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Renewable Energy Policy Evaluation Using A System Dynamics Approach: The Case of Oman

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Abstract: *Oman is as richly endowed with renewable energy sources as it is with hydrocarbons. Over the last decade, the country has been experiencing a gradual shift towards exploring renewable energy resources as a driving force for diversifying the national economy away from fossil fuels. Both public and private sectors have implemented a number of pilot projects for promoting RETs in Oman. The lessons gained from different demonstration of RET projects reveal that with a careful forward planning, renewable energy can provide far-reaching economic, environmental and social benefits to Omani people. This paper presents the progress of a current study being undertaken to quantify these benefits by exploring the impact of a large-scale renewable energy development in Oman on the three domains of sustainability: economic, environmental and social. The analysis in this paper is informed by system dynamics approach that allows providing a systemic account for the impacts of renewable energy development in Oman. This paper seeks to support the national policy makers in their on-going attempts to integrate RETs in Omani power sector through national planning and policies.*

Keywords: Renewable energy; policy evaluation; developing country; Oman, system dynamics; hydrocarbon-rich economies.

1. Introduction

The recent debate over securing national energy supplies combined with the negative impacts of anthropogenic climate change has attracted the attention of policy makers and researchers towards finding strategic ways to manage the transitions towards new domestic energy sources with low carbon footprints such as renewable energy. The Middle East and North African (MENA) countries, as is the case for many countries, are no exception. The MENA region is known to hold more than half of the world's proven crude oil and more than a third of its natural gas reserves (BP, 2014). Since their discovery over the last sixty years, revenues sourced by oil and gas exports have continued to generate significant economic wealth in the regional countries. For instance, in 2013, hydrocarbon export revenues in Oman accounted for 86 per cent of total export sales, 90 per cent in Saudi Arabia, 50 – 60 per cent in Iran, 50 per cent in Kuwait, 60 per cent in Qatar, and 80 per cent in the UAE (EIA, 2013).

Abundance of domestic energy supplies and low costs of these supplies have increased the domestic energy demand to drive the socio-economic developments associated with fast population growth, massive growth in intensive-energy industrialization programmes, urbanization, rapid demand for transportation, increasing standards of living, and increasing demands for water desalination and power generation. These surging pressures on domestic energy supplies have created unprecedented challenges to the energy sector in the MENA countries including energy insecurity and climate insecurity. Regarding the former, natural gas import has become a phenomenon even in some major energy producing countries like Arab States of the Gulf (GCC) which currently meet 10% of their energy demand from imports (BP, 2013). Regarding the latter, the GCC's per capita carbon footprint has grown dramatically since 1960s. According to World Resource Institute, GCC's per capita CO_2 emissions were the highest in the world in 2007 (WRI, 2011). In Qatar, for example, per capita emissions were almost 11 times the global average and 2.5 times the US average (EIA, 2013). Thus, the development of new energy sources with lower carbon footprints such as renewable energy has become inevitable in this region.

In recognition of the overall long-term energy security and sustainability implications of current economic reliance on hydrocarbon exports, some governments around the MENA region have embarked on a policy of economic diversification. Although renewables can play a major role to enhance economic diversification away from hydrocarbons, only a mere 2% of gross regionally primary energy consumption is sourced from renewable energy sources in this region (El-Katiri, 2014). That is despite the fact that more than 45% of the world's renewable energy potential exists in the MENA region (JALILVAND, 2012). This paper aims to address the potential role of renewable energy to enhance economic diversification and sustainability implications by exploring the potential advantages of renewable energy deployment on three domains of sustainability including environment, society and economy as identified by Brundtland (1987).

Research on the development, and implication of renewable energy in the MENA countries is continuously growing (AER, 2008; Al-Karaghouli, 2007; Al-mulali, 2011a, 2011b; Alawaji, 2001; Anagreh & Bataineh, 2011; Bataineh & Dalalah, 2013; Bilen et al., 2008; Chiu & Chang, 2009; El Fadel, Rachid, El-Samra, Bou Boutros, & Hashisho, 2013; Ghorashi & Rahimi, 2011; Nalan, Murat, & Nuri, 2009). One of the key challenges facing many of the regional countries is lack of structured tool to aid a systemic account of energy policy evaluation and planning. The only recognised tools that have been attempted to aid energy planning in MENA countries are LEAP (El Fadel et al., 2013), E3MLab (Fragkos, Kouvaritakis, & Capros, 2013), Panel Data Analysis model (Al-mulali, 2011b; Arouri, Youssef, M'henni, & Rault, 2012), and energy supply modelling (Deichmann, Meisner, Murray, & Wheeler, 2011).

While some of these models are capable of giving valuable insights into analysis of energy demand and supply in an *economy*, they are however, not able to account for thy dynamics relating to *society* and the *environment,* since they are largely based on a static economic modelling approach. Thus, the main contribution of this paper is to apply system dynamics approach in order to provide a systemic account for renewable energy policy analysis. System dynamic approach allows system behaviour exploration of the effects of renewable energy development in MENA countries by simulating the complex relationships between renewable energy development and social, environmental and economic sectors. In this paper, a number of selected energy policy analysis indicators were used in order to explore the performance of these three sectors. These are GDP growth, employment, energy demand, air emission and costs of renewable energy technology production. The findings in this paper aim to inform energy planning and renewable energy policy evaluation in Oman, the case example in this paper.

2. The case of renewable energy development in Oman

The case example for this paper assessment is the deployment of renewable energy technologies in Oman. Oman, like its neighbouring countries, is 'hydrocarbon-rich' country with proven oil reserves stood at 5.5 thousand million barrels at the end of 2013 and 33.5 trillion cubic feet of natural gas at the end of the same year (BP, 2014). To date, Oman's economy continues to rely on oil and gas export revenues which accounted for more than 80% of the country's gross export revenues in 2012 (Omanet.om). Oil and gas export revenues continue to form the backbone of Oman's economy. Their contribution to the government's GDP has relatively raised from 41.9% in 1991 to exceed 50% in 2011 (NCSI, 2012). Figure 1 illustrates the relative share of different economic sectors in Oman's total GDP in 2011, wherein the agricultural, fishing, and manufacturing sectors' contribution, for example, together does not exceed 20% (NCSI, 2012).

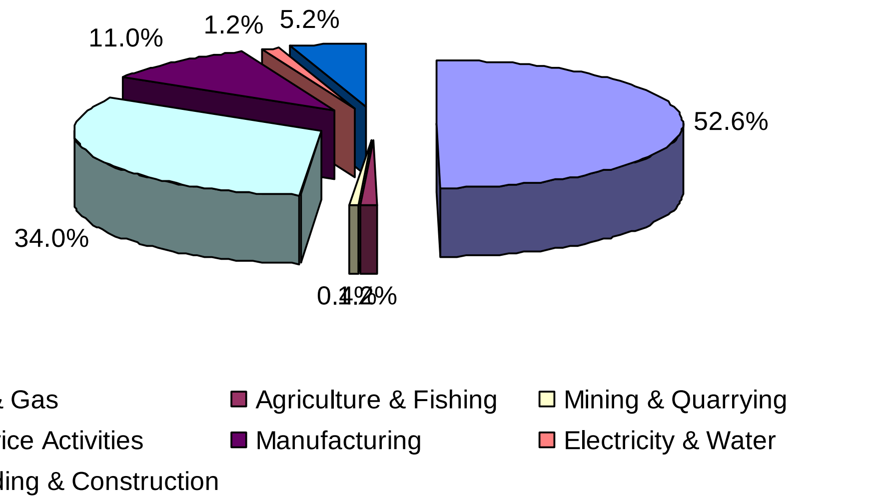

Figure 1 Economic sectors' share to Oman's GDP in 2011, sourced from (Statistical Year Book 2012)

At present, in Oman domestic resources of oil and gas meet almost all of the local energy service demands, including industrial, transportation, and power and water generation. In 2012, more than 70% of total gas production was used locally to meet the domestic energy demands of industrial projects, electricity and water production, and oil fields for Enhanced oil Recovery with total share of 60.5%, 19%, and 18.4%, respectively. Meanwhile, the total domestic consumption of oil did not exceed 15%, as the rest feeds in the country's exports (NCSI, 2012).

Due to the continuous growth of population and the general economic development in the country, the pressure over the domestic gas consumption over the last years has incredibly increased. Over the past decade, the total domestic gas demand doubled from 574 billion Standard cubic feet in 2000 to 1,228 billion Standard cubic feet in 2011. For example, the power sector, which provides electrical services including lightening, heating, cooling, and the use of electrically powered appliances for residential, commercial, industrial, governmental, agricultural and fishery, tourism sectors along with the Ministry of Defence, showed a corresponding increase in natural gas consumption from 104.4 billion Scf in 2000 to 229 billion Scf in 2011 (AER, 2011).

Currently, natural gas accounts for almost over 97% of total fuel-mix used to fire power plants around the country, whereas small amount of electricity is generated from diesel to supply off-grid rural areas (AER, 2011), Figure 2. There is currently no renewable energy source deployed into the electricity supply mix other than the current on-going pilot projects to test the efficiency of renewable energy technologies within the context of Omani environmental conditions. The current total installed capacity of renewable energy pilot projects is estimated at 9.0 MW (Author's estimation).

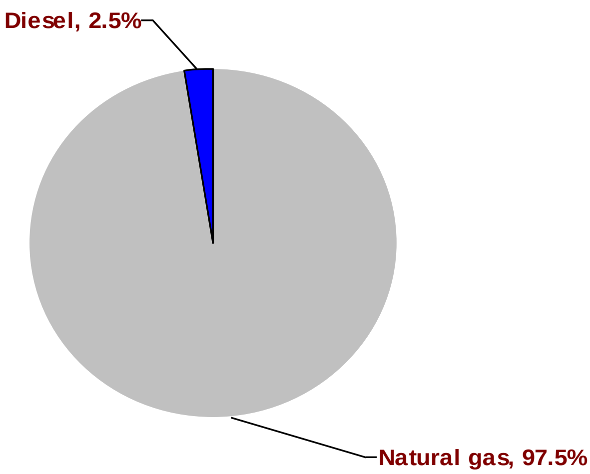

Figure 2 Electricity supply mix in Oman in 2011 (AER, 2011).

Currently there is a limit use of renewable energy technologies in Oman. However, photovoltaics are already used as a technology of choice in a range of applications like in few telecommunication installations where they are used to provide air conditioning for keeping sensitive components within safe temperature limits, navigation aids, cathodic protection, and lights and fans in small installations (Buckley & Holmes, 2000). They are also used for heating water in tanks located on roofs at some private houses, generation of electricity by photovoltaic cells is used for powering street lights, public phones, water pumping system for drinking and irrigation purposes, parking meters, cathodic protection system and microwave and television transmitter station (Al-Badi, Malik, Al-Areimi, & Al-Mamari, 2009).

Under distinct visions, there exist pilot projects, undertaken by several institutions at different sectors, with the aim to test the performance of renewable energy technologies under the local weather and environmental conditions. For instance, Petroleum Development Oman Company, the predominant state-own oil company in the country, has recently completed a construction of a 7MW solar CSP Enhanced Oil Recovery (EOR) project to produce low-cost, 50 ton emission-free steam to be fed directly into PDO's Amal West oilfield in Southern Oman with the purpose of reducing the amount of natural gas burned for thermal EOR[1]. Another recently launched key government-led project is a 303 kilowatts (KW) solar project at rural area of Al Mazyonah in Dhofar Governorate, comprising 151.5 KW of thin film PV modules and 151.5KW of poly-crystalline technology. Next in line project has been already approved by RAECO is a 500KW wind-based pilot project to be based in a rural island of Masirah (Al Harthy, 2013).

3. Modelling methodology

The models were developed using system dynamics methodology. System dynamics is a methodology, originally developed by Jay Forrester and his colleagues at MIT in 1950s. Computer simulation models are used to develop models that enable better understanding of complex systems and their dynamic behaviour under a given set of conditions or scenarios so that to avoid potential negative consequences or prepare for them (Ford, 2009; Forrester, 1996; Sterman, 2000). In this methodology, the dynamic behaviour of the system is assumed to be a result of interconnected web of feedback loops. Feedback loops are illustration of connection between variables, which define a system under question, with causal links. They are of two types: positive (also known as reinforcing) and negative (also known as balancing). Positive feedback loops enhance or amplify the feedback of information. Negative feedback loops are goal seeking and tend to resist change in the system.

Before conducting system dynamic modelling methodology, this research involved a consultation of energy stakeholders in Oman through semi-structured interviews. In total, 18 personal interviews were conducted during a seven weeks visit to Oman in spring 2014. Representatives from three different sectors including academia, government and private sector informed the identification of barriers that challenge the expansion of renewable energy use in Oman; drivers that could possibly promote the use of renewables in Oman as well as identifying measures that could aid overcoming barriers. After a thorough qualitative analysis for renewable energy barriers, motivations and measures

[1] For more information, see GlassPoint website: http://www.glasspoint.com/solar-eor-projects/petroleum-development-oman/

during an early stage of this research (October 2013 to July 2014), the system dynamic methodology was found to be a useful approach for building an integrated dynamic model, which when combined with stakeholders qualitative research analysis, would provide an inclusive approach for a formal, computer-based modelling approach to help understanding the dynamics of the complex interaction of renewable energy development in Oman with three domains of sustainability namely, environment, society and economy.

3.1 Data collection

Along with stakeholders' engagement in identifying renewable energy barriers, motivations and measures, data were collected from different secondary sources including governmental electronic database, assessment studies, accessible country profile, and journal articles, EIA reports in order to provide specific data on the country. In order to demonstrate the construction of simulation equations, data like population and GDP; technology costs including production, operation and maintenance, tariff price, energy data such as electricity production, capacities, demand, and resources import and export were sought to be extracted from above secondary sources.

3.2 Model boundary

The overall conceptual framework that informed the development of the model structure was informed by the consultation of energy stakeholders in Oman. Semi-structured interviews with energy stakeholders enabled us to identify a set of variables that can influence renewable energy policy choices in Oman. These variables are national energy security, local air quality, economic growth, job creation, GHG emissions, saving gas for export, and country's reputation (Figure 3). These variables provided indigenous insights of the important variables that influence the policy choices that have a potential role on promoting the deployment of renewable energy technologies under the modelling question, and hence definition of appropriate modelling boundaries.

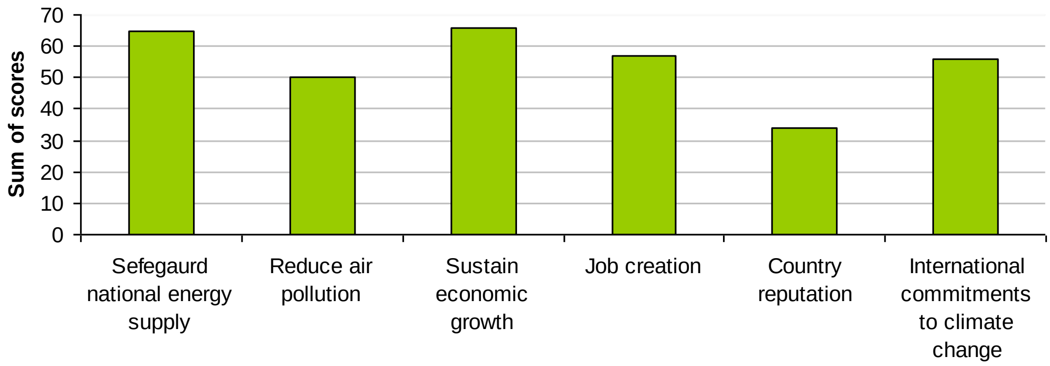

Figure 3 Rank of motivational criteria that can promote renewable energy uptake in Oman, stakeholders' perspectives.

Departing from the stakeholders' identification of important criteria against which renewable energy policy can be evaluated, a broad conceptual framework that informs building the overall structure of the model has been built (Figure4). In this framework, the identified criteria have been classified to undergo under three main sectors: economic, environmental and social sector. Energy security and economic growth criteria, for example, undergo under the economic sector. This, in turn, interacts with another two sectors: social and environmental sectors. Under the social sector, job creation is considered as the main criterion that represents this sector. The environmental sector considers both air quality and GHG emissions for further assessment. These criteria will be used as indicators to evaluate the potential impact associated with renewable energy development in Oman.

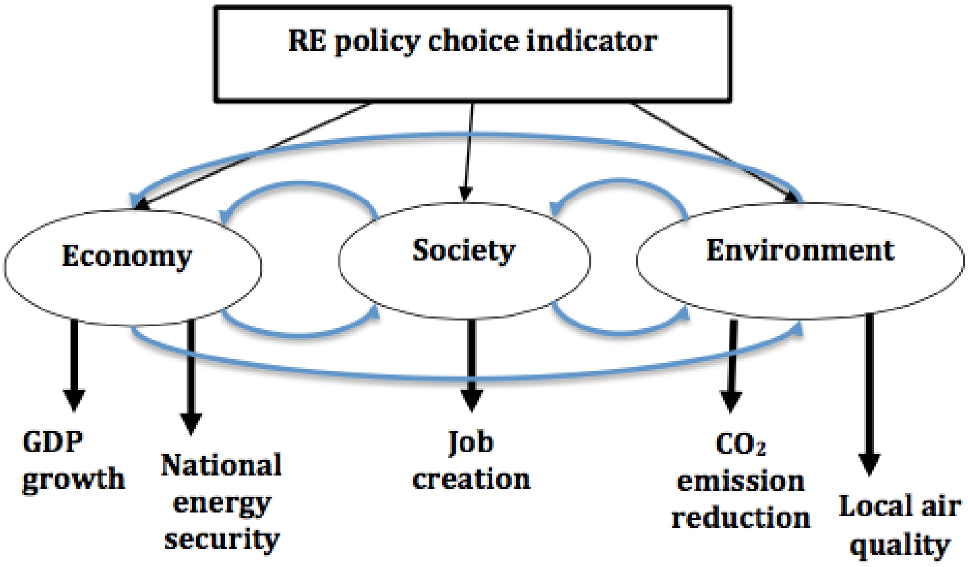

Figure 4 A broad conceptual framework to inform renewable energy policy evaluation in Oman.

3.3 Model dynamic hypothesis

Departing from the criteria identified by interviewees (Figure 4) along with secondary data sources including governmental electronic database, assessment studies, accessible country profile, and journal articles, EIA, World Bank, IMF, BP, and in order to ensure developing a holistic framework depicting the interrelation between the variables under study, a high level mapping for the interaction between Omani energy system and economic, social, environmental and political sector has been prepared (Figure 5).

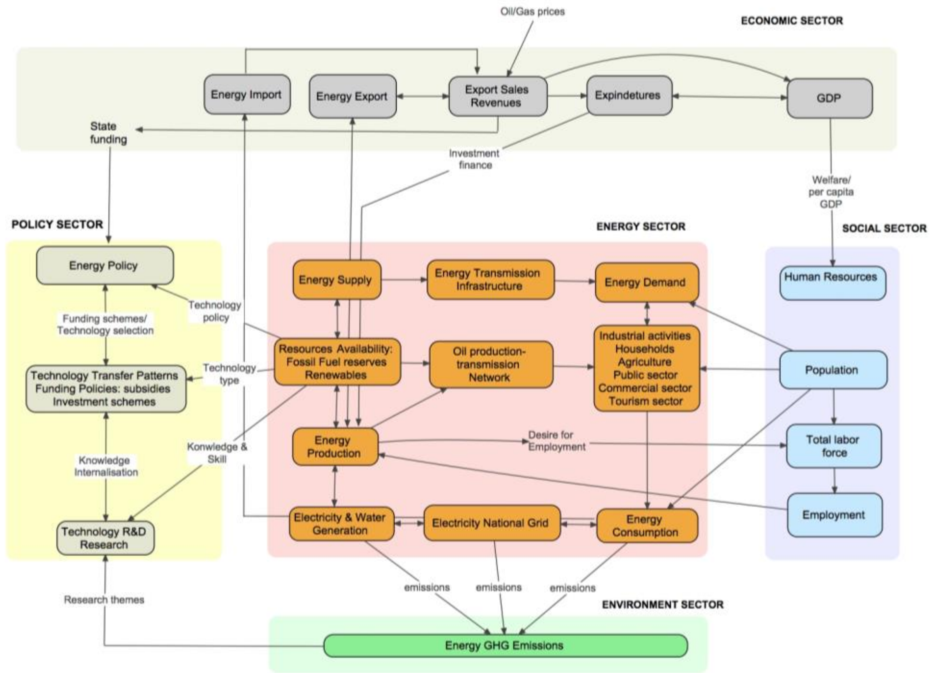

Figure 5 High level mapping for Oman's energy system: A dynamic hypothesis to inform renewable energy policy evaluation in Oman.

Figure 5 offers an endogenous explanation of the structure and processes that formulate the current behaviour of Omani energy system, and hence the diffusion of energy technologies. The model seeks to provide insights on the possible behaviour of the system due the use of selected policy instruments that are proposed to promote the deployment of renewable energy technologies in Oman, and hence to measure the non-linear feedback associated with selected policy instruments. Thus, arrows illustrate the main feedback loops that depict the main flows of information and interactions between economic, environmental, social, energy and policy sectors. For instance, there is a strong interaction between the energy production and GDP: the more energy production is, the more energy exports are, the highest the revenues are from the sales of exports, and the higher the contribution to the national GDP. In return, the increase in GDP leads to increase in state expenditures like in energy production, through investment in innovative technologies, to generate more revenues. This feature is particularly specific for the Middle Eastern countries, including Oman, wherein the current economies are highly reliant on the available resources of fossil fuel. Hence, this model allows observing the behavioural change in the overall system as a result of renewable energy technology deployment. Thus, insights to policy-makers to make appropriate decisions with regards to renewable energy investments can be generated.

3.4 Conceptualising feedback system models

In order to simplify the simulation of energy planning and policy evaluation in Oman, an overall feedback system model that includes all the important feedback loops was produced (Figure 6). Based on Figure 5, the variables that influence the dynamics of the problem are included and presented.

The main assumption of the overall causal loop diagram in Figure 6 is that increasing share of renewable energy installed capacity, decreases the share of natural gas installed capacity in which the total installed capacity remains constant over modelling time. Thus, the causal loop (R1) represents the interaction between the installed capacity of renewable energy and natural gas fuel. Meantime, the causal loop in the right (R4) shows that the larger the investments aimed to increase the renewable energy capacity, the larger electricity production from renewables and hence renewable energy profitability while causal loop on the left (R2) suggests that the larger the investments aimed to increase fossil fuel-based capacity, the larger electricity production from conventional sources and hence fossil fuel-based profitability.

In order to simplify reading the causal loop diagram in Figure 6, the three model sectors are illustrated in green, red, and blue to represent environmental, social and economic sub-models consequently. Environmental sub-model is represented by one reinforcing loop (R5); social sub-model is represented by two reinforcing loops (R6 and R7); and the economic sub-model is represented by two reinforcing loops (R2 and R3) and two balancing loops (B1 and B2).

Each sub-model will be explained in details in the following section.

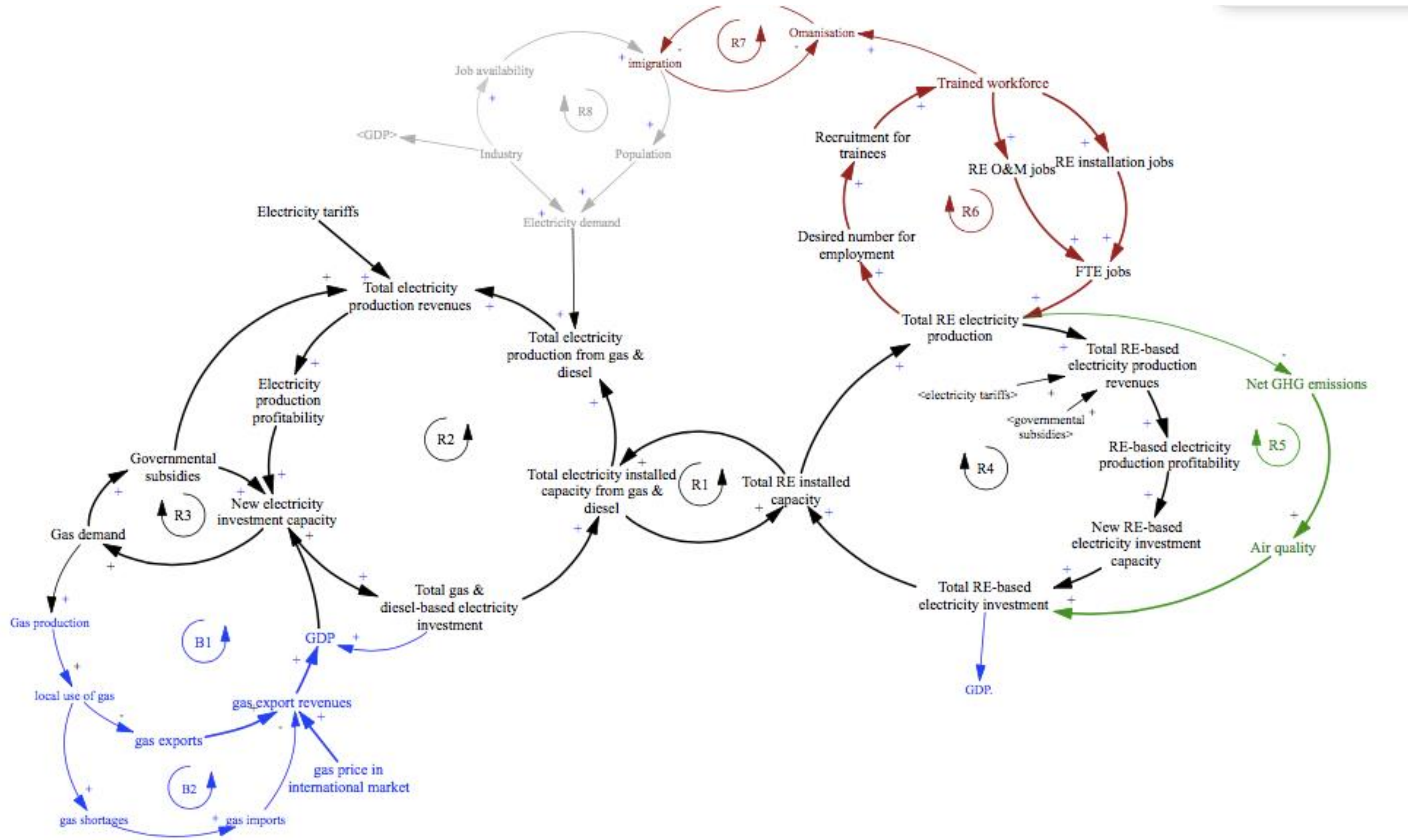

Figure 6 representation of important feedback loops that represent the dynamic behaviour of Omani energy system.

3.4.1 Economic sector

The economic sub-model is informed by the fact that Omani economy continues to rely heavily on oil and gas export revenues. In 2012, the oil export revenues accounted for 73% and gas export revenues accounted for 11.8% of total governmental export revenues (NCSI, 2012). Although gas export revenues depends highly on the gas price in the international market, the fluctuation in revenues as a result in changes in gas price will not be explored here as it goes beyond the scope of this study.

At present, apart from being flared, natural gas is used domestically to fuel power and water production, industrial projects, and oil fields to enhance oil recovery. Figure 6 shows that the total domestic consumption of natural gas has been doubled over the last decade between 2000 and 2011. Figure 7 changes in natural gas consumption by activity in Oman, 2000 and 2011 (AER, 2011).

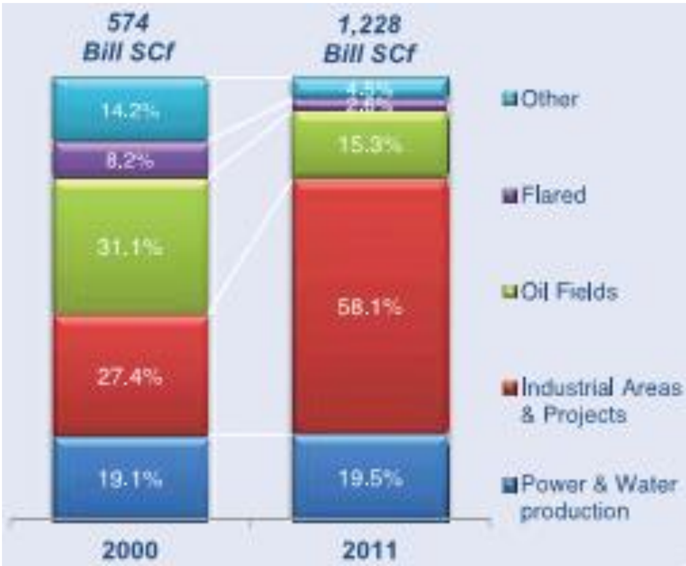

Figure 7 changes in natural gas consumption by activity in Oman, 2000 and 2011 (AER, 2011)

Therefore, the assumption of the economic sub-model is that if the domestic consumption continues to grow without undertaking any measures to diversify domestic supply sources; the losses in Oman's gas export revenues would grow substantially. In fact, in 2007 Oman began to import natural gas from Qatar via Dolphin Pipeline providing approximately 200 million cubic feet per day to meet additional requirements of natural gas (EIA, 2012), and that accounted for 8.3% of the country's own daily production (Bachellerie, 2012; EIA, 2012) and 10% of country's total gas consumption (El-Katiri, 2013). To this end, the economic sub-model presented by Figure 7 tests the following hypothesis:

> "Renewable energy can play a role in diversifying domestic supply of energy and, hence enhance the country's economic wealth"

Thus, the economic sub-model consists of three reinforcing loops (R1) and two balancing loops (B1 and B2). From Figure 8, reinforcing loop (R2) shows that increasing in gas-based electricity investments leads to an increase in domestic gas demand (R3), which, while driving up the domestic gas production, it reduces gas export amounts and hence gas export revenues and its share in GDP (B1). Also, balancing loop (B2) shows as domestic consumption of natural gas increase, gas shortages increase that in turn decreases gas export revenues.

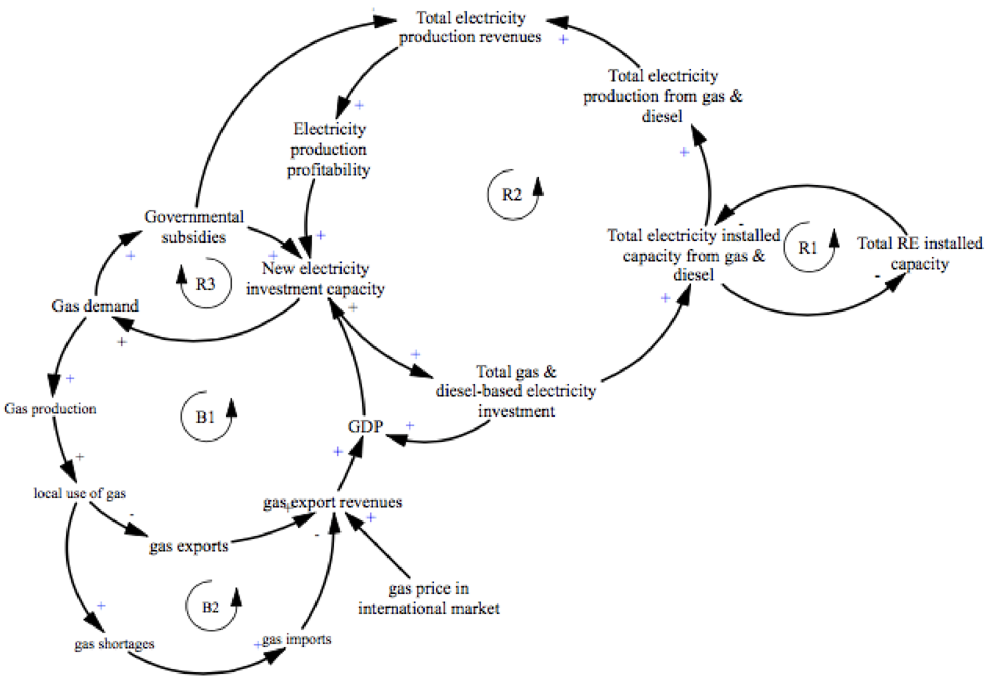

Figure 8 Economic sub-model, impact of renewable energy in Oman.

Reinforcing loop R1 illustrates that as renewable energy installed capacity increases, gas-based electricity installed capacity decreases and this leads to reverse the aforementioned assumption. In other words, investments in gas-based electricity will decrease, thus demand for domestic gas decreases and this leads to allocate produced gas to exports, and hence increase in export revenues.

3.4.2 Social sub-model

In 1995, Oman developed a long-term development strategy (Vision 2020), which overarches the objective of diversifying the economy away from oil in parallel with generating employment opportunities for nationals. Out of Oman's today's population of 4.1 million, no more than 56% are nationals. Crucial to this was repositioning private sector as an engine of economic growth and diversification. To this end, the social sub-model, shown in Figure 8, tests the following hypothesis:

> "Renewable energy investments can drive economic growth in parallel with generating employment opportunities for nationals"

The social sub-model is represented in Figure 9. It consists of four reinforcing loops (R1, R4, R6 and R7). In order to avoid repetition, reinforcing loop R1 will not be explained as it was explained earlier in section 3.4.1. The reinforcing loop R6 suggests that increasing in renewable energy production leads to increasing the requirement of desired employment which in turn increases the training opportunities. As a result, the number of trained workforce increases both for installation and operation and maintenance, which leads to increasing in the renewable energy production. The fourth reinforcing loop R7 indicates that increasing in the trained workforce leads to increase in Omanisation opportunities, and hence a decrease in the number of workforce immigrants. In Oman, the Omanisation programme has been in operation since 1988, working toward replacing expatriates with trained Omani Personnel2. Some companies in the private sector are stipulated to meet a fixed Omanisation target. Thus, reinforcing loop R7 suggests feeding in the governmental policy.

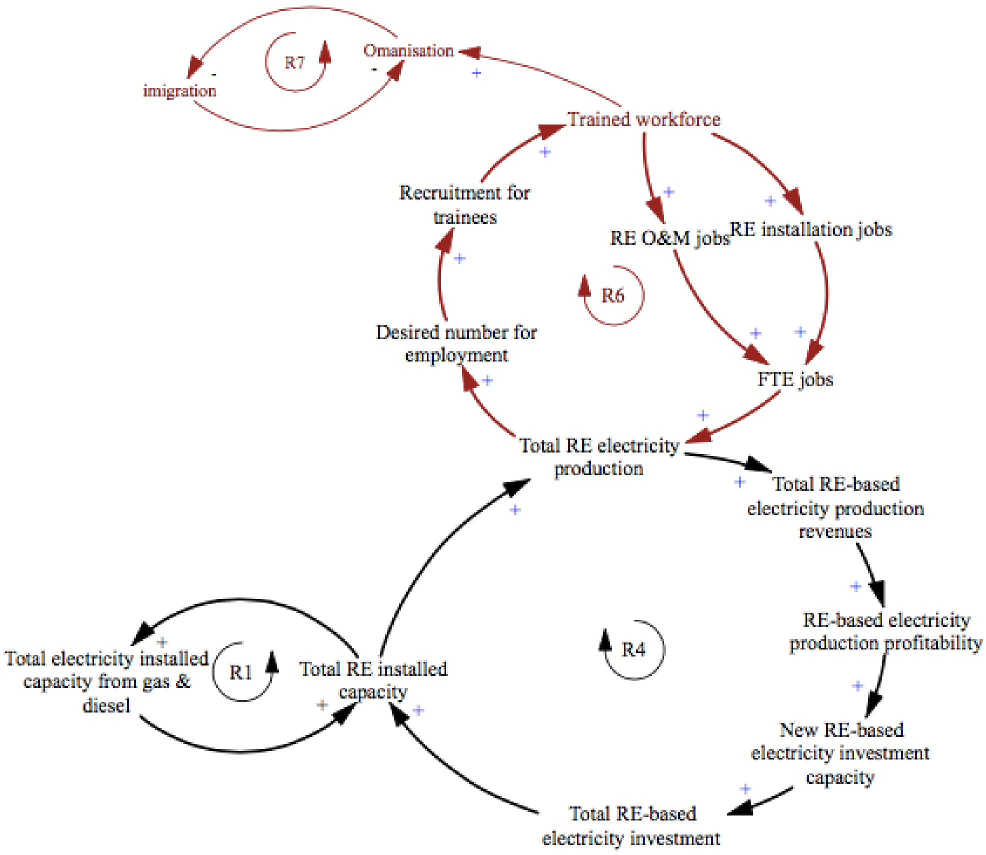

Figure 9 social sub-model, impact of renewable energy in Oman.

3.4.3 Environment sub-model

Oman's emissions are projected to continue to grow by almost 8 per cent a year (World Bank, 2013). Electricity generation, for instance, was the major source of carbon emissions associated with fossil fuel combustion in 2001 and, accounted for more than 60 per cent. Due to the accelerated pace towards industrialisation in the country, industrial activities re now responsible for over a third of Oman's total carbon pollution, thereby making it the largest source of carbon emissions in 2011. Transport and other sectors including 'fugitive' emissions together contribute for around 15 per cent in 2011 (Figure 10).

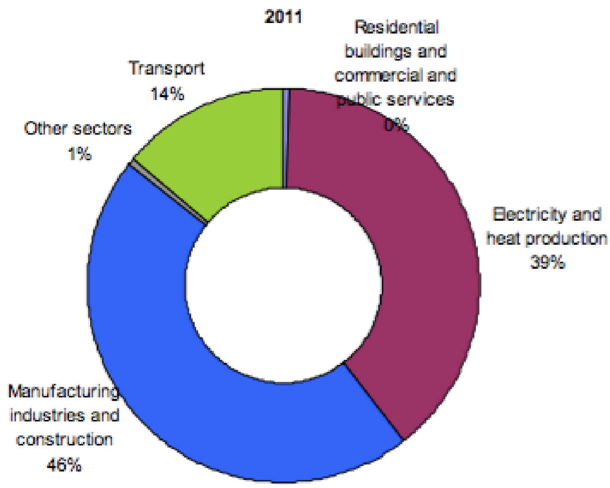

Figure 10 Sectors' contribution to Oman's total CO_2 emissions in 2011. Source: World Bank Development Indicators (WDI).

Therefore, the hypothesis that underlies the environmental sub-model is:

> "Renewable energy investments in Oman can contribute in reducing the carbon emissions associated with fossil fuel-based energy combustion"

The environmental sub-model! Is represented in Figure 11. It consists of two reinforcing loops (R4 and R5). The first reinforcing loop R4 suggests that increasing in renewable energy investment leads to an increase in renewable energy production, which drives up the investment revenues, and hence the annual profitability. The second reinforcing loop R5 shows that an increase in renewable energy production leads to a decrease in the net GHG emissions sourced by the power sector. In turn, the reductions of GHG emissions enhance the ambient air quality in the local environment and consequently drive further investments in renewable energy.

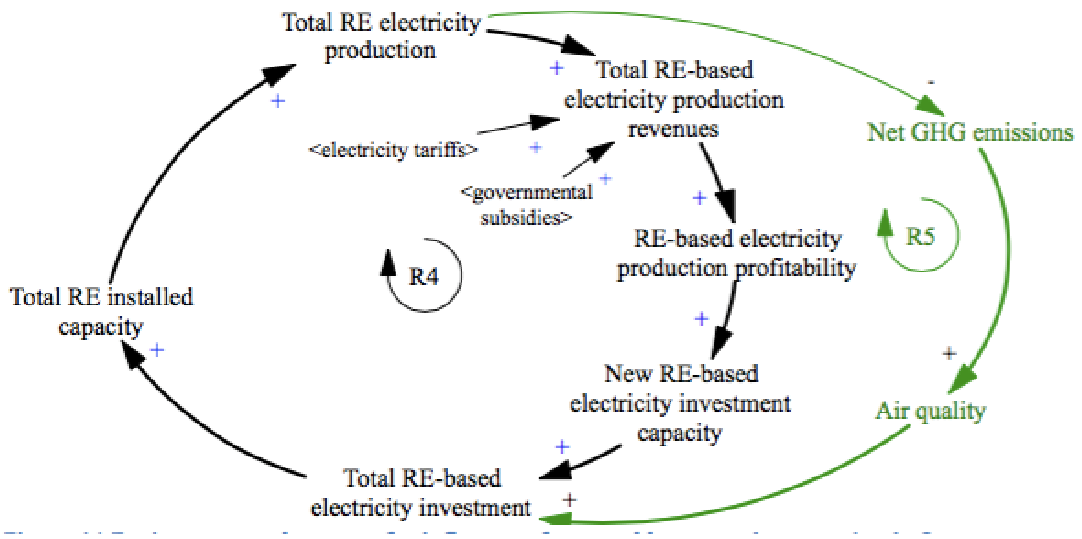

Figure 11 Environmental sub-system to measure the potential impact of renewable energy intervention on CO_2 emissions in Oman.

4. Summary and next steps

This paper, though a work on progress, has set out the theoretical and methodological basis for informing renewable energy policy evaluation in Oman using a system dynamics approach. This has been achieved by developing causal loop diagrams based on data collected from stakeholders' interviews in Oman as well as secondary data sources including governmental electronic database, assessment studies, accessible country profile, journal articles, and EIA, World Bank electronic database. At this stage, three sub-models have been developed; economic, social and environmental sub-models. Economic growth, job creation, and carbon emissions are the main policy choice indicators that have been used to depict each sub-model.

The argument of this paper is that the system dynamic approach contributes to provide a richer analytical basis for the development of energy policy evaluation tool than was the case for previous work on modelling energy planning in the Middle East and North African countries. This paper's approach incorporates interaction between economic, environmental and social sectors, which allows a systemic account for renewable energy policy analysis, and hence informing policy-makers. It also combines system dynamics modelling with qualitative analysis of challenges and opportunities for renewable energy development, which, in turn, provides an inclusive understanding of energy system in Oman.

The next stage of this research will involve a build of stock-and-flow diagrams for each causal loop diagram developed in this paper making the model ready for simulation. These models will be run under different renewable energy integration scenarios of 30%, 50% and 100% consumption of available renewable energy potentials in Oman, particularly wind and solar. According to AER (2008) study, the maximum potential for wind energy in Oman is 750MW and around 420MW for solar PV technology. The output models will be calibrated and validated against 15 years time series data (2000-2015).

The aforementioned step will then be followed by testing different renewable energy policy intervention scenarios to evaluate the impact of these policies on selected policy indicators identified by interviewed policy-makers, namely, energy security, economic growth, air quality and job creation. Renewable energy subsidies, continuity in fossil fuel subsidies and feed in tariff will be examined through a different energy policy scenario. The emerging policy options will be used to inform recommendations for policy makers.

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