Multi Objective Modelling of Biomass Supply Chain in Karachi Cattle Colony Considering Economic, Environmental and Social Aspects

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***Abstract*: Biofuels are the potential energy solution due to increasing oil prices, depleting fossil fuels, renewable and clean energy requirements. Therefore, utilization of biomass, especially dairy farm animal manure is a profound substitution for bioenergy production. The major barrier to develop bio refineries in developing countries is lack of infrastructure and their respective supply chain. This research aims to develop an optimal supply chain network to produce biogas considering economic, environmental and social aspects. A mixed-integer linear programming (MILP) model is proposed for the optimization of biomass supply chain and optimal plant location and purification technology. The proposed model and solution methodology are implemented using a case example of a dairy farm-based biomass supply chain network design in Karachi, Pakistan.**

***Keywords*: Biomass, Supply chain network, Multiobjective optimization, MILP model, Bioenergy**

I. INTRODUCTION

The continuous rising population, mass migration to urban areas and serious effects on climate change have imposed severe effects on the global security[1]. The more dependence on fossil fuels needs to be substituted with the more utilization of renewable sources[2]. It is practicable to produce biogas. The studies reveals a financial system profit-ability, waning of ($CO_{2)}$ and social benefits[3]. An anaerobic digestion (bio digester) technology can be used to produce biogas from different biomass sources[4]. The animal dung, domestic waste, organic waste, grass including seaweed are the best biogas sources. A potential source is an important factor, for example to optimize output by increasing the size of the two cylinder-separated stages of the reactor, increasing the pretreatment time and matter quantity. The examination of design and construction of bio digesters are important for technical, economic and environmental aspects considering performance and financial benefits of the system[5]. The electric power generation, automobile fuel, domestic networks gas and gas grid injections can be produced by the utilization of biogas[6]. The qualitative biogas is used by using upgrading technologies to purify it by taking away the compounds that affects efficiency, equipment and to get rid of health hazards. Therefore, the utilization of renewable energy resources would enable to meet the increasing energy demands, to follow the international regulations for greenhouse gas emissions (SDGs) and to reduce dependence on the utilization of fossil fuels[5, 7]. In addition, it is crucial to avoid moisture (drying), H_2S (desulphurization) and CO_2 (heating value)[8]. The photo synthetic processes including chemical and physical processes can be used to take away the mentioned compounds[1]. The various analysis and reviews have revealed CO2 reduction by purifying biogas with the technology considering chemical and physical processes. A decision model was developed for the waste biomass based energy supply chain considering all the mentioned facts dependent on real-life assumptions and restrictions to deal with problems related to fossil fuel consumption in Karachi and Thatta[9, 10], Having plethoric biomass resources. The study focuses on providing the most convenient supply chain configuration that boosts the profitability all through the related processes for designing the optimal planning for bioenergy production[11, 12]. Moreover, various solutions have been suggested such to maximize biogas plant production based on cost price capability, to raise the bioenergy need and to cut the CO2 emissions [13, 14]. Thus, the proposing research attempts to maximize the biomass supply chain in the regions by putting forward a mathematical model considering economic, environmental and social aspects[2, 15]. Hence, the applicability of mixed integer linear programming MILP is made possible by examining the performance of the model having three objective functions i.e economic, environmental and social[16].

In addition, this study adds up for the best possible plant location for processing, biogas production and to determine either the technology is applicable[17]. Therefore, the purpose of the study can be achieved by a fair biomass supply chain network to maximize the bioenergy production[18]. Hence, the model is formulated for peculiar case study of Karachi and Thatta regions. The model is general and feasible to apply in any geographical region as a decision making tool for multi objective optimization functions[1].

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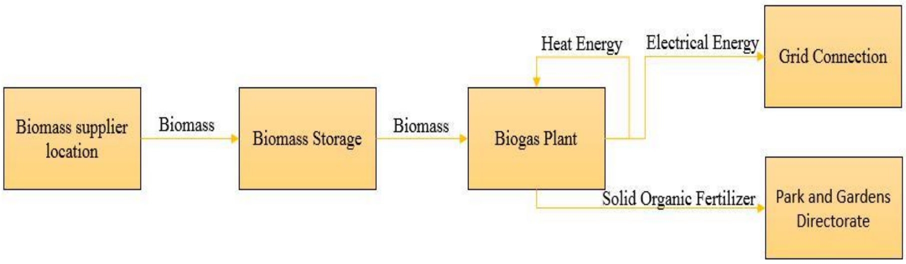

Figure.1 Biomass based supply chain network [16]

Table 1. Shows the authors' objective functions and methodology

Author's Name	OBJECTIVE FUNCTIONS			Methodology
	ECONOMIC	ENVIROMENT	SOCIAL	
This Study	×	×	×	MMILP
Luis Alberto Diaz-Trujillo et al in 2019	×	×		MILP
Dipesh Kumar et al in 2019	×	×		Biomass processing techniques
Bhaba R. Sarker et al in 2019	×			MINLP
Y. Lechón et al in 2019	×		×	Input-Output Analysis
Yong Shin Park et al in 2019	×	×		MILP
Jafaru Musa Egieya et al in 2018	×			MILP
Manuel R. Taifouris et al in 2018	×			MILP
Carl Vadenbo et al in 2018		×		Consequential life cycle assessment(LCA
Hatice Güne ş YILDIZ et al in 2018	×	×		MILP
Maryam Mohammadi et al in 2018	×			MILP
Sandra Silva et al in 2017	×			MMILP
Krystel K. Castillo-Villar et al in 2017	×			Two-Stage Stochastic Model Programming
Lihong Chen et al in 2017	×	×	×	Environmental cost-benefit Analysis
Nicoletta Paolucci et al in 2015	×	×		MMILP Analysis

II. MATERIALS & METHODS

A. Data Collection

The data have been collected from both secondary and primary sources. The primary data is collected from the cattle colony Karachi dairy farms through experts. Whereas, secondary data such as biogas technologies, energy production requirements, and others are collected from existing literature.

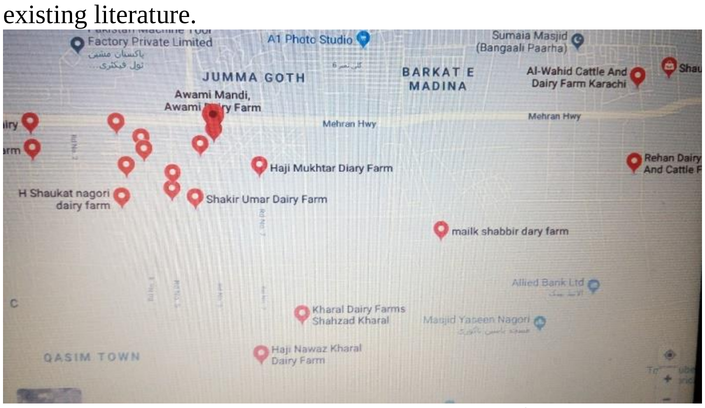

Fig. .2. Karachi cattle colony potential dairy farms

A Mathematical Model

A mathematical model have been formulated to develop biomass supply chain network considering economic, environmental, and social aspects.

Total cost of the system

$$MinZ1 = \sum_{j=1}^{n} \times \sum_{k=1}^{l} \times \ (f_k + vg_k)Y_{jk} + \sum_{i=1}^{m} \times \sum_{j=1}^{n} \times \ 2t d_{ij} q_{ij}$$

Total CO_2 eq. emission

$$MinZ2 = Emission^{total} = Emission^{load} + Emission^{grind} + Emission^{transport}$$

$$Emission^{load} = LD_{k;}FC^{load}\, EM$$

$$Emission^{grind} = GR_k FC^{grind}\, EM$$

$$Emission^{transport} = TRk^{total} FC^{transport}\, EM$$

B. *Social rejection*

$$MinZ3 = \sum_{h=1}^{p}\times\sum_{j=1}^{n}\times\sum_{k=1}^{l}\times rhjkyjk = \sum_{j=1}^{n}\times\sum_{k=1}^{l}\times Pj^{\theta}\ S_k Y_{jk}$$

$$Pj^{\theta} = \sum_{h=1}^{p} Ph \text{ X } (ah_j^{\theta} \div \text{ah})$$

Indices:

i index referring to the dairy farms (*i* = 1, 2, …, *m*);

j index referring to the potential sites for the location of biogas plants (*j* = 1, 2, …, *n*);

k index for biogas plant types (*k* = 1, …, *l*);

h index referring to the parishes in the region (*h* = 1, …, *p*).

Parameters:

a_j area of site *j*;

d_{ij} road distance (km) between dairy farm *i* and site *j*;

t cost of transportation (€) of 1 m^3 of manure per km;

g_k annual operation and maintenance costs (€/year) for a biogas plant of type *k*;

θ radius (km) from any potential site, of concern to the population due to its proximity to the biogas plant (fixed distance);

r_{hjk} social rejection at parish *h*, if a biogas plant of type *k* is located at site *j*;

p_h population in parish *h*;

a_h area (ha) of parish *h*;

a^{θ} area (ha) of the parish *h* that is contained in the buffer of θ km from site *j*;

Pj^θ number of persons who are at a distance of θ km from site *j*;

s_k social penalty of population according to the type of biogas plant *k*.

LD_k Total loading hours required for processing biomass for facility k

FC^{load} Fuel consumption rate during loading process (l hr^{-1})

EM Weight of CO_2 equivalent emissions generated when consuming 1 liter of diesel (Kg1^1)

GR_k Total grinding hours required for processing biomass for facility *k* (h)

FC^{grind} Fuel consumption rate during grinding process (l hr^{-1})

TRk^{total} Total transportation time for conversion technology *k* (h)

$FC^{transport}$ Fuel consumption rate during transportation (l hr^{-1})

C. Variables:

x_{ij} binary variable: x_{ij} = 1 if a transportation link between dairy farm *i* and site *j* is established; x_{ij} = 0 otherwise. This variable is considered null (parameter) for pairs (*i*, *j*) such that $d_{ij} > d$ (i.e., the model imposes a maximum distance from biogas plants to assigned dairy farms);

q_{ij} real variable: amount of manure to transport daily (m^3) from dairy farm *i* to site *j*. This variable is considered null (parameter) in the same circumstance as x_{ij}.

y_{jk} binary variable: y_{jk} = 1 if a biogas plant of type *k* is lo- cated at site *j*; y_{jk}=0 otherwise. This variable is considered null for pairs (*j*, *k*) such that $a_j < a^{min}$ (i.e., the po- tential location of a plant of type *k* on site *j* is not al- lowed if the area of site *j* is less than that required by a plant of that type).

III. RESULTS

In this section, the potential of biofuels is analyzed. The biomass energy potential can yield sufficient bioenergy to the region[19]. As the region (cattle colony Karachi) has 4000 dairy farms having approximately 175 animals per dairy farm. As the data collected, an average animal wastes 4kg of dung material per day. Therefore, the total animals' i-e 7, 00000 yield 28,00000kg per day animal manure. Moreover, the density of manure is 400kg/m^3. Hence, to process all the manure i-e 2800000kg/day can have the immense 7000m^3 of biomass in volume. According to, Bio Energy Technology Application Pak (BETA Pak) about 6kg of dung can produce 1m^3 of biogas (natural gas). Thus, the cattle colony can have the potential of 466666.6667m^3 of natural gas per day.

Considering the capacity of biomass, it has tremendous potential of developing biogas that can be utilized for further bioenergy production plants. It can be an efficient source of economic clean energy generation, to cut greenhouse gas emissions and to avoid social hazards by establishing best possible plant location and energy conversion technology[20]. The proposed model is applicable by bringing it under the above mentioned mathematical model.

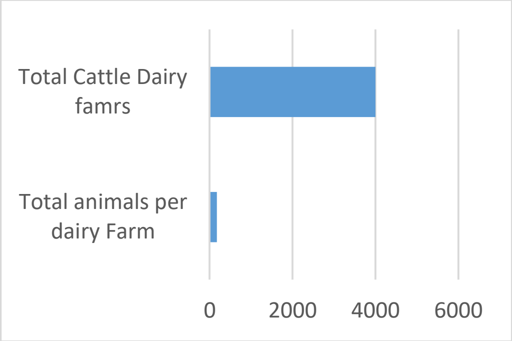

Fig.3 Cattle Dairy Farms in Karachi Cattle colony

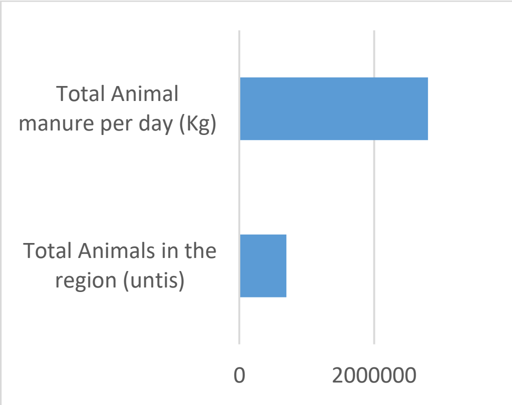

Fig.4 Total Animal Manure per day in the region

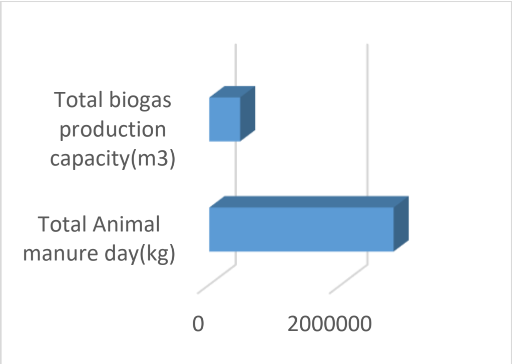

Fig.5 Total Biogas Production Capacity

IV. CONCLUSIONS

A mixed integer linear programming is formulated for the optimal biomass supply chain network. It takes into account the maximum economic profit, to reduce GHG emissions and best possible plant location and purification technology considering the nearby population. A mathematical model is formulated for the maximum outcome of transforming biomass into bioenergy being an efficient alternative of depleting fossil fuels. To show the applicability, the proposed model is developed for the case study of Karachi dairy farms animal dung utilization. It is found that the region has 2800000kg per day animal manure capacity or $7000m^3$ that has the sufficient potential for production of $466666.66667m^3$ of natural gas. Therefore, the biofuels are the energy rich contents to meet the rising energy demands and to produce clean energy requirements.

V. RECOMMENDATIONS

As it is found that Karachi cattle colony has a plethoric amount of biomass waste that can be utilized to generate bioenergy. It is discovered that the region has 4000 total cattle dairy farms comprise of 700000 animals. That has 2800000kg or $7000m^3$ per day animal manure which has the biogas production capacity of $466666.6667m^3$ per day. Therefore, it is found that by locating best possible biogas plants nearby the region can provide huge biogas energy. By converting volume of natural gas from cubic meters into (Metric Million British Thermal Unit) MMBTU, it is necessary to transform it in cubic feet first. Hence,

$466666.6667m^3 \times 35.3147 = 16480193.333ft^3$

Now by getting volume in MMBTU

$16480193.333 \times 0.0012 = 19776.232$MMBTU

As we have 19776.232MMBTU of gas per day. Therefore, the total amount of production of gas per day can yield a handsome potential. Hence, it need of time to install Biogas production plants nearby the Karachi region in order to avoid the mass exploitation of biomass. The utilization of biomass will save much of the depleting fossil fuels, save money, environment friendly and clean energy production requirements.

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