A Future Prospect for Domestic Waste Management in Qatar

Nasser Ayoub[1], Farayi Musharavati[2], and Hossam A.Gabbar[3]

***Abstract*—**Sustainable Waste Management is one of the major challenges that face developing nations, with the mandate to balance between their economic & social development while keeping environmental performance. Qatar, for example, is generating a total of 28,000 tons per day of solid waste, of which only 3% is recycled, 4% is incinerated while the remaining is disposed into landfills. One of the targets of Qatar National Development Strategy, NDS is to raise the recycle share to 38% of solid waste, reducing landfill to 53% and converting waste to energy. Hence, this paper presents a potential view for managing and optimizing domestic waste management that is about 25% of the total generated waste in the country from system prospective. Hence, a detailed methodology for Socio-Technological System, STS, development and operation was presented. The STS is a robust modular system that dynamically changes in response to social activities and deals with the problem from micro and macro details levels. In the proposed STS development methodology, several controllable parameters need to be considered, such as future construction plans, population development, waste collection methods possibilities, generation and recycling business development, strategies for materials use and reuse and so on. Moreover, the STS modularity to deal with the emerging technologies of converting waste to final products as significant fragments was taken care of to be able to adapt new technologies introduced in the future.

***Keywords*—**Qatar, Socio-Technological Systems, Strategies, Waste Management

I. Introduction

WASTE Management is one of the biggest challenges that nations need to deal with in a sustainable manner. The challenge becomes greater for developing nations as there should be a balance between economic & social development and environmental performance. Therefore, it is vital to optimize domestic waste management processes and improve their enactments. In Qatar as well as other Gulf Co-operation Council (GCC) member states the sustainable waste management is one of the hot areas addressed by some governments [1]. Nonetheless, the availability of large areas of deserts makes landfilling the most economic option to treat waste and keeps the other management programs infeasible [2]. This may explain the lack in research work related to waste management in the GCC area, both in technology and control sides. Table 1 shows a summary of the research works published in international journals carried out in the GCC states related to waste management. As seen in Table 1, the research done so far has concentrated on individual processes within the waste management system. None of those regional researches has tackled the issue of waste management from system and decision making view point.

TABLE I
RESEARCH WORKS PUBLISHED IN INTERNATIONAL JOURNALS

Research Topic	Country	Reference	Year
Bio-products (Biogas, Compost)	Qatar, UAE	[3], [4]	2010
Design of landfill liner	Qatar	[5]	2011
MSW characterization	Kuwait	[6]	2014
Collection and transportation cost	Kuwait	[7]	2004
Waste-to-energy	Saudi Arabia, UAE	[8], [4], [9]	2013
Characteristics of landfill leachates and bio-solids	Saudi Arabia	[10]	2001
Recycling	Saudi Arabia, Oman, GCC	[1], [2], [11], [12]	1989, 2004, 2005

Internationally, the waste management research area is very active. However, most of the literatures published in the area are dealing with one face of the problem either it be economic, environmental or technological [13]. Very few studies have tackled the problem of waste management from its entirety to overcome such social and technological burdens. For example, a recent two studies on socio-technical analysis of biogas production and transitions towards sustainability were carried out [14, 15]. The studies took the system analysis part of the system development by identifying the characteristics that can improve biogas production in a local area. They didn't consider providing models or tools to support policy makers to respond to technological and social changes. A more sophisticated system called general Bioenergy Decision System (gBEDS) for bioenergy production planning and implementation was presented by

Nasser Ayoub[1] is with Qatar University, Doha, Qatar, on leave from Helwan University, Cairo, Egypt (e-mail: n.ayoub@qu.edu.qa).

Farayi Musharavati[2], is with the Dept. of Mechanical and Industrial Engineering, Qatar University, Doha, Qatar (corresponding author's phone:00974-5014-8055; e-mail: farayi@qu.edu.qa).

Hossam A.Gabbar[3] is with the Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Ontario, Canada, was with Okayama University, Okayama, Japan (e-mail: Hossam.Gaber@uoit.ca).

http://dx.doi.org/10.15242/IICBE.C1214080

Ayoub *et al* [13]. The gBEDS relied on a robust information base that includes basic and detailed decision information, such as geographical information database, the waste materials' database, the logistics database and the conversion database and was applied to a Japanese case. In section two, the current state of managing wastes in Qatar is presented. Section three shows or prospects on dealing with waste management issue via Socio-Technological systems development. The system development methodology is presented in Section four followed by conclusions and future challenges in Section five.

II. Current State Of Waste Management In Qatar

Qatar is generating a total of 28,000 Tons per day of solid waste, of which only 3% is recycled, 4% is incinerated while the remaining is disposed into landfills. The current recycling portion of household waste and commercial waste are 3% and 1% respectively. The construction & demolition waste generated is about 20,000 tons of which a portion of 4% is recycled. The total domestic waste generated in 2032, excluding the C&D waste, is expected to be about 19,000 tons/day with an annual growth of 4.2% [16]. This comes as a result of the unsustainable growth of the GDP and population of Qatar since year 2000. This trend of increase is expected to continue growing rapidly towards 2022. This extremely upsurge in population number and economic development increases the impact on Qatar's environment that requires plans and policies to address new and emerging national development priorities. One of the targets of the National Development Strategy, NDS, to be achieved by 2016, is to establish a solid waste management plan that strongly emphasizes recycling. The plan aims at raising the recycle share from 8% to 38% of solid waste, reducing landfill to 53% and converting waste to energy. Another target is to contain domestic waste generation at 1.6 kilograms per capita per day [17]. Raising awareness of Qatar's population, on the importance of reducing waste and increasing recycling to the environment sustainable and preserve high quality of life, is another recommendation [17]. In other words, it is a plan to reduce waste, enforce more recycling and encourage more efficient use. The first step taken by Qatar government, to achieve such targets, is the establishment of the Domestic Solid Waste Management Centre (DSWMC) to deal with wastes in a sustainable manner (separation, recycle, bio-energy products). The total cost of the DSWMC is 3.9 Billion QR for design, construction, and operation for 20 years [18]. The DSWMC has 6 main components for incoming waste management, waste to energy, anaerobic digestion & composting plant, energy recovery, engineered solid waste landfill and incinerated bottom ash treatment, and plant facilities. The center is served by five waste transfer stations distributed around the state with a total projected capacity of 4450 tons per day [18]. The current daily capacity of the DSWMC (1557 ton) is less than the domestic waste generated (2500) and the recycled portion is about 1.3% of the total [17]. The Qatar Development Bank has estimated the revenue potential for all solid waste value chains to be about 2.42 BQR. The household waste is accounted for 982 MQR and C&D recycling for 378 MQR based on pricing benchmarks in best in class [16] that shows the high potential of waste management as an emerging market. To meet these challenges a comprehensive environmental management system that aligns the national growth, social changes with environmental limitations to sustain the country's development is required.

III. Future Prospects

There are many forms of potential approaches can be followed to deal with domestic waste such as reducing the amount of waste production through consumption reduction, waste separation from source in addition to waste processing. However, the effect of these methods will remain limited until they are integrated in a complete waste management system. We believe that a robust modular Socio-Technological system, STS, that is altering gradually in response to social activities of people is an ideal solution for this problem as it deals with the problem from micro and macro details levels. For example, when planning for domestic waste management, STS planners have to consider future construction plans, population development, how to collect the wastes (separated or mixed), how many companies are in generation and recycling business, what is the reuse strategy for all types of materials, where are they reused at home or abroad, what kinds of reduction methods, what is the response of the society to system change, and so on. In addition, the planners also consider what kinds of product specifications have to be controlled by the recycle companies. On the other hand, technologies of converting waste to final products continue progressing and as a result several parts of the STS should be modular enough to adapt new technologies introduced in the future. What we mean by the Socio-technological System is explained in details in the next subsection.

A. What is Socio-technological System

Socio-technological systems in the context of this work are the systems that comprise technological, human and managerial mechanisms [21] that interact together and lead to desired or unwanted impacts. The domestic waste management system is a typical socio-technological system that have technological mechanisms (treatment technologies), social (households), and managerial (local laws and regulations). These contrivances need to be harnessed into one robust and sustainable Socio-Technological Systems. Yet, Socio-Technological Systems development is problematic in nature due to its complex and multi-faceted interactions [19]. That results in several environmental, economic, social, and regulatory effects on waste management practices, which complicate local policy analysis as well as global sustainable development [20].

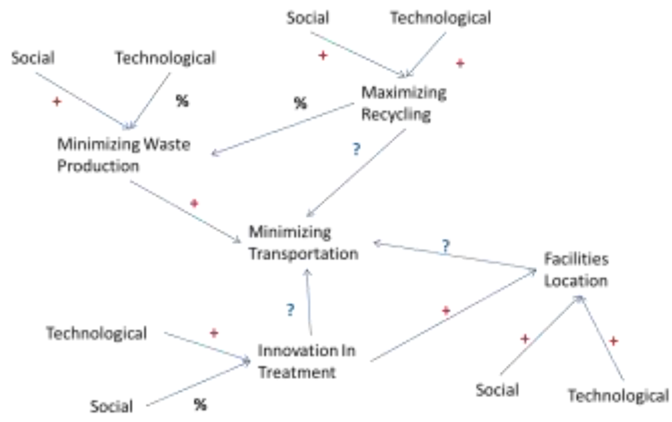

Fig. 1 Schematic representations of the intrinsic relations between waste management schemes

B. Proposed Socio-technological System

As discussed in literature, decisions in waste management era are built on minimizing the transportation of collection vehicles, maximizing the recycling portion, minimizing waste production as well as innovation in waste treatment methods and technologies. Hence, these schemes form the pillars of the proposed system. In building the STS for waste management we have analyzed the intrinsic relations between waste management schemes as well as with social and technological dimension as shown in Fig. 1. The relations are classified as Positive (+), Not Known (?) and Relative (%). For example, maximizing the recycled portion is affected by social dimension (i.e. households, governmental and environmentalists' efforts) and technological dimension where the technological advance can lead to more sophisticated technologies that can be used to increase the recycled portion (i.e. paper board, advanced material treatment). Conversely, the relation between recycling and transportation is Not Known as more recycling can lead to more transportation that need to be assessed by the waste management system. The innovation in producing waste treatment system can affect the location of the facility as smaller and effective facilities can be used more easily than the large scale facilities. For example, smaller size plasma unit can be used in distributed energy supply systems which will consequently lead to help in energy conservation efforts. This relation is only positive for small systems, as the increase in the treatment facility scale may increase constrains, such as an increased transportation.

As seen in Fig. 1, most of the uncertain relations are linked with transportation to or from facilities. Therefore, we have used the Geographical Information System, GIS, as a base to build a responsive waste management system. One of the functions of the GIS is relating the waste quantities data to their generation location. So, it is used in the system to save and visualize the domestic waste data. Using the spatial data in the GIS a location allocation model can be developed by applying clustering methods to identify the feasible locations of waste collection points based on distance using the Qatari addressing system (ENWANY) data developed by the Center of Geographical Information System in Qatar. These waste collection points are further clustered to find the feasible locations of possible waste treatment facilities that need to be established within the waste management system in a specific area depending on production and processing capacities. Once treatment facilities locations are identified, the total costs of management scenarios are evaluated. The scenarios, identified based on social acceptance, should include; the number of collection days, type of waste collection (separation at source or in the central treatment facilities), costs, and technologies used in waste treatment. The evaluation criteria for the scenarios can also include the environmental impacts of applying a specific scenario.

IV. The STS Development Methodology

To achieve the desired outputs from the STS it should be designed to include several modules to support decision making such as simulation module with graph interface and genetic algorithms (GAs) model for optimal decisions. It also included a location allocation module built on data mining methods to calculate the location of storage and conversion plants. The proposed STS architecture is as Fig. 2. The environmental performance is considered in the STS via calculating CO_2 emissions over the predefined material supply chains. The STS should consider a multi-input and multi-output waste treatment system. Hence, a superclass model for domestic waste need to be built to relate waste resources to their products, available processes, and possible future processes of utilization, then the optimization models are used to find the optimal treatment option from the viewpoint of cost and environment. The system presented by Ayoub et al, can be extended to Qatar waste management case while taking into account the clear difference in social, economic and technological aspects of the waste management system between Qatar and Japan.

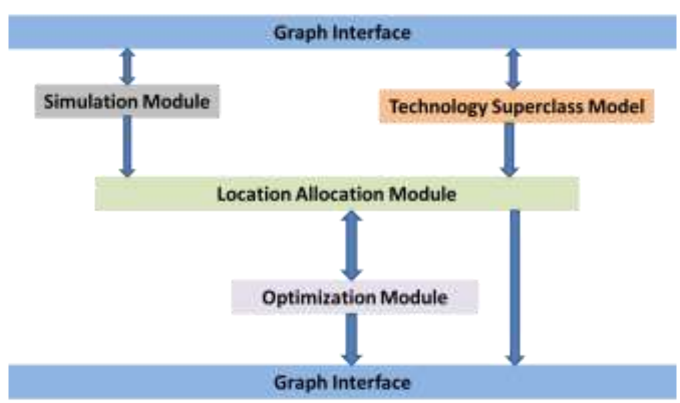

Fig. 2 Socio-technological system architecture

The methodology of the socio-technological waste management system development presented here has three key phases. These research phases are explained in the following subsections.

Phase 1: Data collection about the current waste management situation in a representative area to identify its controllable factors, weak points and possible improvement.

Review the related literature about the possible systems that can be applied. The current waste management system and its practices should be outlined. Hence, the AS-Is model to project the current should be built in this phase. The following steps have to be carried out to complete this phase:

- Identifying the waste collection method in the target area (controllable factor).
- Defining the different contents of the domestic waste produced by the citizens in the area under study and their potential quantities (controllable factor).
- Pinpointing the current waste treatment methods.
- Finding the current waste management regulations (controllable factor).
- Identifying the current waste collection method in the target area.
- Future residential houses construction plans and population development in the area understudy.
- Reviewing related work in the international literature as well as market development.
- Identifying the waste collection methods possibilities in the country.
- Revising the national business development prospective and plans for materials use and reuse
- Build the As-Is Model for the current waste management system in the target area.

Phase 2: The main task here is analyzing the collected data and building the To Be Models for the future household waste management systems. Hence, more representative and suitable systems is identified through applying the following steps:

- Explain the current system's strengths and weakness based on evaluation criteria (Economic, Environmental, social etc.)
- Build questionnaires and use them in data collection.
- Analyze the questionnaires to identify the social aspects of the current and future systems (Satisfaction, willingness to follow new rules, suggestions, etc.)
- Build the To-Be Model for potential system(s) and explain its merits and possible demerits.
- Plan the possible application scenarios and the number of required collection, separation, and treatment (recycling, biological processing, etc.) facilities.

Phase 3: This is the final part of the system design cycle (data collection, data analysis, system proposal and system application). Fig. 3 shows a schematic representation of the optimization techniques carried out in this research work and applied as follows:

- The addresses data points are associated to the quantities of waste produced in the four zones produced.
- The selected clustering method is applied to identify the locations of the collection and separation units if an intermediate processing is suggested in the As-Is Model. If this is not the case the spatial data is clustered to the predefined number of treatment facilities. The clustering methods used in this research optimize the location based on distances between current location of the waste and the cluster center.
- Using the resulted locations, proposed management scenarios, processing technologies, the economic and environmental performance of the waste management system is optimized.
- The optimal locations, costs and emissions are mapped and visualized using zones map on the Geographical Information System software.

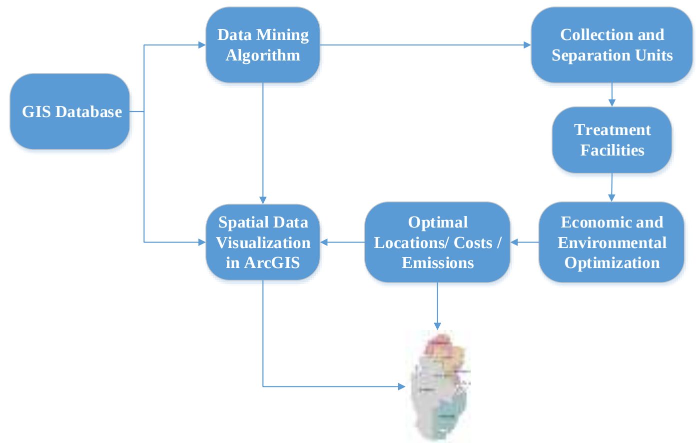

Fig. 3 The optimization Modules in the proposed system

V. Conclusions

Sustainable domestic waste management encompasses complicated and multidimensional interaction among large number of technological choices, economic mechanisms, and control frameworks. To deal with this issue in Qatar, the current state of waste management and future prospects for the country is presented in this paper. A small portion of the generated waste is recycled or incinerated. The annual growth rate of domestic waste generation is growing in an unsustainable manner in the last 15 years an expected to continue in the same trend towards 2022. A robust modular Socio-Technological System is presented. An analysis of intrinsic relations between waste management schemes as well as with social and technological dimension is made to clarify the uncertain relations and, hence, deal with them. The GIS is used to relate the waste quantities data to their generation location and building a location allocation model using the Qatari addressing system using data mining methods to calculate the location of storage and conversion plants. In addition, STS includes several modules support decision making such as simulation module with graph interface and genetic algorithms (GAs) model for optimal decisions. The environmental performance is considered in the STS via calculating CO2 emissions over the predefined material supply chains. The STS development also contains building a multi-input and multi-output superclass model for domestic waste treatment processes. The model relate waste resources to their products, available processes, and possible future processes of utilization, then the optimization models are used to find the optimal treatment option from the

http://dx.doi.org/10.15242/IICBE.C1214080

viewpoint of cost and environment. This shows the significance of the proposed research that, we think, will set the ground for future advancement in management of all waste types.

ACKNOWLEDGMENT

We would like to thank the Center for Geographic Information Systems, Qatar, CGIS, for providing the GIS Database used in this study.

REFERENCES

[1] J. M. Alhumoud, I. Al-Ghusain, and H. Al-Hasawi, "Management of recycling in the Gulf Co-operation Council states," Waste Management, vol. 24, pp. 551-562, // 2004.

[2] J. M. Alhumoud, "Municipal solid waste recycling in the Gulf Co-operation Council states," Resources, Conservation and Recycling, vol. 45, pp. 142-158, 10// 2005.

[3] H. Abu Qdais, K. Bani Hani, and N. Shatnawi, "Modeling and optimization of biogas production from a waste digester using artificial neural network and genetic algorithm," Resources, Conservation and Recycling, vol. 54, pp. 359-363, 4// 2010.

[4] H. A. Arafat and K. Jijakli, "Modeling and comparative assessment of municipal solid waste gasification for energy production," Waste Management, vol. 33, pp. 1704-1713, 8// 2013.

[5] H. T. Eid, "Shear strength of geosynthetic composite systems for design of landfill liner and cover slopes," Geotextiles and Geomembranes, vol. 29, pp. 335-344, 6// 2011.

[6] R. Al-Jarallah and E. Aleisa, "A baseline study characterizing the municipal solid waste in the State of Kuwait," Waste Management.

[7] P. A. Koushki, U. Al-Duaij, and W. Al-Ghimlas, "Collection and transportation cost of household solid waste in Kuwait," Waste Management, vol. 24, pp. 957-964, // 2004.

[8] O. K. M. Ouda, H. M. Cekirge, and S. A. R. Raza, "An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia," Energy Conversion and Management, vol. 75, pp. 402-406, 11// 2013.

[9] H. A. Arafat, K. Jijakli, and A. Ahsan, "Environmental performance and energy recovery potential of five processes for municipal solid waste treatment," Journal of Cleaner Production.

[10] M. I. Al-Wabel, W. S. Al Yehya, A. S. Al-Farraj, and S. E. El-Maghraby, "Characteristics of landfill leachates and bio-solids of municipal solid waste (MSW) in Riyadh City, Saudi Arabia," Journal of the Saudi Society of Agricultural Sciences, vol. 10, pp. 65-70, 6// 2011.

[11] M. Z. A. Khan and F. A. Burney, "Forecasting solid waste composition — An important consideration in resource recovery and recycling," Resources, Conservation and Recycling, vol. 3, pp. 1-17, 11// 1989.

[12] R. Taha, A. Al-Rawas, K. Al-Jabri, A. Al-Harthy, H. Hassan, and S. Al-Oraimi, "An overview of waste materials recycling in the Sultanate of Oman," Resources, Conservation and Recycling, vol. 41, pp. 293-306, 7// 2004.

[13] N. Ayoub, R. Martins, K. Wang, H. Seki, and Y. Naka, "Two levels decision system for efficient planning and implementation of bioenergy production," Energy Conversion and Management, vol. 48, pp. 709-723, 3// 2007.

[14] L. Olsson and M. Fallde, "Waste(d) potential: a socio-technical analysis of biogas production and use in Sweden," Journal of Cleaner Production.

[15] M. Fallde and M. Eklund, "Towards a sustainable socio-technical system of biogas for transport: the case of the city of Linköping in Sweden," Journal of Cleaner Production.

[16] T. O. (QDB), "Qatar: Solid Waste Managemen- Phase 1 Assessment," in Waste Statistics Training Workshop, Doha, 2013.

[17] M. S. B. M. Al–Muhannadi, "Developing The Waste Management Sectors," in Waste Statistics Training Workshop, Doha, 2013.

[18] S. Ng, "Managing and Monitoring National Development Strategy 2011-2016 Outcomes & Qatar National Vision 2030 Goals, Reduced waste, more recycling and more efficient use," in Waste Statistics Training Workshop, Doha, 2013.

[19] N. Ayoub and N. Yuji, "Demand-driven optimization approach for biomass utilization networks," Computers & Chemical Engineering, vol. 36, pp. 129-139, 1/10/ 2012.

[20] A. Pires, G. Martinho, and N.-B. Chang, "Solid waste management in European countries: A review of systems analysis techniques," Journal of Environmental Management, vol. 92, pp. 1033-1050, 4// 2011.

Nasser Ayoub is a Tenured Associate Professor in the Production Technology Department, Faculty of Industrial Education, Helwan University, Egypt. Currently he is a Researcher in the Mechanical and Industrial Engineering Department, The Collage of Engineering, Qatar University. Ph.D. (Environmental Engineering), Tokyo Institute of Technology (Japan), M.Sc. (Engineering Materials), Eindhoven University of Technology, (The Netherlands). B.Sc. (Industrial Engineering), Production and Industrial Engineering Department, Zagazig University, (Egypt). Research Associate (2007~2010) Tokyo Institute of Technology.

Dr. Ayoub is specialized in systems development, waste management, renewable energies and their applications. Has worked in several international projects in Japan in the area of biomass supply chains and networks, life cycle assessment and environmental policy making, and in Qatar he is working, on energy conservation in buildings.

Farayi Musharavati is an Assistant Professor in the Department of Mechanical and Industrial Engineering, College of Engineering at Qatar University. He obtained his PhD in manufacturing Systems in 2008. His research interests include: simulation modelling and optimization, sustainable engineering, cleaner production, waste management, energy conservation and management, energy efficiency and optimization as well as applications of computational intelligence. He has participated in a number of projects funded by Qatar Foundation. Dr. Musharavati is the author of more than 30 publications; including books, book chapters, and journal papers, in the broad areas of production systems as well as simulation modelling and optimization.

Hossam A. Gabbar is the director of the Energy Safety and Control Lab (ESCL), The Faculty of Energy Systems and Nuclear Science, and cross appointed in the Faculty of Engineering and Applied Science, University of Ontario Institute of Technology (UOIT). He is also adjunct professor in McMaster University (2010~). Ph.D. (Safety Engineering), Okayama University (Japan), B.Sc. (Automatic Control), Alexandria University, Egypt. Specialized in safety and control engineering and their applications on smart grid, energy, power, and process systems. Tenured Associate Professor (2004~2008), the Division of Industrial Innovation Sciences at Okayama University, Japan. Research Associate (2001~2004) Tokyo Institute of Technology, Japan. Participated in national projects green energy and smart grid systems. Leading projects in risk-based smart grid design, protection, and control, and hybrid energy supply systems.

He is a Senior Member of IEEE, the founder of SMC Chapter - Hiroshima Section, the founder and chair of the technical committee on Intelligent Green Production Systems (IGPS), and Editor-in-chief of International Journal of Process Systems Engineering (IJPSE), president of RAMS Society, and editorial board of the technical committee on System of Systems and Soft Computing (IEEE SMCS). He is founding general chair of IEEE Smart Grid Engineering Conference, invited speaker in several Universities and international events, and PC / chair / co-chair of several international conferences. Dr. Gabbar is the author of more than 160 publications, including books, book chapters, patent, and papers in the area of safety and control engineering for smart grid and hybrid green energy and production systems.