately 48 kg/h of sized fuel per hours against 50 kg/h wood for 11 h per day. The developed system is in position to save about 24.15 tons of CO_2 in 1800 working hours [106].

6.4. Gasifier based power generation system

Biomass use for power generation has become an attractive option for the increase of energy production with the increase of efficiency, decrease of environment degradation and waste utilization. Gas turbines cannot be fired directly with biomass, because the biomass combustion products would damage the turbine blades. However, by first gasifying the biomass and cleaning the gas before combustion, it is feasible to operate gas turbines with biomass

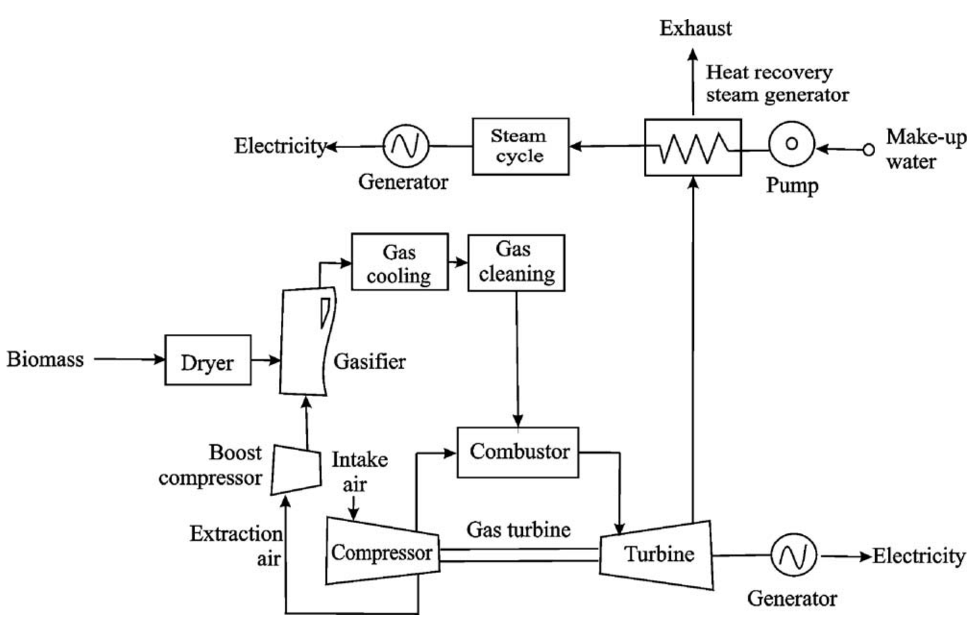

Fig. 11. A biomass-gasifier/gas turbine combined cycle.

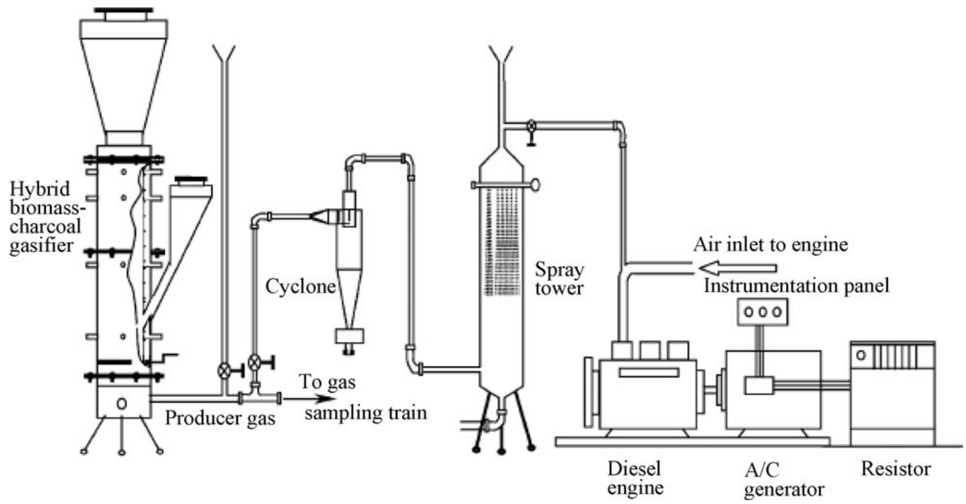

Fig. 12. Experimental gasifier–engine system.

fuels. Fig. 11 is a schematic representation of a biomass-integrated gasifier (BIG)/gas turbine (GT) combined cycle, a leading first-generation candidate for BIG/GT systems [107].

This process gives high efficiency of electricity production in a gaseous power plant than in the classic power plant during the combustion of biomass and steam cycle. Besides, this process enables considerably lower emission of harmful gases and particles.

For this attractive biopower option based on gasification, size of biopower plant is 75MW and total efficiency would be $\eta = 36\%$. Cost of this power plant is estimated to be 2750$/kW and electricity costs of 0.03$/kWh [108].

Bhattacharya et al. [109] conduct a study on a multi-stage hybrid biomass–charcoal gasification to produce low tar content gas for engine application using coconut shell as a fuel as shown in Fig. 12. Study report that almost all of the tar content in producer gas could be removed by passing it through the spray tower so that it could safely run a diesel engine without any tar problems. At the optimal water flow rate, producer gas could be cooled down to less than 40 °C. Engine-generator efficiency at dual fuel operation was lower than that of diesel fuel operation. With the experimental system, engine-generator efficiency of 14.7% was achieved at a maximum electrical power output (11:44 kWe) with 81% of the total energy input coming from producer gas. Maximum electrical power output for dual fuel operation was about 79% of that for diesel fuel operation.

6.5. Improved cookstoves

The combustion process in traditional cooking stove is non-ideal and favoring incomplete combustion. Incomplete and inefficient combustion by traditional cookstoves produce significant quantities of products of incomplete combustion (PIC) comprising of fine and ultra fine particles which have more global warming potential (GWP) than CO_2 [110]. Emission study was also conducted by Bhattacharya and Salam Abdul [111] and it was concluded that incomplete combustion of biomass in the traditional cooking stove released carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4), polycyclic aromatic hydrocarbons (PAHs), particles composed of elemental carbon or black carbon, and other organic compounds. Improved cookstove is best solution to overcome this type of emission problems. Improved cookstoves performed better fuel economy, better indoor air environment and clean kitchen (Fig. 13). Improvements in households biomass burning stoves potentially bring three kinds of benefits: (1) reduced fuel demand, with economic and time saving benefits to the household and increase sustainability of the natural resources base; (2) reduced human exposure to health damaging air pollutants; and (3) reduced emission of the greenhouse gases that are thought to increase the probability of global climate change [112]. Single stove can save about 700 kg of fuel wood per year and at the same time it reduces the CO_2 emission by 161 kg per year. It helps to improve health stan-

Fig. 13. Double pot improved cookstove.

Table 7
Main Advantage and limitation of biomass to hydrogen [92].

Advantages
Use of biomass reduces CO_2 emissions
Crop residues conversion increases the value of agricultural output
Replacing fossil fuels with sustainable biomass fuel
Costs of getting rid of municipal solid wastes
Limitations
Seasonal availability and high costs of handling
Nontotal solid conversion (char formation) and tars production
Process limitations: corrosion, pressure resistance and hydrogen aging

dard of women and child, also reduces the burden of fuel collection [113].

7. Hydrogen as fuel

Hydrogen has fascinated generations of people for centuries, including visionaries like Jules Verne. Hydrogen is expected to play a key role in the world's energy future by replacing fossil fuels. Hydrogen is gaining increasing attention as an encouraging future energy [89]. Its conversion to heat or power is simple and clean. When burnt with oxygen, hydrogen generates no pollutants, only water, which can return to nature. However, hydrogen, the most common chemical element on the planet, does not exist in nature in its elemental form. It has to be separated from chemical compounds, by electrolysis from water or by chemical processes from hydrocarbons or other hydrogen carriers. The electricity for the electrolysis may come eventually from clean renewable sources such as solar radiation, kinetic energy of wind and water, or geothermal heat. Therefore, hydrogen may become an important link between renewable physical energy and chemical energy carriers [90].

Most H_2 is currently produced from nonrenewable sources such as oil, natural gas, and coal [91]. Thermochemical conversion processes such as pyrolysis and gasification of biomass have considerable potential for producing renewable hydrogen, which is beneficial to exploit biomass resources, to develop a highly efficient clean way for large-scale hydrogen production, and to lessen dependence on insecure fossil energy sources [92]. The main advantages of biomass to hydrogen are:

1. The use of biomass reduces CO_2 emissions, and thus replacing fossil fuels with sustainable biomass fuel is one option that needs consideration in reducing CO_2 emissions.
2. The residues conversion increases the value of agricultural output.
3. The costs of getting rid of municipal wastes are mounting as land resources are constrained.

7.1. Production of hydrogen from biomass

Production of hydrogen from renewable biomass has several advantages compared to that of fossil fuels [93]. Producing hydrogen from woody biomass is mainly carried out via two thermochemical processes: (a) gasification followed by reforming of the syngas, and (b) fast pyrolysis followed by reforming of the carbohydrate fraction of the bio-oil [94,95]. Table 7 shows the main advantages and limitations of converting biomass to hydrogen. Table 8 shows the conditions of thermal treatment of biomass.

Table 8
Conditions of thermal treatment of biomass [96].

Process	Temperature (K)	Heating rate (K/s)	Solid residence time (s)
Pyrolysis	675–875	0.1–1.0	600–2000
Fast pyrolysis	975–1225	250–300	1–3
Gasification	975–1225	300–500	0.5–2.0

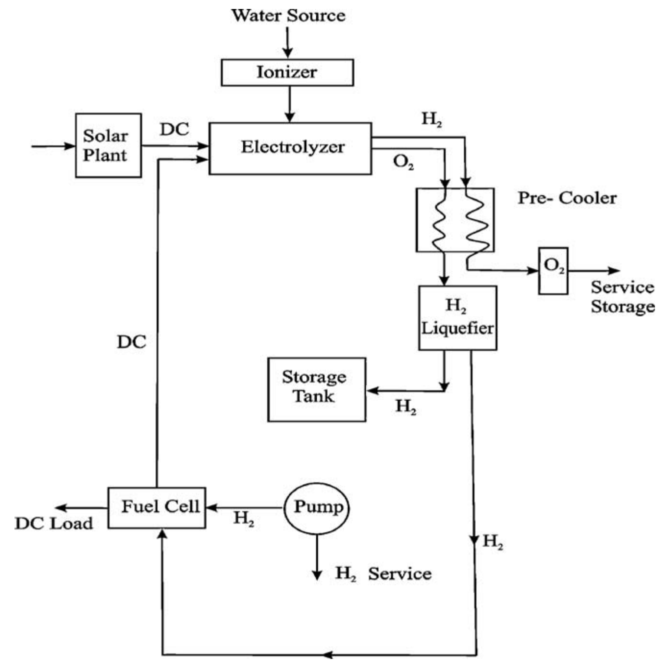

Fig. 14. Structure of production and utilization of hydrogen gas.

The main gaseous products from biomass are [94] the following:

$$\text{Pyrolysisofbiomass} \rightarrow H_2 + CO_2 + CO + \text{Hydrocarbongases}$$

$$\text{Catalyticsteamreformingofbiomass} \rightarrow H_2 + CO_2 + CO$$

$$\text{Gasificationofbiomass} \rightarrow H_2 + CO_2 + CO + N_2$$

Hydrogen from organic wastes has generally been based on the following reactions:

$$\text{Solidwaste} \rightarrow CO + H_2$$

$$\text{Biomass} + H_2O + \text{Air} \rightarrow H2 + CO_2$$

$$\text{Cellulose} + H_2O + \text{Air} \rightarrow H_2 + CO + CH_4$$

The closed loop system of hydrogen production and its utilization to generate electrical energy is shown in Fig. 14. The system consists of a solar plant (photo-voltaic energy stand-alone), electrolyzer, ionizer, storage unit, pump, cooler, liquefier, and fuel cell, which are integrated in one system. The PV energy powered the electrolyzer with a limited DC current flow to de compose the water electrochemically into gases, hydrogen and oxygen (H_2 and O_2). The produced gases are pumped intermediately into high pressure storage tanks. The fuel cell is connected to the storage tank via pressure reduction valves to generate electricity, in a closed loop production and utilization cycle of hydrogen and oxygen [97].

8. Conclusion

A comprehensive literature survey of major renewable energy gadgets for domestic and industrial applications such as solar water heaters, solar cookers, dryers, wind energy, biogas technology, biomass gasifiers, improved cookstoves and biodiesel was made. The review gives an overview of the development and scope of CO_2 mitigation for clean and sustainable development. The use of solar drying of agricultural produce has good potential for energy conservation in developing nations. Biodiesel from nonedible vegetable oil reduces carbon dioxide emissions and petroleum consumption when used in place of conventional diesel [114]. Biodiesel is technically competitive with or offer technical advantages compared to conventional petroleum diesel fuel. The presence of oxygen in biodiesel improves combustion and, therefore, reduces hydrocarbon, carbon monoxide, and particulate emissions; oxygenated fuels also tend to increase nitrogen oxide emissions [115,116]. Wind energy also present good potential in minimization of greenhouse gases where wind potential is available.

The application of biomass gasifier at small scale industries is found suitable and it save considerable amount of conventional fuel. The improved cookstoves provide better kitchen environment to rural women and improve their health standards. At the same time it also reduces fuel collection burden for them. The paper explicitly points out the greenhouse gas emission mitigation potential depending on the use and availability of renewable energy sources and fuel replaced by it.

Acknowledgements

The author (N.L. Panwar) gratefully acknowledges Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India and Indian Institute of Technology, Delhi for sponsorship under the quality improvement programme of the Government of India.

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