International Journal of
Renewable Energy and its Commercialization
https://chemical.journalspub.info/index.php?journal=IJREC

ISSN: 2582-4120
Volume 10, Issue 2, 2024
DOI (Journal): 10.37628/IJREC

Review | IJREC

Sustainable Innovations and Research in Bio-Energy Technology

Abdeen Mustafa Omer*

Abstract

This paper thoroughly examines the interconnections between ecology, sustainable development, and biomass energy sources, with a focus on mitigating climate change through energy efficiency and conservation. It highlights key strategies, such as heat recovery, reducing energy demand, and promoting the sensible use of energy, all of which contribute to decreasing overall energy consumption. The expansion of reliable and efficient energy services has accelerated the adoption of green energy, a cornerstone for addressing the current energy crisis. A sustainable approach to energy is deemed essential to running societies responsibly, with renewable energy playing a critical role. This involves exploring alternative energy generation methods and understanding their current and potential roles in reducing carbon emissions. The paper emphasizes the importance of using biomass energy technology, a viable green energy source, which not only reduces reliance on fossil fuels but also aids in managing CO2 emissions. Given that CO2 is the primary greenhouse gas driving global warming, sustainable energy systems offer a dual benefit – lowering emissions while enhancing energy security. Societies can strike a balance between supplying energy needs and preserving the environment by emphasizing green technologies and enhancing energy-saving techniques. This paper underlines the urgent need for sustainable energy solutions to mitigate climate change while promoting long-term environmental sustainability.

Keywords: Bioenergy, biogas, biomass, renewable energy, greenhouse gases (GHG), carbon emissions, climate change

INTRODUCTION

Energy is vital for economic growth and development, making it a crucial component of global progress. However, as fossil fuels like oil and natural gas are finite, there is an urgent need to focus on alternative energy sources. The depletion of traditional energy resources, combined with environmental degradation, has driven the global demand for energy conservation and environmental protection. In many regions, alternative energy sources offer a solution to growing energy demands while supporting economic development.

National energy policies are typically driven by three main goals: environmental preservation, economic growth, and energy security. The world's population is growing at an accelerated rate, which is leading to a dramatic increase in the need for energy. Even though they only comprise 25% of the world's population, industrialized nations currently consume 75% of their energy.

This consumption results in around 6.6 billion metric tons of greenhouse gas (GHG) emissions annually, with carbon emissions from energy fuels accounting for about 80% of the total. The reliance on fossil fuels is unsustainable, as oil, natural gas, and uranium resources are expected to deplete in a few

***Author for Correspondence**
Abdeen Mustafa Omer
E-mail: abdeenomer2@yahoo.co.uk

Research Scholar, Energy Research Institute, Nottingham NG7 4EU, United Kingdom.

Received date: September 27, 2024
Accepted date: October 29, 2024
Published date: November 08, 2024

Citation Abdeen Mustafa Omer. Sustainable Innovations and Research in Bio-Energy Technology. International Journal of Renewable Energy and its Commercialization 2024; 10(2): 18–35p.

decades.

Bioenergy, derived from organic waste, is gaining prominence as a renewable energy source in efforts to mitigate climate change. Energy from biogas, biofuels, and woody biomass offers significant potential in reducing emissions. Technological advances have improved energy efficiency and alternative energy options, but they have also contributed to environmental challenges like global warming. Renewable energy sources, such as solar, wind, biomass, and hydropower, offer sustainable solutions, particularly through small-scale, rural-based power plants that can be locally produced and contribute to long-term energy efficiency. Ultimately, greater emphasis on renewable resources is essential to achieving energy sustainability and environmental protection [13].

- Conventional sectors: transportation, industry, etc.
- End-use: process steam, space heating, etc. Final demand: energy consumption in automobiles, food, etc.
- Energy sources: oil, coal, etc.
- Energy forms at the use point: electric drive, low-temperature heat, etc.
- Organic waste energy options: biogas, biofuels, woody biomass.
- Biomass energy has the potential to combat climate change.
- Energy is essential for both urban and rural development; renewable technology can help meet the modest energy needs of rural areas.
- Renewable energy can improve living standards and reduce poverty.
- For rural development:
- Analyze potential and constraints of rural energy.
- Assess socio-technical information needs for decision-makers.
- Use techniques/models for rural energy planning.
- Design surveys for relevant data to aid planners.

BIOMASS POTENTIAL OVERVIEW

This section reviews biomass energy sources, environmental impacts, and sustainable development. It covers biomass energy technologies, energy efficiency, conservation, and emission reduction strategies.

Bio-Wastes Development

Waste includes materials discarded or designated for reuse, recycling, or reclamation, regulated by the Waste Incineration Directive (WID). WID aims to enhance control of NOx emissions, acid gases, and particulates using cleaner technologies and improved abatement techniques.

The term “bioenergy” describes energy derived from biological materials, such as animal and plant waste. Animals store energy as lipids, while plants use photosynthesis to store solar energy. When burned, these materials release energy, producing heat, steam, and carbon dioxide. Bioenergy is renewable since carbon is quickly replenished compared to fossil fuels. Sustainable biofuels, like some waste-to-energy technologies, help reduce CO_2 emissions and global warming. However, certain biofuels, like corn-based ethanol, are unsustainable due to high petrochemical inputs.

Biogas, biofuels, and bioheat are examples of waste-derived bioenergy. Biomass is ideal for rural power supply and encourages local industry through technologies like solar dryers and wind turbines, which are cheaper and easier to maintain than conventional systems (Tables 1–3).

Although inefficient, non-commercial fuels, including wood, crop waste, and animal dung are frequently utilized for cooking and heating in developing nations [46].

Considerations for Power Plants

- Power level (continuous/discontinuous).
- Cost (initial, running, and maintenance).
- Simplicity and local manufacturing potential.
- Maintenance and spare parts availability.

Adaptability to Regional Circumstances

Table 1. Energy sources for individuals in developing nations [79].

Energy Source	Energy Carrier	Energy End-Use
Vegetation	Fuel-wood	Cooking. Water heating. Building materials. Animal fodder preparation.
Oil	Kerosene	Lighting. Ignition fires.
Dry cells	Dry cell batteries	Lighting. Small appliances.
Muscle power	Animal power	Transport. Land preparation for farming. Food preparation (threshing).
Muscle power	Human power	Transport. Land preparation for farming. Food preparation (threshing).

Table 2. Energy applications [10, 12].

Systems	Applications
Water supply	Rain collection, purification, storage, and recycling
Wastes disposal	Anaerobic digestion (CH_4)
Cooking	Methane
Food	Cultivate the 1-hectare plot and greenhouse for four people
Electrical demands	Wind generator
Space heating	Solar collectors
Water heating	Solar collectors and excess wind energy
Control system	Ultimately hardware
Building fabric	Integration of subsystems to cut costs

Table 3. Energy needs in rural areas [13].

Transportation, such as boats and tiny cars.
Farm equipment, such as two-wheeled tractors.
Processing of crops, such as milling.
Pumping water.
Equipment for small industries, such as workshops.
generating electricity, such as in schools and hospitals.
Domestic, such as lighting, heating, and cooking.

Due to its reliance on fossil fuels, internal combustion engines are a major source of CO_2 emissions worldwide. As its usage rises in developing economies, automotive research should focus on low-emissions technologies to maintain clean urban environments. Strong security measures are required to avoid theft, vandalism, and arson due to the increased value of waste management materials, particularly considering the growing demand for metal in nations like China and India (Table 4).

Table 4. Methods of energy conversion [14].

Muscle Power	**Man, Animals**
Internal combustion engines	Petrol-spark ignition.
Reciprocating	Diesel-compression ignition.
Rotating	Humphrey water piston.
Heat engines	Gas turbines.
Vapour (Rankine)	
Reciprocating	Steam engine.
Rotating	Steam turbine.
Gas Stirling (Reciprocating)	Steam engine.
Gas Brayton (Rotating)	Steam turbine.
Electron gas	Thermionic and thermoelectric.
Electromagnetic radiation	Photo devices.
Hydraulic engines	Wheels, screws, buckets, and turbines.
Wind engines (wind machines)	Vertical axis and horizontal axis.
Electrical/mechanical	Dynamo/alternator, and motor.

Like the natural processes in the biosphere, the environment should be incorporated into energy consumption since it is vital to human life. However, industries like petrochemicals and nuclear energy produce harmful substances that disrupt this balance. Recognizing the economic value of the environment, new approaches like Life Cycle Analysis promote sustainable design, though challenges remain in implementation. Attention is needed to be new designs and information dissemination to advance biomass energy technologies [15, 17].

Energy Use and the Environment

Energy use impacts both developed and developing countries differently. Developing nations can achieve a higher quality of life while reducing energy consumption through improved efficiency, energy conservation designs, and recycling strategies (Figure 1).

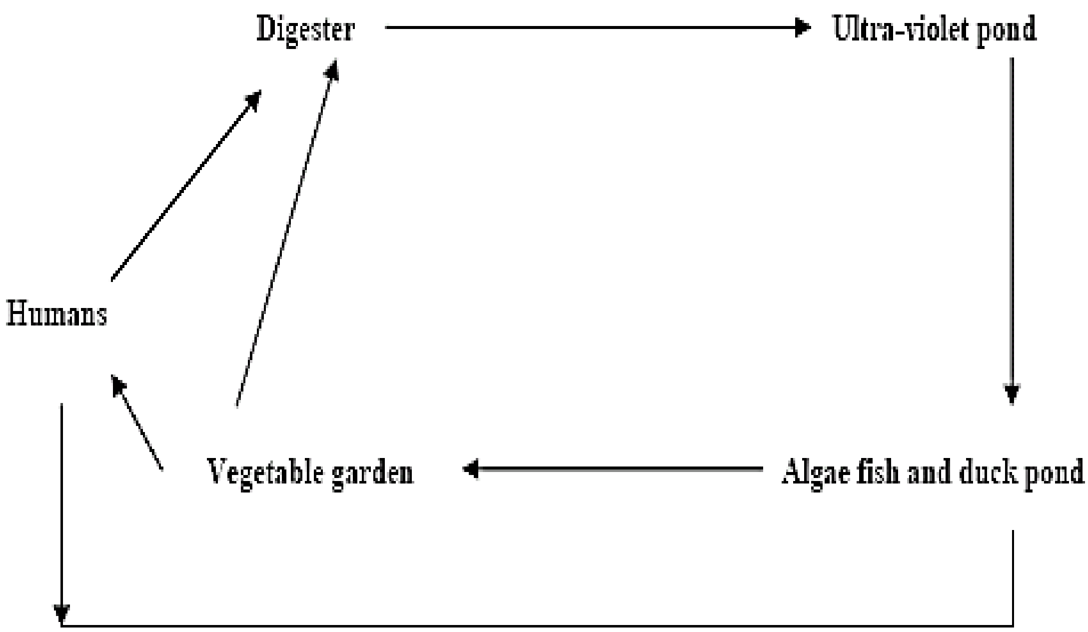

Figure 1. Biomass utilization concept.

In modern biomass energy systems for transportation, the goals include maximizing yields with minimal inputs, selecting appropriate plant materials, and optimizing land, water, and organic fertilizer use. Developing a robust R&D infrastructure is crucial, along with enhancing waste valorization from sources like household waste, market waste, and byproducts from industries, such as cotton, leather, and pulp. Methods like incineration, gasification, digestion, fermentation, and cogeneration can convert waste into usable energy, supporting the reduction of fossil fuel reliance and promoting green energy, especially in building sectors.

Energy use can be reduced by minimizing demand, rationalizing usage, recovering heat, and utilizing green energy sources. The energy ratio (Er), defined as the energy content of a food product (Ec) divided by the energy input to produce it (Ei), highlights efficiency in food production [18, 20].

Combined Heat and Power (CHP)

CHP systems are commonly used in greenhouses and can replace thermal plants by modernizing existing power plants for better efficiency and environmental performance. Transitioning from gas-fired CHP to biomass and utilizing wind power can decrease dependence on fossil fuels, ensuring energy demands are met sustainably in the short term (Tables 5 and 6).

Table 5. Annual GHG emissions from various power plant sources [21].

Primary Source of Energy	Emissions (X 10^3 metric tons)		Waste (X 10^3 metric tons)	Area (km^2)
	Atmosphere	Water		
Coal	380	7–41	60–3000	120
Oil	70–160	3–6	Negligible	70–84
Gas	24	1	–	84
Nuclear	6	21	2600	77

Table 6. Energy consumption per population [22].

Region	Population (millions)	Energy (watt/m^2)
Africa	820	0.54
Asia	3780	2.74
Central America	180	1.44
North America	335	0.34
South America	475	0.52
Western Europe	445	2.24
Eastern Europe	130	2.57
Oceania	35	0.08
Russia	330	0.29

Transitioning to a sustainable energy system is complex but feasible within 20 years, requiring initial investments and long-term strategies. Key benefits include:

- A more stable energy supply.
- Improved environmental performance.
- Social advantages.

Modeling scenarios utilize data on government programs, renewable energy potential, economic growth, and environmental studies. Projected advantages include:

- Reduced energy import dependence.
- Lower environmental impacts.
- Efficient use of agricultural land.
- Development of new technologies.

Countries are implementing economic incentives to protect the environment, such as pollution taxes, subsidies, deposit-refund systems, financial penalties for non-compliance, and tradable permits for harmful activities (Table 7) [21, 25].

Table 7. Synopsis of construction industry material recycling practices [22].

Construction and Demolition Material	**Recycling Technology Options**	**Recycling Product**
Asphalt	Cold recycling: heat generation; Minnesota process; parallel drum process; elongated drum; microwave asphalt recycling system; surface regeneration.	Recycling asphalt; asphalt aggregate.
Brick	Burn to ash, crush into aggregate.	Slime burn ash; filling material; hardcore.
Concrete	Crush into aggregate.	Recycling aggregate; cement replacement; protection of levee; backfilling; filter.
Ferrous metal	Melt; reuse directly.	Recycled steel scrap.
Glass	Reuse directly; grind to powder; polishing; crush into aggregate; burn to ash.	Recycled window unit; glass fibre; filling material; tile; paving block; asphalt; recycled aggregate; cement replacement; manmade soil.
Masonry	Crush into aggregate; heat to 900°C to ash.	Thermal insulating concrete; traditional clay.
Non-ferrous metal	Melt.	Recycled metal.
Paper and cardboard	Purification.	Recycled paper.
Plastic	Convert to powder by cryogenic milling; clopping; crush into aggregate; burn to ash.	Panel; recycled plastic; plastic lumber; recycled aggregate; landfill drainage; asphalt; manmade soil.
Timber	Reuse directly; cut into aggregate; blast furnace deoxidization; gasification or pyrolysis; chipping; molding by pressurizing timber chip under steam and water.	Whole timber; furniture and kitchen utensils; lightweight recycled aggregate; source of energy; chemical production; wood-based panel; plastic lumber; geofibre; insulation board.

District heating, or DH, is a cost-effective method of generating high-quality heat while lowering CO_2 emissions and conserving energy. It is most viable in areas with high heat density, but in countries like Denmark, it can also be economical for lower-density developments due to high fuel taxes and efficient production (Figure 2) [23–25].

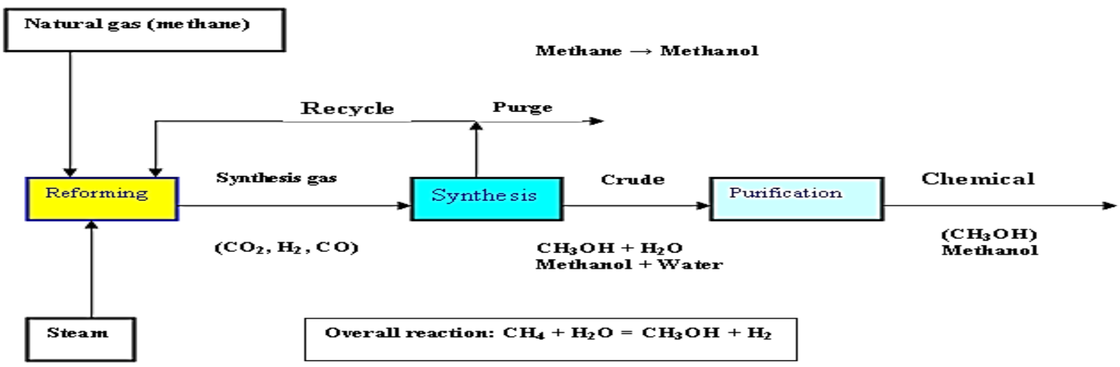

Figure 2. Schematic process flowsheet.

To enhance DH opportunities, local councils should:

- Analyze heat supply options during planning.
- Integrate DH as an essential infrastructure for all buildings.
- Connect all public buildings to DH.

- Secure government funding or low-interest loans for conversions.
- Utilize legislation to mandate building connections to DH schemes.

Denmark's CHP evolution shows three scales: large (>50 MW), medium (5–50 MW), and small (5 kW–5 MW), with large plants dominating heat production. Efficient low-temperature DH can use various sources, including:

- CHP waste heat.
- Biomass or gas boilers with economizers.
- Excess industrial heat.
- Large-scale solar energy.

Heat tariffs typically consist of connection, fixed, and variable charges, incentivizing lower return temperatures. Best practices for DH companies include:

- Developing a connection plan.
- Evaluating cost-effective heat production.
- Implementing competitive solutions through partnerships.
- Monitoring costs and improving efficiency.
- Maintaining strong consumer relationships.

Pursuing DH aligns with environmental goals and energy efficiency, offering consumers affordable, quality heat through collaboration among stakeholders (Table 8).

Table 8. Final energy estimates (Mtoe, or millions of tons of oil equivalent) that account for biomass.

Region 1995				
	Biomass	**Conventional Energy**	**Total**	**Share of biomass (%)**
Africa	205	136	341	60
China	206	649	855	24
East Asia	106	316	422	25
Latin America	73	342	415	18
South Asia	235	188	423	56
Total developing countries	825	1632	2457	34
Other non-OECD* countries	24	1037	1061	2
Total non-OECD* countries	849	2669	3518	24
OECD countries	81	3044	3125	3
World	930	5713	6643	14
Region 2020				
	Biomass	**Conventional Energy**	**Total**	**Share of Biomass (%)**
Africa	371	266	637	59
China	224	1524	1748	13
East Asia	118	813	931	13
Latin America	81	706	787	10
South Asia	276	523	799	35
Total developing countries	1071	3825	4896	22
Other non-OECD* countries	26	1669	1695	2
Total non-OECD* countries	1097	5494	6591	17
OECD countries	96	3872	3968	2
World	1193	9365	10558	11

Development and Economic Cooperation Organization

Biomass Utilization and Development of Conversion Technologies

Sustainable energy minimizes negative impacts on human health and ecosystems, contributing no net atmospheric CO2 when biofuel production matches its consumption without fossil fuel input. However, corn-based ethanol is not sustainably produced due to heavy reliance on petrochemicals.

The rising interest in renewable energy necessitates a focus on sustainable development, despite challenges like high information costs and policy inefficiencies. Agric-environment schemes can enhance landscape diversity, wildlife habitats, archaeological conservation, recreational opportunities, and land restoration (Tables 9 and 10) [26].

Table 9. Key Parameters for Energy System Analysis: Existing and Future Data Requirements

	Plant Data	**System Data**
Existing data	Size. Life. Cost (fixed and variation of operation and maintenance). Forced outage. Maintenance. Efficiency. Fuel. Emissions.	Peak load. Load shape. Capital costs. Fuel costs. Depreciation. Rate of return. Taxes.
Future data	All the above, plus. Capital costs. Construction trajectory. Date of service.	System leads to growth. Fuel price growth. Fuel import limits. Inflation.

Table 10. Effective biomass resource utilization.

Subject	**Tools**	**Constraints**
Utilization and land clearance for agriculture expansion	Stumpage fees. Control. Extension. Conversion. Technology.	Policy Fuel-wood planning Lack of extension Institutional
Utilization of agricultural residues	Briquetting. Carbonization. Carbonization and briquetting. Fermentation. Gasification.	Capital. Pricing. Policy and legislation. Social acceptability.

The future of successful treatment by-products lies in effective marketing and potential use in construction as concrete fillers, with solid residue locking metals to prevent environmental harm. Improving energy efficiency involves maximizing high-efficiency generation plants and renewable resources. Waste is increasingly viewed as a valuable energy source [27].

Efficient Bio-Energy Use and Improvement

In biomass energy, trade-off analysis requires data on system performance and future developments, with challenges in harvesting and regulations. Biomass is gaining interest for its environmental benefits and entrepreneurial opportunities. Direct combustion remains the most common usage, while thermo-chemical processes like charcoal production and gasification are emerging, despite being in demonstration phases. Water consumption for wet procedures is high (Table 11).

Table 11. Farming.

Source	**Process**	**Product**	**End Use**
Agricultural residues	Direct.	Combustion.	Rural poor. Urban household. Industrial use.
	Processing.	Briquettes.	Industrial use. Limited household use.

	Processing.	Carbonization (small-scale).	Rural household (self-sufficiency).
	Carbonization.	Briquettes Carbonized.	Urban fuel.
	Fermentation.	Biogas.	Energy services. Household. Industry.
Agricultural and animal residues	Direct.	Combustion.	(Save or less efficient as wood).
	Briquettes.	Direct combustion.	(Similar end-use devices or improved).
	Carbonization.	Carbonized.	Use.
	Carbonization.	Briquettes.	Briquettes use.
	Fermentation.	Biogas.	Use.

Biomass Technologies Include

- Farming (Table 11).
- Briquetting.
- Better stoves.
- Biogas.
- Better charcoal.
- The process of carbonization.
- Gasification.

The increased need for gas, petroleum, food crops, seafood, and plant materials has led to a rise in carbon harvesting worldwide. Routes for the development of residues. Essentially, humanity is now extracting nearly everything, with municipal solid waste being the last significant carbon source yet to be fully utilized. To optimize biowaste recovery, the waste management industry must enhance awareness and invest in better infrastructure. This requires stricter regulations on landfilling organic materials, public understanding of the benefits of waste-derived carbon products for soil and crops, and increased investment in processing facilities. Significant efforts are necessary to capture more carbon from waste streams for beneficial applications.

Waste practitioners need further research and pilot programs to ensure the extracted carbon meets quality and quantity requirements for desired end products. Measurement techniques, diversion estimates, sequestration values, and acceptable contamination levels are all crucial topics to cover. Effective marketing of treatment by-products is crucial for future success, and there’s potential for using solid residues in construction, where they can safely lock metals away from the environment.

Briquettes, made from agricultural and forestry waste, are a promising energy-dense solid fuel alternative to bulky wood fuels, which are costly to transport. By forming briquettes, energy density increases, reducing transportation costs and making the resource more competitive. Additionally, improved cook stoves can enhance fuel efficiency for both urban and rural households, providing better energy solutions as traditional wood fuel becomes scarce.

Biogas technology offers an alternative fuel source and supports sustainable agricultural practices, enhancing sanitation and environmental protection in rural areas. The acceptance of biogas plants depends on factors like credit access and technical support, which should be integrated into macro-policy and government investment planning. Biogas is produced by the anaerobic breakdown of organic matter and is mainly made up of carbon dioxide and methane. The waste sector has mainly focused on controlling biogas emissions, but there’s potential to utilize this gas to generate electricity.

Renewable energy contributions for heating come from biomass, geothermal systems, and solar technologies. Successful implementation of renewable energy initiatives in cities often hinges on political commitment, dedicated municipal departments, public awareness, and building regulations supporting renewable energy integration (Figure 3) [28].

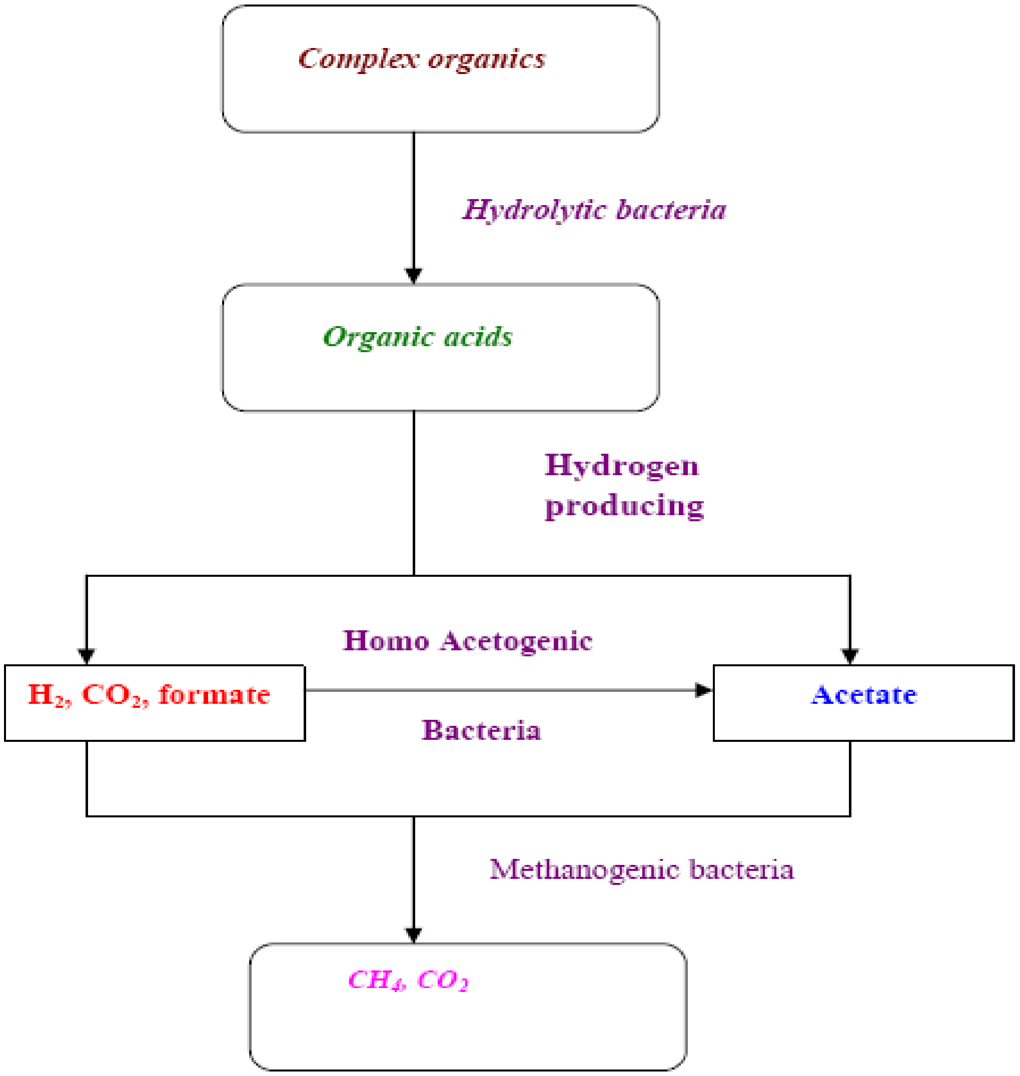

Figure 3. Biogas production process.

Here is a very concise summary of bullet points:

- Thousands of biogas units built globally for methane production (cooking, water pumping, electricity).
- Key planning successes highlighted by D'Apote.
- Goals include:
- Reviewing economic evaluation models for biogas.
- Compiling methodologies for economic analysis.
- Investigating commercial supply constraints.
- Analyzing supply–demand relations for feedstock.
- Documenting methods for assessing indirect consequences (growth, silviculture, employment).

Table 12. Anaerobic degradation of organic matter [29].

Level	Substance	Molecule	Bacteria
Initial	Manure, vegetables, wastes	Cellulose, proteins	Cellulolytic, proteolytic
Intermediate	Acids, gases, oxidized, inorganic salts	CH_3COOH, CHOOH, SO_4, CO_2, H_2, NO_3	Acidogenic, hydrogenic, sulfate reducing
Final	Biogas, reduced inorganic compounds	CH_4, CO_2, H_2S, NH_3, NH_4	Methane formers

Biogas naturally occurs in anaerobic conditions, such as wetlands, and is mainly composed of 50–65% carbon dioxide and methane. It is a valuable fuel source because of its high methane content. Anaerobic digestion is appropriate for moist (40–95%) organic materials with low lignin and cellulose contents. Sludge treatment; however, can concentrate viruses, trace organics, and dangerous heavy metals, posing a concern to the environment. Crops, animals, and people can all be impacted by these heavy metals that seep into the soil and enter the food chain (Table 12).

In response to fossil fuel depletion and climate change, both European and American markets are focusing on converting organic waste into two main products: a liquid solution of humic substances and a solid residue. Biomass has significant potential, especially through biogas production via anaerobic digestion. This process allows agricultural waste to be converted into energy and chemicals using microorganisms. Successful investment in renewable energy projects typically relies on thorough technology assessment, secure contracts, planning permissions, and proven reference plants. Overall, waste management has evolved towards comprehensive collection and controlled treatment strategies (Figures 4 and 5).

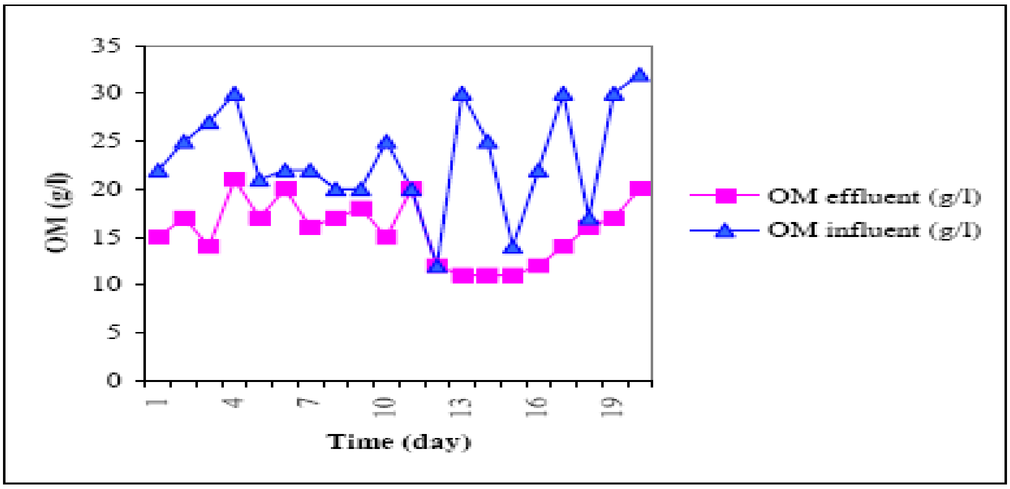

Figure 4. Organic matters before and after treatment in digesters.

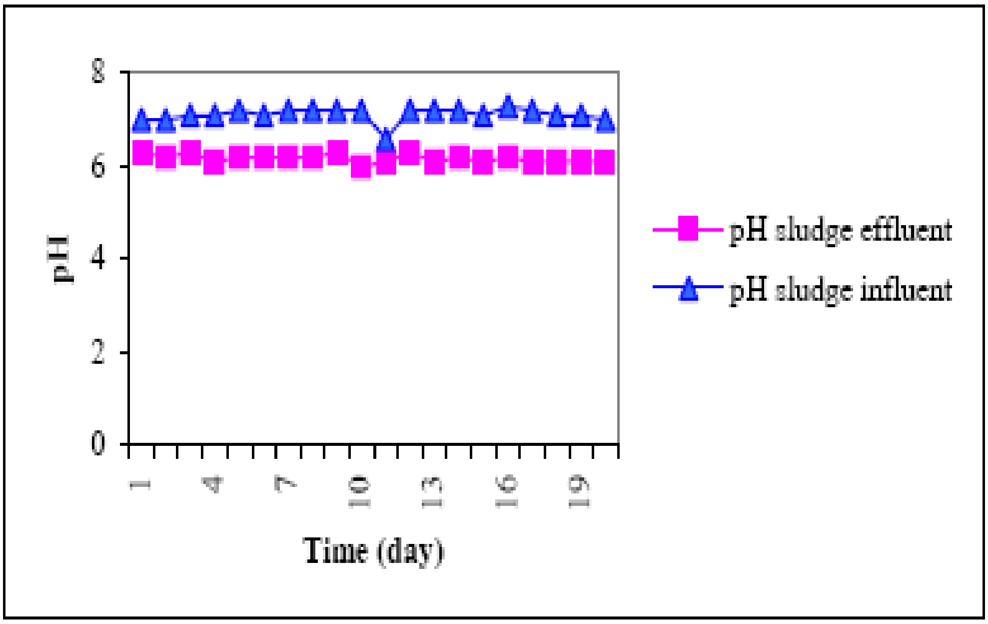

Figure 5. pH sludge before and after treatment in the digester.

- The success of technology promotion depends on efficient planning, management, implementation, training, and monitoring. Among the crucial elements of gasification initiatives are:
- Networking and institutional development.
- Extension and promotion initiatives.
- The development of pilot initiatives. Research, development, training, and monitoring.

Different biogas utilization pathways have varying ecological impacts. Key comparisons include:

- Heat demand-controlled gas engines connected to the natural gas grid (500 kWe, 37.5% electrical efficiency, 42.5% thermal efficiency, 0.01% methane loss).
- Local gas engines at biogas plants (500 kWe, same efficiencies, 0.5% methane loss).
- Biogas from maize silage in covered storage (1% methane loss).
- Biogas upgrading (0.3 kWhe/m^3, 0.5% methane loss).

Direct biomass burning leads to economic losses and health issues in developing countries. Converting biomass to solid briquettes and fuel gas enhances efficiency. Biomass is essential for energy supply, categorized into residues and dedicated resources.

Gasification converts solid fuels into fuel gas (CO and H_2) through partial oxidation at high temperatures, using diverse fuels and gasifier designs. Rich in nutrients, sewage sludge has been utilized as fertilizer and to help remediate soil.

Developing renewable energy faces challenges, including funding and regulatory hurdles influenced by EU directives and climate regulations. Economic incentives include landfill fees, penalties, energy prices, and investment subsidies (Tables 13 and 14) [30].

Table 13. Biomass residues and current use.

Type of Residue	Current Use
Wood industry waste	Residues available.
Vegetable crop residues	Animal feed.
Food processing residue	Energy needs.
Sorghum, millet, and wheat residues	Fodder and building materials.

Groundnut shells	Fodder, brick making, and direct fining oil mills.
Cotton stalks	Domestic fuel considerable amounts available for a short period.
Sugar, bagasse, and molasses	Fodder, energy need, and ethanol production (surplus available).
Manure	Fertilizer, brick making, and plastering.

Table 14. Different fuels are compared.

Fuel	Calorific Value (kcal)	Burning Mode	Thermal Efficiency (%)
Electricity, kWh	880	Hot plate.	70
Coal gas, kg	4004	Standard burner.	60
Biogas, m^3	5373	Standard burner.	60
Kerosene, l	9122	Pressure stove.	50
Charcoal, kg	6930	Open stove.	28
Soft coke, kg	6292	Open stove.	28
Firewood, kg	3821	Open stove.	17
Cow dung, kg	2092	Open stove.	11

Financial institutions are preparing for an environmental revolution as global prosperity increases waste generation. Key points include:

- *Renewable Energy Demand:* Continues to grow.
- *Government Responsibility:* Public expectations for government action are high.
- *Diminishing Fossil Fuels:* Pressure is mounting to find alternatives.
- *Investment Availability:* Traditional sources are increasingly funding green technologies.
- *Market Opportunities:* Technologies for carbon and waste reduction are gaining traction.

A major concern is the treatment of sludge, which can concentrate heavy metals and harmful pathogens, threatening environmental safety through soil and groundwater contamination. Biomass, a versatile raw material since ancient times, is pivotal in sustainable energy. Gasification processes, utilizing steam with carbon char, enhance the surface area of carbon and contribute to energy production through reactions that produce hydrogen and carbon monoxide (Figure 6).

The endothermic stream gasification reactions that follow show how the steam and carbon char interact

$$H_2O\ (g) + C_x\ (s) \rightarrow H_2\ (g) + CO\ (g) + C_{x-1}\ (s) \quad (2)$$

$$CO\ (g) + H_2O\ (g) \rightarrow CO_2\ (g) + H_2\ (g) \quad (3)$$

$$CO_2\ (g) + C_x\ (s) \rightarrow 2CO\ (g) + C_{x-1}\ (s) \quad (4)$$

Energy and Environmental Problems

Technological advances have significantly shaped the world, but they have also led to serious environmental challenges. In the last two decades, the threats posed by environmental degradation have become increasingly evident, largely due to population growth and industrial activities. While the initial focus was on conventional pollutants like SO_2, NO_x, and CO_2, concerns have now expanded to include hazardous air pollutants and broader issues, such as climate change. Key environmental challenges include major accidents, water and marine pollution, land use impacts, solid waste disposal, and global warming, which may cause rising sea levels and heightened flooding risks in low-lying areas (Tables 15 and 16) [31].

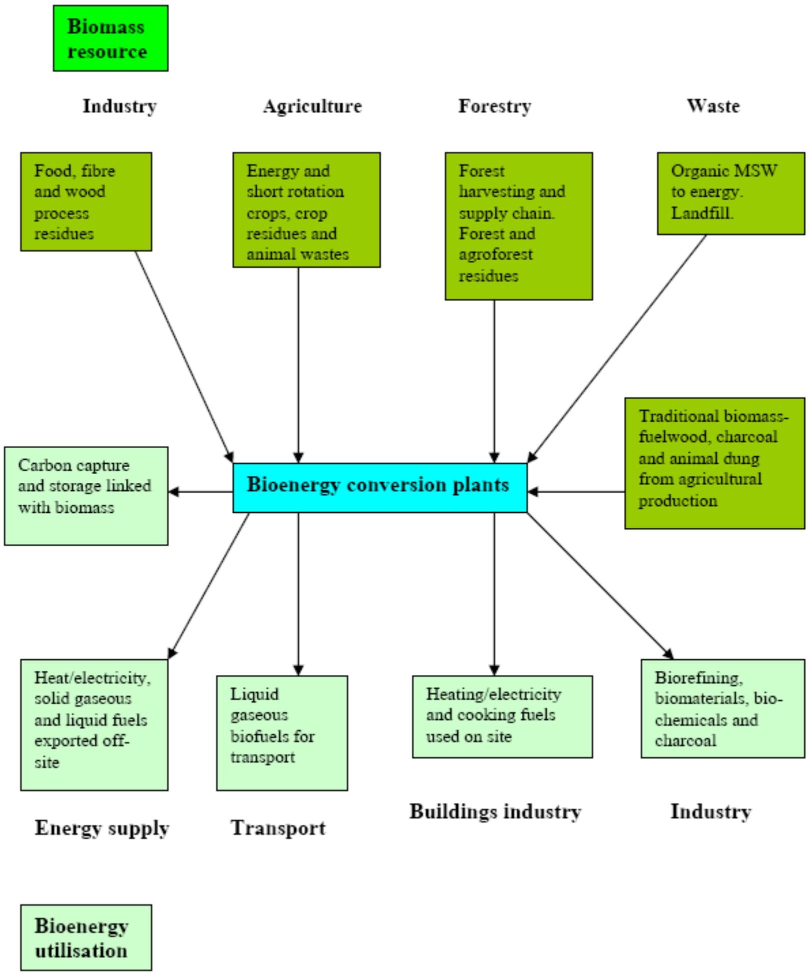

Figure 6. Shows how biomass resources from various sources are transformed into a variety of goods used by the building, transportation, and industrial sectors.

Table 15. Pollutant standards in ambient air according to EU guidelines.

Pollutant	**EU Limit**
CO	30 mg/m^2; 1 h
NO_2	200 μg/m^2; 1 h
O_3	235 μg/m^2; 1 h
SO_2	250-350 μg/m^2; 24 h 80-120 μg/m^2; annual
PM_{10}	250 μg/m^2; 24 h 80 μg/m^2; annual
SO_2 + PM_{10}	100-150 μg/m^2; 24 h 40-60 μg/m^2; annual
Pb	2 μg/m^2; annual
Total suspended particulate (TSP)	260 μg/m^2; 24 h
HC	160 μg/m^2; 3 h

Table 16. Key EU environmental regulations pertaining to the air, water, and land environments.

Environment	Directive Name
Water	Surface water for drinking. Sampling surface water for drinking. Drinking water quality. Quality of freshwater supporting fish. Shellfish waters. Bathing waters. Dangerous substances in water. Groundwater. Urban wastewater. Nitrates from agricultural sources.
Air	Smokes in the air. Sulfur dioxide in the air. Lead in the air. Large combustion plants. Existing municipal incineration plants. New municipal incineration plants. Asbestos in air. Sulfur content of gas oil. Emissions from petrol engines. Air quality standards for NO_2. Emissions from diesel engines.
Land	Protection of soil when sludge is applied

Over the previous century, global surface temperatures have increased by roughly 0.6°C every century, despite the Atlantic, Pacific, and Indian Oceans' average temperatures rising by 0.06°C since 1995. In 2001, global temperatures were 0.52°C above the long-term average of 13.9°C from 1880 to 2000 (Figure 7).

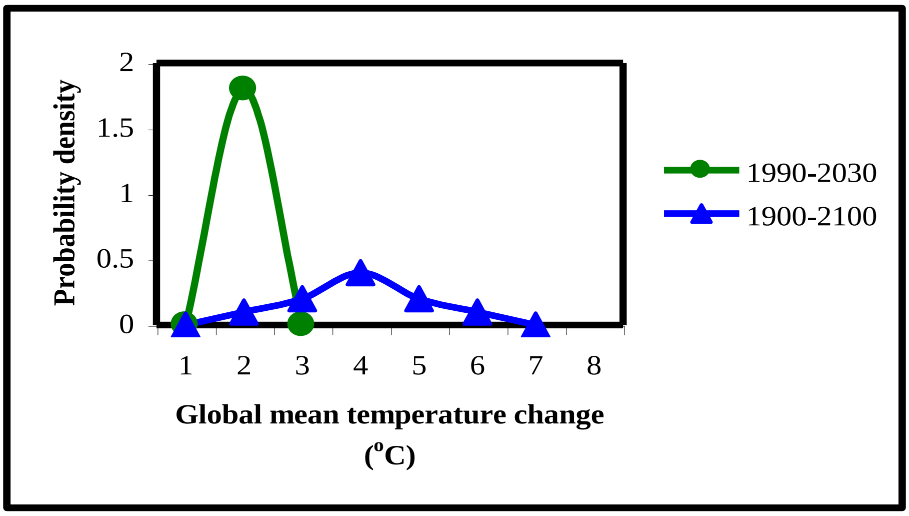

Figure 7. Shows the variations in the average global temperature between 1990 and 2030 and 1990 and 2100.

At the 1992 UN Earth Summit, 153 countries committed to sustainable development, focusing on reducing carbon dioxide and GHG emissions. A key strategy is minimizing energy use in buildings, prompting designers to adopt low-energy designs. Evidence indicates that continued environmental degradation will adversely affect the future (Table 17).

Table 17. The external environment.

Damage	Manifestation	Design
NO_x, SO_x	Irritant. Acid rain land damage. Acid rain fish damage.	Low NO_x burners. Low sulfur fuel. Sulfur removal.
CO_2	Global warming. Rising sea level. Droughts, storms.	Thermal insulation. Heat recovery. Heat pumps.
O_3 destruction	Increased ultraviolet. Skin cancer.	No CFC's or HCFC's. Minimum air conditioning. Refrigerant collection.
Legionellosis	Crop damage. Pontiac fever Legionnaires.	Careful maintenance. Dry cooling towers.

Energy plays a crucial role in talks about sustainable development, as seen by the growing interest in environmental issues related to energy. According to the lifecycle study, corn has the lowest emission displacement (about 0.5 tons of CO2 per ton of feedstock), while corn stover and switchgrass have the most (around 0.65 tons). Although corn and wheat cultivation and harvesting emit more GHGs than lignocellulosics, the latter's higher energy requirements are offset by biomass residue, making them carbon neutral.

Table 18. Global CO_2 emissions overview.

Rank	Nation	CO_2	Rank	Nation	CO_2
1.	USA	1.36	7	Canada	0.11
2.	Russia	0.98	8	Italy	0.11
3.	China	0.69	9	Mexico	0.09
4.	Japan	0.30	10	Poland	0.08
5.	India	0.19	11	South Africa	0.08
6.	UK	0.16	12	South Korea	0.07

Table 18 presents global CO_2 emissions from the top twelve nations (in billion tonnes). By 2015, global emissions are projected to rise 54% above 1990 levels, leading to potential warming of 1.7–4.9°C by 2100.

Environmental Impact of Fuels

Coal formation and sulfur content vary widely among different coal types. Key sulfur control methods include:

1. *Pre-combustion:* Desulfurization of fuels.
2. *Combustion:* Trapping SO_2 during burning.
3. *Post-combustion:* Removing SO_2 from flue gases.

Nitrogen Oxides (NOx) Control

NOx emissions are significant, even without fuel nitrogen. Strategies include internal and external recirculation of burnt gases.

Waste Management

Unwanted material for recycling or disposal is referred to as waste. Through recycling, regulations seek to lessen dependency on raw materials and enhance pollution management.

Sustainable Development

Sustainable development meets present needs without compromising future generations. The World Energy Council projects a 50–80% increase in global energy demand by 2020. Addressing environmental challenges requires a shift to renewable energy sources. The goal is to improve material efficiency, encourage sustainable behaviors, and disentangle economic progress from environmental deterioration [32].

CONCLUSIONS

Adopting green practices is essential for addressing the global energy crisis, primarily by reducing CO_2 emissions, a key contributor to global warming. Alternative energy generation methods, such as extensive fuel-wood farming, can provide significant energy, economic, and environmental benefits, especially in rural areas where energy demand is high. These initiatives enhance energy access and stimulate rural economic growth while also reducing foreign exchange costs and improving national energy security. A country's resource base may be strengthened by a nine-fold increase in forest plantations, which would provide sustainable raw materials and energy. On a global scale, these efforts can reduce pollution, mitigate climate change, and create new trade opportunities through renewable energy initiatives. Additionally, several non-technical issues have gained attention, including the environmental benefits of carbon sequestration, the CO_2-neutral role of renewables, and the importance of data quality regarding renewable energy. Understanding the health impacts of traditional biomass energy on communities is also critical. When taken as a whole, these elements demonstrate how urgently sustainable energy practices are needed for future development.

ACKNOWLEDGMENTS

The financial support for this research work from the Energy Research Institute is gratefully acknowledged. It is a pleasure to acknowledge, with gratitude, all those who, at different times and in different ways, have supported the development and evaluation of biomass energy technologies. Special thanks to my spouse Kawthar Abdelhai Ali for her support and her unwavering faith in me. Her intelligence, humor, spontaneity, curiosity, and wisdom added to this article.

REFERENCES

1. Haripriye G. Estimation of biomass in India forests. Biomass Bioenergy. 2000;19:245–58.
2. Omer AM. Energy demand for heating and cooling equipment systems and technology advancements. Nat Res Econ Manag Pol. 2008;131–65.
3. Omer AM. Ground-source heat pumps systems and applications. Renew Sustain Energy Rev. 2008;12(2):344–71.
4. Huttrer GW. The status of world geothermal power generation 1995–2000. Geothermics. 2001;30(1):1–27.
5. Lam JC. Shading effects due to nearby buildings and energy implications. Energy Convers Manag. 2000;41(7):647–59.
6. Trevor T. Fridge recycling: bringing agents in from the cold. Waste Manag World. 2007;5:43–7.
7. International Energy Agency (IEA). 'Indicators for industrial Energy Efficiency and CO_2 Emissions: A Technology Perspective. 2007;5–16.
8. Brain G, Mark S. Garbage in, energy out: landfill gas opportunities for CHP projects. Cogener On-Site Pow. 2007;8(5):37–45.
9. Omer AM. The environmental and economical advantages of agricultural wastes for sustainability development in Sudan. J Brew Distill. 2010;1(1):1–0.
10. Omer AM. Biomass energy potential and future prospect in Sudan. Renew Sustain Energy Rev. 2005;9(1):1–27.
11. Overbye PM. Danish lessons on district heating. Energy Environ Manag. 2004;16–8.
12. Lazzarin R, D'Ascanio A, Gasparella A. Utilization of a green roof in reducing the cooling load of a new industrial building. In: 1st Conference on Sustainable Energy Technologies. Porto, Portugal. 2002. pp. 32–7.
13. David E. Sustainable energy: choices, problems and opportunities. Roy Soc Chem. 2003;19:19–47.
14. Omer AM. Biomass energy potential and applications. Agri Develop Arab World. 2000;19(4):1–5.

15. Aroyeun SO, Adegoke GO, Varga J, Teren J. Reduction of aflatoxin B1 and Ochratoxin A in cocoa beans infected with Aspergillus via Ergosterol Value. World Rev Sci Tech Sustain Develop. 2009;6(1):75–89.
16. Vilinac D. Plant medicines: A herbalist’s perspective. World Rev Sci Tech Sustain Develop. 2008;5(2):140–50.
17. Brain G, Mark S. Garbage in, energy out: landfill gas opportunities for CHP projects. Cogener On-Site Pow. 2007;8(5):37–45.
18. Dieng AO, Wang RZ. Literature review on solar adsorption technologies for ice-making and air-conditioning purposes and recent developments in solar technology. Renew Sustain Energy Rev. 2001;5(4):313–42.
19. Jeremy L. The energy crisis, global warming and the role of renewables. Renew Energy World. 2005;8(2):23–8.
20. Zuatori A. An overview on the national strategy for improving the efficiency of energy use. Jordan Energy Abstr. 2005;9(1):31–2.
21. Omer AM. Green energies and the environment. Renew Sustain Energy Rev. 2008;12(7):1789–821.
22. Lund JW, Freeston DH, Boyd TL. Direct application of geothermal energy: 2005 worldwide review. Geothermics. 2005;34(6):691–727.
23. Abdeen MO. The puzzle of consumption, development and sustainability. In: Proceedings of the National Conference for Development and Environment, Khartoum, Sudan. Sudan Eng Soc J. 2006;52(47)35–43.
24. Robinson G. Changes in construction waste management. Waste Manag World. 2007;3:43–92.
25. Sims R. Not too late-IPCC identifies renewable energy as a key measure to limit climate change. Renew Energy World. 2007;10(4):31.
26. Omer AM, Fadalla Y. Biogas energy technology in Sudan. Renew Energy. 2003;28(3):499–507.
27. Omer AM. Organic waste treatment for power production and energy supply. J Cell Anim Biol. 2007;1(2):034–47.
28. Omer AM. Renewable energy resources for electricity generation in Sudan. Renew Sustain Energy Rev. 2007;11(7):1481–97.
29. Overbye PM. Danish lessons on district heating. Energy Environ Manag. 2004;16–8.
30. D’Apote SL. IEA biomass energy analysis and projections. In: Proceedings of Biomass Energy Conference: Data, Analysis and Trends. Paris, France. 1998 March. pp. 23–4.
31. Abdeen MO. Chapter 3: Energy use, environment and sustainable development. Environ Cost Manag. 2009;129–66.
32. Omer AM. Green energies and the environment. Renew Sustain Energy Rev. 2008;12(7):1789–821.

