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Agricultural Utilization of Renewable Domestic Energy in Jordan: Potential and Future Production of Biogas

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Abstract: Secure enhanced energy and mitigate and cope with the climate change impacts are the main drivers to transform energy from fossil to renewable sources. Biogas is arguably a more versatile of these renewable energy source (cf. wind and solar energy), due to its determinate energy value and ease of storage where, potential utilization of such energy is significantly independent of factors such as geographical location and season. This manuscript discusses the potential of biogas and biomethane as sources of renewable energy along with the researchers and manufacturers efforts to find suitable fuel alternatives that are more environmentally friendly and can be produced from abundant resources in addition to what was achieved recently in Jordan. Generating biogas from methane (CH_4) can offer a higher profit for farmers as a fuel for farm machinery and vehicles, as it is used to generate heat and electricity in both stationary and mobile engines. For this reason, ignition process of diesel engine, the prime movers in farms, was thoroughly analyzed assist directly influences the resulting toxic emissions. Several solutions and cases have been investigated all over the world and some reached the market stage.

Key words: Biogas · Jordan · Renewable Energy · Dual Fuel Engine and Biogas Upgrading

INTRODUCTION

The World's economies are dependent today on crude oil. There is some disagreement among scientists on how long this fossil resource will last. According to researchers, the "peak oil production" has already occurred or it is expected to occur within the future as shown in Fig. 1 [1].

Unlike fossil fuels, biogas from Anaerobic digestion (AD) is permanently renewable, as it is produced from biomass, which is actually a living storage of solar energy through photosynthesis. Biogas from AD will not only improve the energy balance of a country but also make an important contribution to the preservation of the natural resources and to environmental protection. The term "biogas" includes all gas produced by anaerobic digestion of organic matter. In the absence of oxygen various types of bacteria break down the feedstock to form a secondary energy carrier, a burnable gas which mainly consists of methane and carbon dioxide.

The production and collection of biogas from a biological process was documented for the first time in United Kingdom in 1895 [2]. In 1895, Donald Cameron recognized the importance of methane gas where a septic tank built and modeled on the Mouras Automatic Scavenger in Exeter, England was designed to collect this gas for heating and lighting [3]. In 1897, waste disposal tanks at a leper colony in India, were designed with a biogas collection system and the gas used to drive gas engines [4]. Biogas from liquid manure is extremely efficient in reducing the green house gas (GHG); CO_2 emissions compared to fossil fuels such as petrol and diesel. This is due to low fossil inputs and it avoids natural emission during storage. Further, as digestate provides an efficient source of nutrients for crop cultivation which reduces the dependence on energy intensive mineral fertilizers_iFachagentur, [5].

Biogas is arguably a more versatile renewable energy source due to its determinate energy value and ease of storage. Depending on the nature of the biogas source and the local demand, it can be used directly for heating and electricity generation by fuel cells or micro-turbines, compound heat and power as vehicle fuel and as a substitute for fossil fuel applications (Figure 2) [6, 7].

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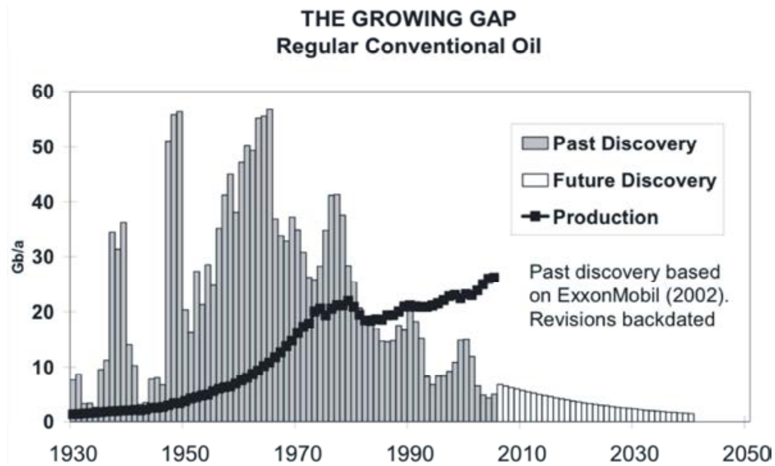

Fig. 1: Global oil production; past discovery and future discovery
Source: http://peakoildebunked.blogspot.com/2006/02/230-growing-gap.html

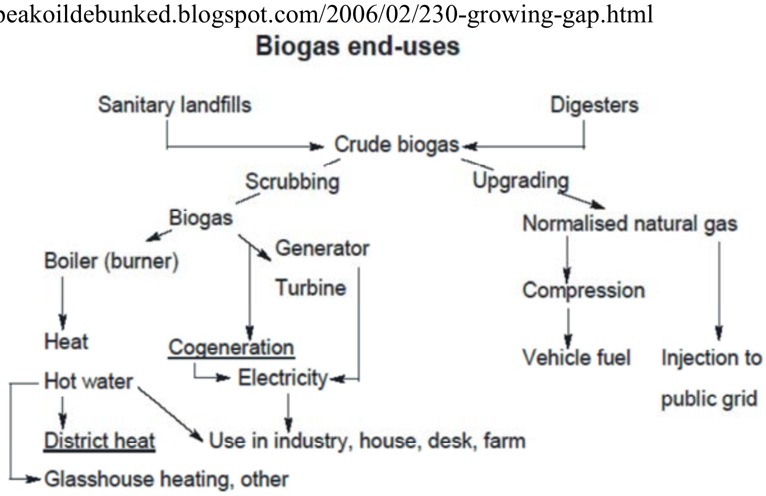

Fig. 2: Overview of biogas utilization (adapted from http://lemvigbiogas.com)

Scientists and engineers proves the high potential utilization of biogas in generating thermal energy, illumination, heating and electricity have increased in the last decades. However, these have not been significantly implemented; due to biogas lower heating value, low flame speed, high percentages of inert gases and presence of sulfur. Moreover, engines intended exclusively to run by biogas are costly and they are not commercially available for powers smaller than 100 kW. As a result, -and with no dependence on diesel fuel- the use of biogas in diesel dual mode becomes difficult [8, 9].

FAO has initiated and used energy basic indicator of sustainable agriculture. The indicator is the energy utilized in agriculture on a yearly basis expressed as a ratio of energy inputs and agricultural production measured in unit of Joules per tonne of agricultural products. The purpose of developing such term is to provide a measure of energy intensity in agriculture. Agricultural co-generation using biomass in an agro-industrial plant offers the prospect of producing process requirements for heat and power and the export of any surplus electricity to a local grid distribution system. Biomass fuels are not always traded commodities, but are locally collected and transferred to the point of use and fuel supply security then becomes an important issue [10]. Underlying this approach is the desire to capture the agricultural, industrial and energy benefits of biomass resources. However, the potential for co-generation varies according to site location and the nature and type of crop, the capital costs and the economics of the operation [10].

Biogas can be used in both spark and compression (diesel) engines. The spark ignition engine is easily modified to run on biogas by using a gas carburetor. Ignition systems need not be altered, other than minor timing adjustments. Supplementary fuels can be used with biogas in spark ignition engines. Diesel engines have been in the market over 100 years and have had a number of adaptations, including the use in the dual mode conversion with gaseous fuels to reduce fossil fuel consumption [11-13]. In spite of the high estimated global potential biogas production on our plant, only a very small part of this potential is utilized today. Thus there is a real possibility of significant increase of the actual production of biogas. The European Biomass Association (AEBIOM) estimates that the European production of biomass based energy can be increased from the 72 million tones oil equivalent (Mtoe) in 2004 to 220 Mtoe in 2020 [14]. The largest potential lies in biomass originating from agriculture, where biogas is an important player. According to AEBIOM, up to 20 to 40 million hectares of land can be used for energy production in the European Union alone, without affecting the European food supply.

The U.S.A. ranks second after Brazil in ethanol production with about 26.3 Mtoe and it uses corn as starting material. Its ethanol barely replaces 2.6% of its gasoline consumption [15]. Sweden is the world leader in upgrading and use of biomethane for transport and has more than 44,000 gas vehicles, 1800 buses as well as biogas train [16]. Germany produces more than 50% of biodiesel in the world and it is followed by France. Biodiesel is characterized by its very low sulfur content and its combustion leads to a two third reduction in CO_2 emissions as compared to fossil diesel [17, 18].

The Middle East is the world's leading oil producing region and given the extent of its known reserves, this status seems likely to intensify. Five countries (Saudi Arabia, Iran, the United Arab Emirates, Iraq and Kuwait) each produce more than 2 million barrels per day, contributing by far the largest proportion of regional production; The Middle East and North Africa together account for 35% of world oil production [15]. Jordan is totally dependent on imported crude oil and some petroleum products to meet domestic energy demand required for its socio-economic development.

Jordan consumption of oil products has been on the rise in recent years as a result of an increase in the number of people residing in Jordan through natural population growth and the influx of refugees from Iraq and Syria. Moreover, the expansion of Amman's borders following the real estate boom means that distances travelled have also risen. In 2011, however, the increase in consumption was exacerbated by a need to compensate for the decline in imported natural gas used to generate electricity, resulting in a 24% increase in oil consumption year-on-year. Of the 6.14Mtoe of oil supplied in 2011, 2.25Mtoe in the form of diesel and fuel oil was utilized for the generation of electricity [19].

The Jordanian energy bill averaged at 13% of gross national product (GNP) and consumed most of the foreign exchange earned by exports of all Jordanian commodities in the last 3 decades, i.e., 80s to now. Jordan consumption of diesel fuel ranged between 37.5% and 39.6% in 2006 and 2011, respectively as shown in Table 1 [20].

The energy issue has posed a difficult challenge for Jordan. Its lack of conventional commercial energy resources places a burden on the national economy due to the relatively high cost of imported oil and the high energy investment needed for economic and social development of the country.

The country investment in renewable forms of energy would partially participate in minimize such burden. Renewable energy includes wind, solar, hydro, geothermal, tides, waves and biomass. The development and use of such renewable energy helps sustainable development through economic growth and pollution control.

This paper discusses the potential role of biogas and biomethane to support Jordan national economy by reducing imported petroleum highlighting the possible paths to achieve such objective. The manuscript shed light on the efforts of researchers and scientists and manufacturers to find suitable fuel alternatives that are

Table 1: Jordan Petroleum consumption (MT)

Year	LPG	Gasoline	Jet fuel	Kerosene	Diesel	Fuel oil	Total petroleum
2006	313,072	740,595	299,568	150,073	1,774,362	1,279,228	4,726,564
2007	335,137	839,641	296,747	130,659	1,746,054	1,246,820	4,750,230
2008	321,272	861,177	297,681	99,633	1,508,376	1,096,251	4,352,426
2009	338,553	1,022,515	318,437	110,654	1,613,536	823,043	4,421,713
2010	311,977	1,065,405	350,577	69,355	1,543,479	1,380,905	4,874,155
2011	377,985	1,083,147	353,779	75,166	2,406,709	1,669,826	6,076,074

Source: JPRC. Adapted from www.jopetrol.com.jo/ engDef.aspx

Table 2: Composition of Biogas (reference)

Matter	%
Methane CH_4	50-75
Carbon dioxide CO_2	25-45
Water vapor, H_2O	2.0-7.0
Nitrogen, N_2	< 2
Oxygen, O_2	< 2
Others 1)	

1) Others: NH_3, H_2, H_2S, trace gases

Source: WPA factsheet, 2013.

more environmentally friendly and can be produced from abundant resources and the obstacles that they face on the long run.

Analysis and Discussions: In Jordan, biogas is produced under anaerobic digestion of animal manure and slurries as well as of a wide range of digestible organic wastes, converts these substrates into renewable energy and offers a natural fertilizer for agriculture. Anaerobic digestion is a microbiological process of decomposition of organic matter, in the absence of oxygen, common to many natural environments and largely applied today to produce biogas in airproof reactor tanks, commonly named digesters. At the same time, it removes the organic fraction from the overall waste streams to increase the efficiency of energy conversion by incineration of the remaining wastes and the biochemical stability of landfill sites. Biogas is a combustible gas consisting of methane, carbon dioxide and small amounts of other gases and trace elements as shown in Table 2. A wide range of micro-organisms are involved in the anaerobic process which has two main end products: biogas and digestate. Digestate is the decomposed substrate, rich in macro- and micro nutrients and therefore suitable to be used as plant fertilizer.

There are many types of digesters such as covered lagoon, plug-flow and complex-mix digesters. Covered lagoons are actual man-made lagoons which are filled with slurry (manure with 0.5 to 3% solids) where biogas is trapped under a cover; and because they are not heated, the biogas output flow is dramatically reduced during colder weather conditions. They are usually the cheapest and very efficient in reducing odors, even in cold climates. Plug flow digesters consist of long relatively narrow, heated tanks with a gas tight cover and they are generally used with diary farms, because they can tolerate 11% to 13% solids as well as some bedding which is collected by scraping. The charge is pushed forward by feeding new manure to the digester from one side; and it takes from 15 to 20 days for manure to be completely digested. It is noted that the majority of digesters currently built are of the plug type. Complex mix digesters consist of a steel or reinforced concrete tank heated and tightly sealed, where manure with 3 to 10% solids is periodically mixed using a pump or impeller; they are usually more expensive to install and have the highest maintenance cost. The output of plug-flow and complex-mix digesters is stable year round because they are heated [21]. Many millions of small family-scale biogas plants are constructed in India and China. In Nepal about 10,000 of such unheated unstirred fixed-dome family-scale digesters of between1 and 10 m^3 biogas/day for cooking are being constructed per year [22].

After production the raw biogas can be cleaned and upgraded to methane; it is called biomethane and in this pure form can be compressed and injected into gas grids or used as transport fuel. The energy content of raw biogas varies between 5 and 7 kWh/Nm^3 of biogas depending on the composition; as an average 6 kWh/Nm^3 biogas is assumed (i.e., assuming 60% methane content).

For pure biomethane the energy content is approximately 10 kWh/m^3 [23]. A typical landfill also emits biogas produced as a result of microbial decomposition of wet organic matter in the absence of oxygen; the gas is normally called landfill gas and for larger properly managed sites this is captured and used for energy production purposes (usually by fuelling a spark-ignition motor driving a generator), instead of being allowed to escape to the atmosphere and thus contribute to greenhouse gas emissions. On some landfills it is simply flared so that the methane is converted to the less damaging greenhouse gas carbon dioxide [24]. After digestion, biogas goes to the gas handling system while the effluent is stored for future use as high quality soil amendment. The biogas handling system starts with purifications, because anaerobic digestion generates methane (40% to 70%), carbon dioxide (CO_2, 30 to 50%), water vapor, hydrogen sulfide (H_2S) and traces of ammonia [25].

CO_2 removal from biogas can be done by using chemical solvents like mono-ethanolamine (MEA), di-ethanolamine and tri- ethanolamine or aqueous solution of alkaline salts, i.e. sodium, calcium hydroxide and potassium. Biogas bubbled through 10% aqueous solution of MEA can reduce the CO_2 content from 40 to 0.5-1.0% by volume. Chemical agents like NaOH, Ca $(OH)_2$ and KOH can be used for CO2 scrubbing from biogas. In alkaline solution the CO_2 absorption is assisted by agitation. NaOH solution having a rapid CO_2 absorption of 2.5-3.0% and the rate of absorption is affected by the concentration of solution.

Highly hydrogen sulfide content is the common problem for IC engines. During combustion, H_2S will react and forms SO_2 and H_2O. SO_2 then reacts with H_2O to form H_2SO_3 sulphurous acid. SO_2 can also react with O_2 to form SO_3 and then with H_2O to H_2SO_4. These acids lead to engine parts corrosion. Very rapid oil degradation and engine wear is reported is reported due to acid formation [26]. Water vapor must be removed for two reasons: first to prevent freezing and water accumulation in the installation especially during cold weather and second to prevent corrosion of high pressure storage containers.

H_2S must be removed because of its own toxicity, corrosive nature as well as its harmful combustion product Sulfur Dioxide (SO_2). Passing the biogas through an iron sponge (wood shavings mixed with iron oxide) or catalytic oxidation of H_2S on activated carbon in the presence of oxygen are means to reduce the H_2S content [27].

It is also important to mention that diesel engines providing power to agricultural tractors are ranked high speed because their operation speed ranges from 800 to 2700 rpm. In high speed engines, diesel fuel injection commonly occurs at about 20º before top dead center [28]. Fuel is injected at high pressure, in atomized form and with a very high speed reaching 250 m/s [29]. The injected fuel combustion occurs in 3 stages. Stage one consists of physical lag, where injected fuel mixes and vaporizes into the hot air of combustion chamber. This stage is called "ignition delay" and defined as "the time laps between the fuel injection and the first rise in pressure due to exothermic reaction of combustion of fuel" [30]. In stage two, some of the vaporized fuel burns in an explosion like combustion causing a sharp and quick increase in pressure inside the combustion chamber; this is commonly known as the premature combustion. The time required by various stages of combustion affects the efficiency and emissions of diesel engines and therefore plays an important role in optimization. Generally speaking, a long physical lag results in a strong pre-combustion causing impaired starting ability, while a short ignition lag shifts the combustion to the less efficient diffusion stage increasing particle matter emission (black smoke), specially at high loads [31]. Ignition lag such is mainly a function of fuel quality commonly called cetane number. The cetane number is the most commonly cited indicator of diesel fuel ignition quality. It measures the readiness of the fuel to auto-ignite when injected into the combustion chamber of an engine. It is generally dependent on the composition of the fuel and can impact the engine start ability, noise level and exhaust emissions [32]. As a matter of fact, cetane number indicates the time the fuel needs to ignite after being injected; and its measurement procedure is currently designated as ASTM D 613 [33]. Diesel fuels with higher cetane number have shorter ignition lag, therefore they improve the starting ability of the ignition while increasing the smoke at full load. On the other hand, fuels with low cetane number have longer ignition lag, therefore they reduce the starting ability of the engine and have a tendency to knock at high loads [34].

Although characterized by a higher efficiency as compared to spark ignition engines, diesel engines still produce different types of harmful emissions that actively contribute to pollution, with every combustion, carbon dioxide (CO_2) is generated and diesel engines are no exception. The problem of CO_2 is that it is considered a greenhouse effect gas, in other words it contributes effectively to global warming; a phenomenon that is making itself more apparent with recent weather related catastrophes and that is driving world lawmakers to regulate CO_2 production [35] described the effects of some exhaust gases on health: carbon monoxide CO binds irreversibly to hemoglobin reducing supply of oxygen to body tissues. Nitrous oxide (NO) binds to oxygen in air to form nitrous dioxide (NO_2), which is a respiratory irritant. Volatile organic compounds, benzene, polycyclic aromatic hydrocarbons can be toxic and carcinogenic. Carbon monoxide, nitrous oxides and volatile organic hydrocarbons promote the formation of ozone: a respiratory irritant.

The petroleum based fuels seem unbeatable and irreplaceable in the near future, so combining two fuels appears to be an attractive alternative solution to reduce environment harm and preserve hydrocarbon resources [36]. It is interesting to mention that the idea of burning gas fuel into diesel engines is not new and as a matter of fact, it is as old as diesel engine itself, since Rudolph Diesel wanted to use coal dust as fuel [37, 38] also added that the high compression engines are very well suited to dual-fuel operation not only with natural gas, but also with other gaseous fuels, including biogas and landfill gases provided a suitable time. Natural gas, even though it is a fossil fuel, when compared to diesel, is found to be more abundant, requires less refining and combusts with lower emissions. Its main component, methane, could be generated form anaerobic digestion of wastes as mentioned in previous paragraphs, which gives the technology using natural gas as fuel a renewable aspect [39]. Another advantage of methane on other fuels is that its lean combustion in engines produces relatively insignificant amounts of NO_x and particulate matter [40]; also they used the term “low-pi-lot” to designate engines where diesel amounts for 2 to 3% of their energy and “dual-fuel” for engines where diesel provides 20% of the energy. The gas fuel could be either carbureted into the intake system to produce a lean mixture with air, or it could be injected into the cylinder just like diesel fuel is injected. In fact, the pilot ignited natural gas engines regardless of the amount or type of substitution have been shown to match diesel efficiencies and produce significantly lower $NO_x$and particulate matter. Nevertheless, at very high load, with very high intake temperatures or pilot quantities, these dual-fuel engines are susceptible to knock; while at low loads and high gaseous fuel substitutions, they are prone to misfire. Heavy hydrocarbon emission, especially methane, is also observed; methane is a problematic not only because it is difficult to filter out, but also because it significantly contributes to potential ozone and global warming [41]. Dual-fuel engine applications are finding ground in fleets vehicle and heavy duty trucks, in buses and rail way locomotives, in marine, agriculture and industrial applications. Nevertheless, they are still most widely used in stationary applications for electrical production, pumps and cogeneration (hot water or steam with electricity). On the other hand, there are several obstacles against the mass conversion of diesel engines to dual-fuel engines: an engine variability and operation ranges, knock control is dual-fuel mode at high temperature and high load conditions and reduction of emission of NO_x and unburned hydrocarbons, especially methane. Outside of the engine, on-vehicle storage possibilities for methane further complicate the wide adoption of such technology because methane has low energy concentration and should be stored at high pressure in big volumes. At the nation’s level, the word “mass conversion” is translated into a huge bill to provide vehicle owners the required engines, fuel, parts and services needed [42].

In an interesting experiment, a gaseous fuel, such as liquid petroleum gas (LPG) was mixed with additives to attain various cetane numbers and then it was fed into the engine, the performance of LPG fuel was compared to diesel fuel of almost the same cetane number. Expectedly, it was found that ignition delay increases with decreased cetane numbers in both LPG and diesel; however a more interesting remark was that the combustion of diesel occurred in the middle of combustion chamber while the combustion of LPG took place at the peripheries [43]. The location of combustion is affected by the type of fuel and the flame propagation speed. It is also affected by the shape of combustion chamber and the piston crown, which also affects the bath taken by the injected fuel and the degree of mixing of these fuels with air [44]. In China, a more simple approach was tested by [45] and consisted of feeding LPG in diesel engines through a Venturi set on the intake manifold with a cam to optimize both diesel and LPG usages. They said that LPG could be easily replaced by natural gas. This system fed LPG at variable rates depending on engine load and speed; with the highest replacement rates at 75% load and full speed. They have found that soot emissions were greatly reduced; however other emissions are still a problem. It seems that when LPG is present, ignition lag becomes more important leading to more important pre-mature combustion, causing higher pressure and higher temperatures therefore knocking and NO_xemissions. At lower loads, the ignition lag becomes so important that engine operation becomes sluggish causing high CO and unburned hydrocarbons emissions as well as higher fuel consumption. More results were practically verified in an experiment conducted by [46]. Homogenous charge compression ignition (HCCI) engines found their applications with methane fuels as well. For instance, [47] injected pilot diesel into the combustion chamber of HCCI engine to better control its ignition and consequently they were able to increase the power density by 25%-35% without affecting the levels of toxic emissions; furthermore, their engines supported larger intake air temperature ranges.

Jordan is a rapidly growing country with a current population growth rate around 3.3%. The growth in the Gross National Product (GNP) is currently a healthy 6%. This contributes to the increase in the standard of living in Jordan. Increased population, coupled with high standards of living. Jordan imports around 95 percent of its primary energy each year and has always placed high emphasis on energy supply security. In Jordan, potential source of energy from biomass is significantly arising from municipal waste. Preliminary studies carried out by National Energy Research Center (NERC) shows that biogas from animal and domestic waste can save up to 4 percent of imported oil which equivalent to 130,000 toe per year Table 3. A project which was funded by Global Environment Facility (GEF) started its operation in the year 2000 in Russifeh landfill site. The project has two objectives: (1) demonstrating the environmental and energy benefits from using municipal and industrial organic wastes for producing biogas and then electricity and (2) collecting the biogas generated from Russifeh landfill to produce electricity via electrical generators. The total amount of biogas generated from the landfill is

Table 3: Manure production lead to Biogas production per cattle in Jordan

Type of farm	Number of Heads	Moist manure (ton/yr)	t/d	Biogas m^3/head/d	Biogas m^3/t manure
Milking cow/general	10,417	114,066	313	1.5	50
Deep bedding/Cow	7,970	43,636	120	0.8	50
Laying chicken	864,862	20,757	57	0.012	188
Fattening Chicken	2,372,975	28,476	78	0.007	225
Sheep manure	65,000	35,588	98	0.132	88

Source: computation by GTZ- expert, adopted from (Salah A. Wolfgang T., 2010).

around 2000 m. /hr where 50 - 60 percent of the biogas is methane. The project is owned by the Greater Amman Municipality (GAM) and Central Electricity Generating Company. The plant receives 60 tonnes of pure organic waste daily. The waste consists mainly of blood from slaughterhouses that are managed by GAM and food waste from restaurants and hotels [48]. The National Energy Strategy; updated in 2013; had identified several options for further enhancing energy security. These include: (i) developing renewable energy, (ii) promoting energy efficiency, (iii) developing domestic energy resources. For Jordan, a number of reports on biomass potential have been published in the past years. The difficulty of estimating this potential is driven by, the issue of reliable data for both existing and future resources as many biomass residues have no market and therefore no trade records and the definition of potential (i.e., technical, economic, sustainable). Furthermore, the availability of land for energy crops largely depends on the level of (possible) competition with alternative land use.

The biggest challenge to bioenergy development in Jordan is the scattered wastes across the country especially regarding bio-wastes from animal husbandry and farming (sheep, dairy cattle and beef) and poultry production farms. The "*All in all out*" approach means centralizing all production facilities of poultry production in one location and that location is established away from residential areas, which centralizes the bio- wastes in one utilizable location. In this prospect, encouraging large farms to develop methods of utilizing the available bio-wastes into usable forms of energy is an attractive policy and developmental approach, which reduces the costs of production by generating part of the energy needs. Olive cake and vegetables cropping residues are currently underutilized quantities thus need to be targeted and included in future bioenergy develop- ment plans. Olive cake is presently processed and pressed to produce briquettes for space heating or charcoal-like product for grill use. When conducting the [49] experiment results revealed that olive cake provides the highest potential for biodiesel production with a ratio of 39%. Chemical analysis showed varying levels of sulfur contents, which required desulfurization unit to produce standard quality biodiesel.

CONCLUSION

Jordan not yet invested in its oil shale or biomass resources and a lot of research and training is needed in this regard. The biogas production and its usage industry is still face serious challenges; economical considerations remain the decisive constrain facing further widespread of such technologies.

Extending the usability of biogas to fuel vehicle engines seems promising to increase revenues of biogas plants and reduce dependability of fossil fuels [50]; development and use of such renewable forms of energy helps sustainable development through economic growth and pollution control. The replacement of fossil fuel by renewable and clean forms of energy would relieve the environment from serious types of pollution. Investment in renewable forms of energy would at least partially relieve Jordan from burdens of Oil imports as well as the creation of new job opportunities.

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