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Economic feasibility of using date stone as a source of clean energy in Saudi Arabia

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ABSTRACT

Date palm is one of the main agricultural products in the Saudi Arabia, it has been playing a significant role in the daily life of the people in the Middle East and North Africa for the last seven thousand years. Saudi Arabia is the third largest global producer of dates, while Egypt occupies the number of one position as the largest date producer across the world. the total production of date in 2018 in Saudi Arabia was reported at 1,399,762 metric tonnes in 2018 from an estimated 30,429,607 trees, which were cultivated in an estimated area of 155,118 hectares.

Date palm trees generate large quantities of agricultural wastes, which each date tree can generate nearly 20 kilograms of dry leaves each year. It can be used as a source of biomass. By Using Riyadh region in Saudi Arabia as a case study, the overall potential to recover energy from the residues of date palm has been forecasted to be 15.63 PJ. Therefore, this concludes that the residues of date palm may be considered as an important source of clean energy to fulfil the growing demand of energy wherein natural resources are finite, particularly in the date palm producing countries wherein date palms are cultivated commercially for fruits.

KEYWORDS: *Image Processing, Electronic invoicing, pdftotext, tesseract, tesseract*

INTRODUCTION

Date palm is one of the main agricultural products in the arid and semi-arid regions across the world, particularly in the Middle East and North Africa (MENA) region. Being a tropical and subtropical tree that belongs to the Palmae family, the date palm has been playing a significant role in the daily life of the people in the MENA region for the last seven thousand years [1]. The latest data from The World Bank (2020) shows that Saudi Arabia has only 1.6% arable land in 2016 out of 2.149 million km^2 of its total land, which is characteristically comprised with an arid and semi-arid climate. Although the country has between three and four times as much arid land as arable, the potential arable land is not yet used. The main region of Saudi agricultural land lies in regions that are short of water, with rainwater averages at 250 mm per year or more. The temperature in Saudi Arabia is comparatively high and can reach up to 50°C during the summer in places, while the humidity is comparatively high in the eastern part of the country. The soil in Saudi Arabia is normally fragile and it is eroded by wind and water, while the high salinization degrades the soil. According to Erskine *et al.*[2] more than ninety percent of the Arabian Peninsula's land suffers from desertification, of which sixty percent of the desertification is caused by wind and water erosion, and more than forty percent of this desertification can be considered as severe to very severe.

According to Aleid et al. [3] the total number of named date palm cultivars across the world has been estimated at 5,000, but the flavour of date palm differs between cultivars and location, and can even vary within date groves, . The most widely grown fruit tree in Saudi Arabia is the date palm, which is mainly grown in areas that have long dry summers and mild winters. The date palm trees thrive in desert and oasis climates, wherein the temperature should be high but the level of groundwater should be near to the soil surface [4]. According to Al-Alawi *et al.*[5], the production of date fruit depends on the availability of heat, and the dry areas have the most number of the dry fruit cultivars due to the availability of humid and semidry land. Saudi Arabia's date palms can grow in various types of soil, but the light deep soils provide the best conditions. The date palms in Saudi Arabia can tolerate high degrees of salinity, for example up to 22,000 ppm, but the cultivars' grown trees and fruits also differ according to the level of salinity[3]. According to Sirisena et al.[6], the level of salinity provides negative influence of the growth and chlorophyll contents of the date palm trees.

The global cultivation of date palm has increased rapidly in recent years. The annual production of date across the world in 2018 has been reported at 8.83m metric tonnes[7], which have been valued at US$ 4.2bn. Saudi Arabia is the third largest global producer of dates, while Egypt occupies the number of one position as the largest date producer across the world[8]. Based on the data provided by the Ministry of Agriculture, Riyadh has the highest annual production of date at 361,649 metric tonnes within an estimated area of 42,208 hectares. The Kingdom of Saudi Arabia is divided into thirteen regions. The Riyadh region, which contains the Administrative Capital, which was used as a case study in this chapter, is considered the highest area with numbers of date palms (7.86 x 10^6) and consequently, dates production. And it comes in second place in numbers of date palms (7.33 x 10^6) is the Qassim region, which is an agricultural region that produces the most luxurious types of dates in the Kingdom, which are exported abroad. The Medina region comes in third place (4.62 x 10^6) and one of the most important types of dates produced in Al Madinah is Al-Ajwa, which is considered one of the most expensive types of dates. The eastern region comes in fourth place in the production of dates (3.92 x 10^6), which is considered one of the richest regions in the world due to the presence of many oil fields in it.

Table (1) shows the date production and approximate areas by region in 2018 in Saudi Arabia.

Table 1The production of date and estimated areas in Saudi Arabia in 2018 [9].

Region	No of date palm	Production	Area (ha)
Riyadh	7.86 x 10^6	361,649	42,208
Qassim	7.33 x 10^6	337,220	39,301
Madinah	4.62 x 10^6	212,614	18,502
Eastern	3.92 x 10^6	180,565	13,625
Hail	1.89 x 10^6	87,310	16,187
Makkah	1.24 x 10^6	57,220	8,068
Asir	1.11 x 10^6	51,415	4,297
Tabuk	1.01 x 10^6	46,573	2,966
Jouf	0.91 x 10^6	41,898	5,471
Najran	0.39 x 10^6	18,394	3,070
Baha	73,554	3,383	1,095
Northern	14,329	659	40
Jazan	8,719	401	288
Total	30.42 x 10^6	1.39 x 10^6	0.15 x 10^6

Table (7-1) shows that the total production of date in 2018 in Saudi Arabia was reported at 1,399,762 metric tonnes in 2018 from an estimated 30,429,607 trees, which were cultivated in an estimated area of 155,118 hectares. Figure (7-1) shows that the central region of Saudi Arabia – Riyadh – has the highest production of dates in 2018, which accounts more than 25% of the estimated total production. The second and third places go to Qassim region and the Eastern region with an estimated more than 19% and 15% of the total production respectively [9].

The orchards of date palm are also distributed in different places in Saudi Arabia, and according to NCFP [9], there are more than 400 date cultivars in the main four regions, such as Riyadh, Qassim, Eastern, and Madinah, of which only 50 to 60 cultivars produce dates commercially in these four regions [10]. Figure (1) shows the 13 geographical regions that contain various cultivars of date palm.

Figure 1The regions that produce the date through various cultivators [3].

According to Al-Shreed et al.[11], Saudi Arabia has the highest per capita consumption of dates in the world, which reached to nearly 35 kg per person per year. The econometric analyses of the costs of the date productions depend on a number of variables, such as the increasing level of citrus in dates, the quantity sold, and the prices of the final products [3]. According to Dhehibi et al.[12], additionally, the production of date and the prices of dates are also influenced by the cultivators, the costs of production, the intercropping within the orchards, and the optimal level of operations. In relation to the econometric analyses, Aleid et al. [3] noted that the labour cost is the most crucial cost factor in the production of dates. During the harvest seasons, the cultivators hire many part-time and seasonal workers, and the cultivars have little control over these seasonal labours.

PRODUCTION OF ENERGY FROM DATE PALM WASTE

Date palm trees generate large quantities of agricultural wastes, and the study of Chandrasekaran and Bahkali found that each date tree can generate nearly 20 kilograms of dry leaves each year[1].

Other wastes, for example date stones can provide an average of 30% of the date fruits, and these agricultural wastes contain cellulose, hemicellulose, lignin, and other composites that are commercially used in various biological processes. The harvesting of date palm fruits is frequently accompanied by considerable fruit losses that occur during the picking of fruits, and subsequent storage and processing. Because of their insufficient textures (too soft), the lost dates, generally named as date by-products, are not fit for human consumption and are generally rejected [5]. Actually, all organic waste materials that arise from date processing may have the potential for use as elements for the production of compost [1]. The leaflets, date palm rachis, fruit stalk pruning, and trunk are the residues of the date palm as shown in Figure (2). Additionally, Table (7-2) shows the applications of these residues.

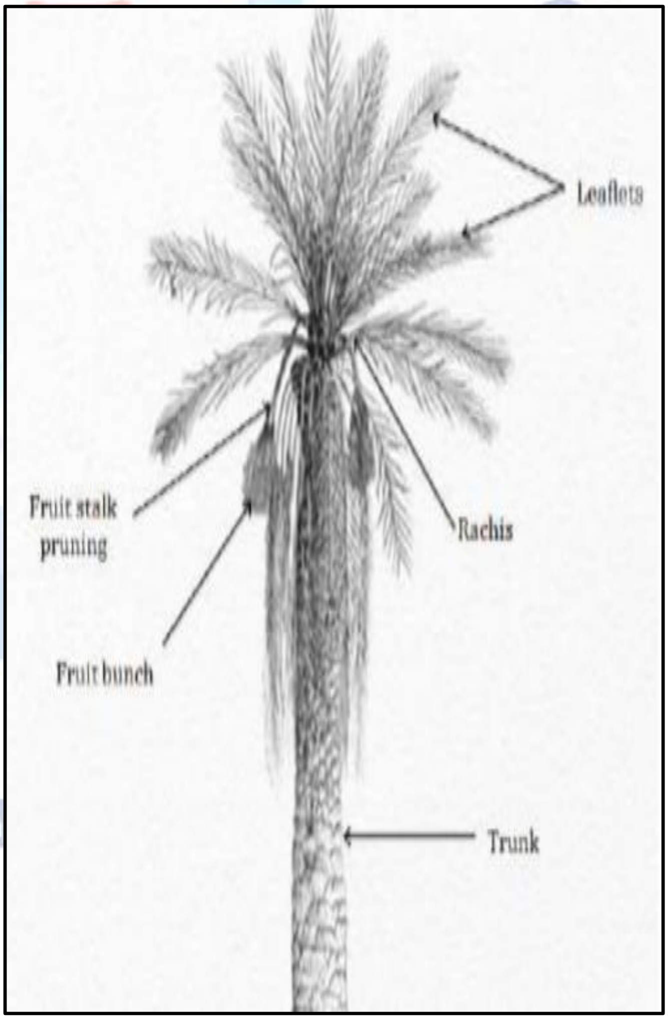

Figure 2A date palm tree [16].

Table 2 the applications of the residue

Type of residue	Applications
leaflets	Baskets, crate, carpets, fan, food covers, etc.
Rachis	Timber, wood, furniture, mats, paper, fuel. Etc
Fruit pruning	Cages, trays, vases, cords, twine, etc.
trunk	Poles, beams, girders, etc

After the cultivation of the date fruits, various residues are separated from the tree parts. A full-grown date palm tree generally contains 100-130 green palms and develops 10-30 new leaves each year. However, it is necessary to remove the leaves when they become dry, and the branches of the date palm contains nearly 45% of leaflets and approximately 54% of rachis [13]. Sait et al. [14] found that an adult date palm tree produces nearly 20 kilograms of dry leaves each year. With date fruits, the overall mass of a solo bunch fruit pruning has been reported at nearly 8 kilograms, while the dried fruit pruning without the fruits weighs nearly 400-500 grams [15]. On average, each acre of land contains date palm trees of 80-130, while the trunk of a date palm tree has average mass of 60 kilograms in each acre of land, as two to three tresses die each year in an acre, and they are removed, while new trees are planted. Table (3) shows the average weight of various residues of date palm.

Table 3Average weight of residues of date palm [16].

Type of residue	Weight of Residue
Leaflets	9.2 kg/tree/year
Rachis	10.8 kg/tree/year
Fruit pruning	0.5 kg/tree/year
Date palm trunk	60 kg/acre/year
Date stone	90 kg/tree/year

A field survey has been performed for quantifying the availability of the residues of the date palm in Riyadh, Saudi Arabia, as this region produces nearly 30% of the total dates in the Kingdom. For reducing the moisture contents, the samples were left in the natural environment to dry for three days. For developing a standardised product to analyse, it was necessary to pulverize the samples into particles by hammering and each particle weighted less than two millimetres.

The Measurement of Heating Value

Experiment was conducted to determine the calorific or heating values of the residues and the samples were analysed by a bomb calorimeter, model number 6100, from Parr Instrument Company.

Table 4Measurement of Heating Value

Type of residue	HHV($MJkg^{-1}$)	References
Leaflets	17.9	[14]
Rachis	10.9	[14]
Date stone	18.965	This study

The Measurement of Total Residues (R_{Ti})

To estimate the total residue, the total tree number (N) in the region multiplied by the residues produced by these trees (R_{gi}) to find out the total residues of the date palm in the Riyadh region:

Table 5Measurement of Total Residues

Type of residue	**Weight of Residue**	**Total Residues in Riyadh (kg)**
Leaflets	**9.2 kg/tree/year**	**72.3×10^6**
Rachis	10.8 kg/tree/year	84.9×10^6
Date stone	90 kg/tree/year	707×10^6
total		864×10^6

THE TOTAL POTENTIAL ENERGY

Equation (1) has been developed to calculate the potential produced energy [17].

$Ep = \sum_{i=0}^{N} Rai.Hi$ *Equation 1*

Where:

Ep = The contained energy in the residues, mega joule per year.

R_{Ai} = The quantity of available residues for each type of residue (i) in tonnes per year for the energy.

H_i = The value of heating for each type of residue (i) in MJ per kg.

n = The number of types of the residue.

Table 6total Potential Energy

Type of residue	Total Residues in Riyadh (kg)	HHV (MJkg-1)	Total energy (MJ)
Leaflets	72329737.6	17.9	1294702303
Rachis	84908822.4	10.9	925506164.2
Date stone	707573520	18.965	13419131807
total	864812080		15,639,340,274

Economic Analysis

OVERVIEW OF THE GASIFICATION PROCESS

This includes design details as well as a look int the gasifier's operation.

Plant Construction and Design

Plants employing gasification of biomass often share the same set of equipment and parts, the main components of such a plant are:

- Feedstock (date palm) supply and handling unit.
- Gasifier feeding system.
- The gasification unit (the actual reactor used for the process and inclusive of the bed material).
- Utilities equipment such as scrubbing, cooling and processing.
- A turbine or an engine (usually gas engine).

There are various factors that must be considered when designing the gasifier. This includes the biomassfeedstock, the medium of gasification, the plant size (quantity of feedstock and produce) and the destination of the produced gasses. A biomass gasification system is shown on Figure (2). This design was chosen since it represents a proven, reliable gasifier that could be deployed into the industry in the short term, rather than using a more conceptual, unproven design.

biomass handling and supply

The material used as a biomass in this plant is date palm which is factory supplied; the properties of this material have been summarised in Table 4. Before feeding, it is chipped to form smaller particles before being allowed into the primary biomass silo. The silo can handle 7 to 8 tonnes of biomass for storage. It was known that the base case does not assume any of the biomass production, as the data used in this study is retrieved directly from a live plant.

Gasifier feed system

The feedstock is fed into the gasification unit using the biomass feed screw via the biomass silo. Motors are used to achieve this motion, while the amount of feedstock is controlled using a silo agitator discharge rotary valve which then leads the feedstock to the main gasification skid unit. within the skid unit, the feedstock is entered into the biomass feed hopper unit via the external feed screw. It then is transported into a spiral conveyor for the biomass feed through a flexible spiral coil screw feeder. A mechanical agitator is used to drive this operation. The date palm feeding rate is then controlled by changing the rotational speed of the screw; which is a pitch auger screw in an upward motion and motor-driven at varied speed levels. The date palm is fed into a high-pressure rotary gas blower This feeds the date palm. This operation enables the hopper to provide loads of 200 kg of date palm hourly.

A venturi is used to entering the date stone through 4 different vales to mitigate gas leaking from the reactor, as following:

- A motorised slide valve.
- An actuated solenoid valve.
- A char rotary valve.
- A motorised air inlet slide valve.

The Gasifier

The gasifier is initiated using natural gas around 30 minutes prior to the feeding of the biomass feedstock, which generally accepted in the industry[18].

The gasifier heat is initiated by a burner system to reach temperatures up to 800 °C which is sufficient to initiate the reaction. The burner must provide a stable supply of heat to avoid any interrupting to the reactions in the gasifiers, and therefore this must be considered in its design. It also must not be fouled by biomass particles. Once the gasifier starts flue gas production, this becomes the main heat supply and therefore the burner valves shut down when the biomass feedstock starts to be used.

The configuration of this particular gasifier is similar enough to the conditions that have been studied within this thesis, therefore it is assumed that the gas compositions measuredthroughout the research conducted herein are sufficiently robust that they can be extended to the case study in this paper.

Assuming atmospheric conditions, the system designed to gasify 200 kg date stone hourly. This creates energy back to the gasifier of 3,600 MJ/hour (which is about 1,000 kWh), if the energy content of the date stone waste is at 18 MJ/kg (ECN, 2009). The system achieves a conversion efficiency for gasification of 75%. The net electrical efficiency is described in the next section.

Processing, scrubbing and cooling equipment.

The produced gas enters the scrubber at a temperature of about 750 °C, so it must be cooled down beforehand. Therefore, it goes through a heat

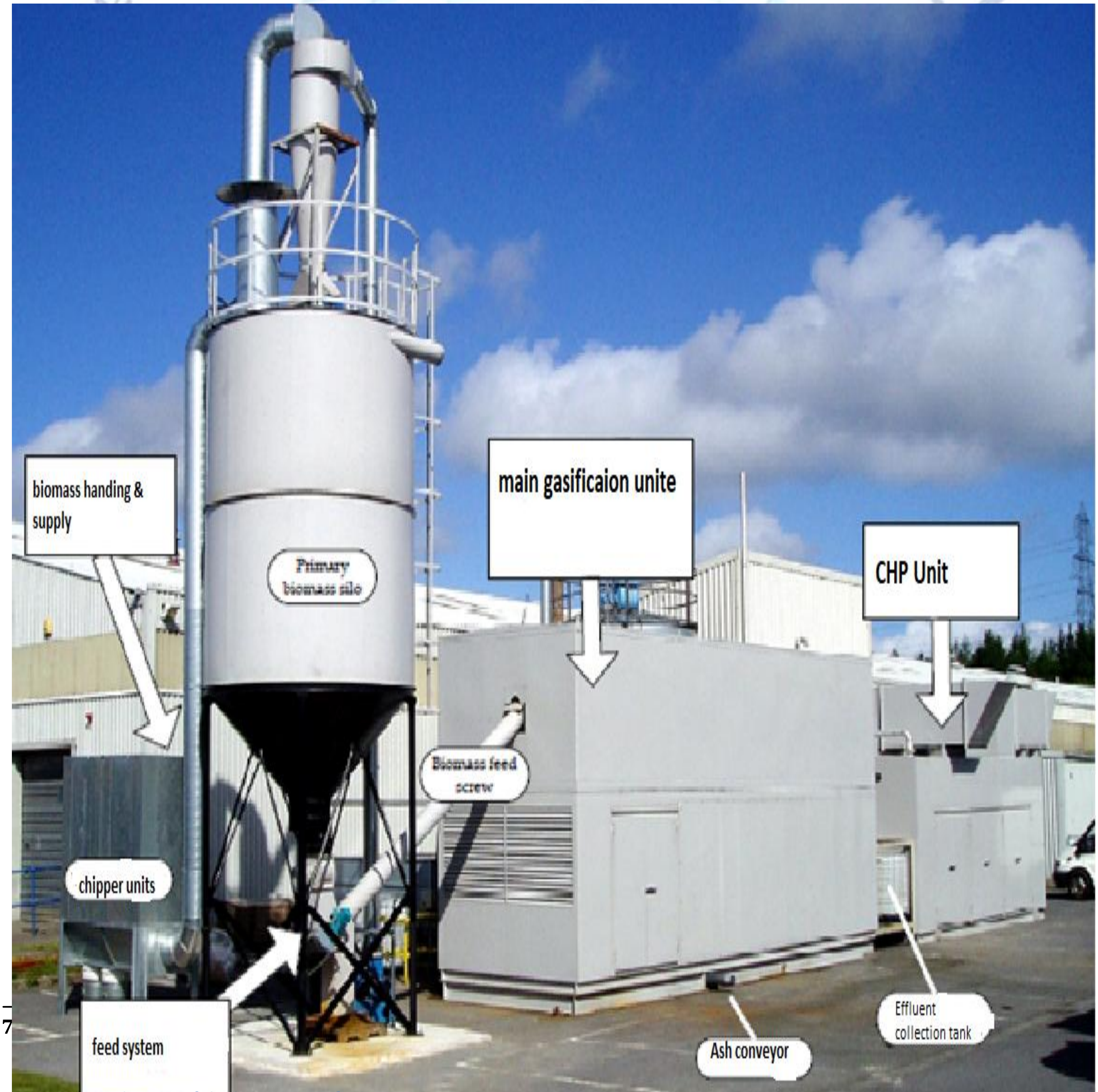

Figure 3Outside view of the biomass gasification system exchanger, firstly through a venturi scrubber where it is scrubbed with water at 1 l/min. At this stage, both the gas and liquids are mixed resulting in droplets to be dumped at the scrubber's outlet and resulting in the gas temperature at dew point of water at around 90 °C; it is then subsequently filtered and cleaned. The syngas is cooled further to 30 °C, where condensates are removed. Finally, to ensure complete removal of any droplets that may have been produced during the condensation, the gas goes through a demister (filter). The gas flow is driven by a rotary gas blower.

CHP unit

The CHP united is housed with the gas engine in a separate unit alongside an electric generator, control, and recovery equipment, and conveying exhaust gasses; as shown in Figure (7-3). The product gas is conveyed from the primary skid unit and supplied to the gas engine through the fuel supply pipes. It then fires up the gas engine which subsequently powers the electric generator, making electricity available to use either back into the grid or locally. The overall electrical efficiency stands at 34% [18].

Building

The plant is designed to be mobile in case it needs to be transported to a different site and therefore are not considered a permeant structure and can be loaded on a lorry. The skid unit of the primary gasification unit is in a stainless-steel structure. Also, the CHP unit is provided by Cogence and has a stainless-steel exterior as well.

Gross Energy Requirement (GER)

Plant construction

An initial step is needed to estimate the main energy input for the plant construction which can be translated as the Gross Energy Requirement (GER). It was estimated to be 1,988.5 GJ for the biomass gasification plant [18]. This includes energy required for the plant construction; it is defined as the summation of the indirect and direct energies needed for the construction of the plant. Main energy added to the net energy analysis includes the following factors. The input energy levels have a directly proportional relationship with the plant's operation time.

- The plant construction embodied energy.
- Consumption of natural gas at the start-up phase of the plant operation.
- The parasitic electricity loaded for the plant.
- The energy required and consumed un the chipping of the date palm biomass into smaller particles.
- Energy needed for handling the water supply.
- Lubricating oil and ash disposal energy requirements.

The GER energy analysis was estimated for the proposed location in the city of Riyadh in Saudi Arabia, and considering the following conditions and facts:

- The palm waste within the city disposal is currently the sole responsibility of municipal services sectors and the local farming association.
- The Riyadh Region is in the centre of the country and has a total area of 404,240 km^2.
- There are two main scenarios for the number of plants and possible locations within Riyadh Region:

1. A single plant in Zulfi city.
2. Two separate and similar plants in north of region Az-Zulfi and in Al-Kharj.

The first scenario is one factory in the city of Zulfi.

The city of Al-Zulfi is in the north of the Riyadh as shown on the map on Figure (4). It is in proximity to the Qassim region, which is second highest region in Saudi Arabia for the production f date palms, it also is surrounded by a large number of farms from nearby cities.

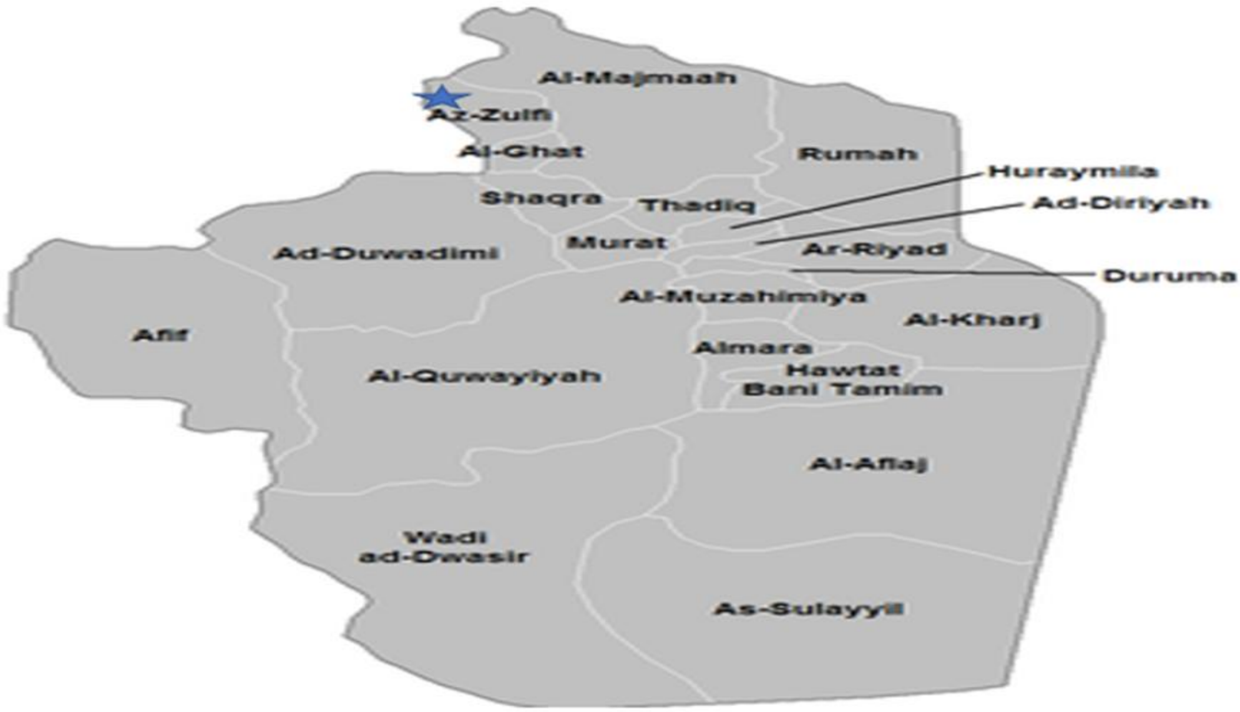

Figure 4located Az-Zulfi

The key disadvantage of this scenario is that almost half of the quantity needed of the raw materials needs to be shipped and transported from nearby cities. Therefore, shipments are prepared in the neighbouring farms and prepared for shipment (ideally in smaller load quantities), while the remainder of the materials are shipped from the main cities of the country.

The required GER is 1,988.5 GJ as shown in Table (7) and can produce 15.9 x 10^6 MJ and thus the net energy produced is 15.6 x 10^6 MJ/year.

Table 7Total net energy

Total energy (GJ) input	**Total energy (MJ) output**	Total net energy (Mj)
1,988	15.6 **x 10^9**	15,64 **x 10^9**

The second scenario is two factories in the north of region Az- Zulfi and other one in Al-Kharj.

The first plant is to be set up in the city of Al-Zulfi for the same reason that was mentioned in the first scenario i.e. its proximity to the Qassim region. The second site is the city of Al-Kharj. This eliminates the need for transportation to deliver/transport the date palm and biomass wastage, and therefore it is more economical feasible.

The savings made in the transportation costs had increased the feasibility of this scenario, and thus the cost value of electrical production decreased to 3.61 pounds per kilowatt hour. Therefore, it can be concluded that whilst some additional complexity is present when using a distributed system, the long term implications are that this will outperform a large, centralised site.

CONCLUSION

Using a case study in Riyadh region in Saudi Arabia, this chapter has demonstrated that the use of biomass from date palm may provide the availability of sustainable energy supplies in Saudi Arabia. This study has considered three types of residue from date palm trees, such as date palm leaflets, date palm rachis and date stone, and the study area in Riyadh can be used to produce energy from the residues of date palm. From the Riyadh region in Saudi Arabia the amount of the Rachis has the highest availability of 84.9 thousand tonnes per year, which is followed by Leaflets 72.3 thousand tonnes per year, and date stone (70.7 tonnes per year). Additionally, the heating values of residues from date palm in Riyadh region range from 10.9 to 19.0 MJ/kg. The total quantity of potential biomass generated from the residues of date palm in the Riyadh region to produce energy would be 865 x 10^6 tonnes per year. The overall potential to recover energy from the residues of date palm has been forecasted to be 15.63 PJ. In this chapter, two scenarios for the configuration of the operation of example gasifiers were studied, bearing the results presented herein imply that a distributed system where the biomass is processed in situ (at the growers site) is more favourable than a large centralised process with a single point source of energy generation. This finding has resulted from studying the specific case of Saudi Arabia, which may not be applicable to other parts of the world, and have been governed by growing conditions, environmental factors and topography. This proposes an interesting subsequent implication in that compact, portable gasification process are clearly more beneficial than a scaled-up large plant. Hence this finding implies that research and development into small-scale biomass gasification in Saudi Arabia would be advantageous.

Therefore, this chapter concludes that the residues of date palm may be considered as an important source of clean energy to fulfil the growing demand of energy wherein natural resources are finite, particularly in the date palm producing countries wherein date palms are cultivated commercially for fruits.

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