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Research paper

Strategic pathways and regulatory choices for effective GHG reduction in hydrocarbon based economy: Case of Oman

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ABSTRACT

The sultanate of Oman is a high-income country with economy dominated by hydrocarbon production accounting for 47.2% of GDP in 2014. Of the total, crude oil production contributed 43.8% to GDP while natural gas output accounted for contributed 3.4% of economic output. The sustained economic growth, urban sprawl and industrialization have maintained a continuous rising in energy demand. The consumption of oil and natural gas has doubled and tripled respectively, over the last decade. The diversification of the economy faces concerns about future energy security as conventional fossil fuel resources dwindle and its young population continues to grow rapidly. Oman faces the challenge of harmonizing its aspirations for rapid economic growth with a pressing need to address low-carbon, climate-resilient development. Internationally, Oman has voluntarily agreed to reduce GHG emissions 2% by 2030. The diversifications of the economy away from hydrocarbons requires an ambitious plan to diversify Oman's energy mix while driving economic growth and technological innovation. Specifically, this paper focuses on providing an objective strategic pathways and regulatory choices that can serve as a starting point for policy makers when discussing how best to achieve GHG emission reductions in Oman. This study intentionally focus on the energy sector, the sector responsible for the largest share of GHG emissions in Oman.

1. Introduction

Addressing climate change mitigation in developing countries with oil based economy poses complex challenges of cost, policy and economic security. Another set of challenges is rooted in difficulties on addressing climate change risks, disasters, and resilience and adaptation pathways. The sultanate of Oman is a member of the countries of the Gulf Cooperation Council (GCC), which holds 40% of the wold's proven oil reserves and 24% of the wold proven gas reserves. The economy of GCC countries is built since six decades on the extraction and sales of these resources. In 2015, GCC countries were ranked in the top 15 countries with highest emission of CO_2 per Capita (World Bank, 2017). Few academic studies have been published about transition to low carbon economy in each GCC countries individually. Most of the published work are about the GCC as a geopolitical entity and suggesting some common recommendations (Raouf, 2008; Qader, 2009; Loumi, 2014; Al Sarihi, 2018). Four of the GCC countries, namely Saudi Arabia, Kuwait, Qatar and UAE are members of the Organization of the Petroleum Exporting Countries (OPEC). In the OPEC energy, consumption has increased by 685% from 1970 to 2010, while the CO_2 emissions increased by 440% because of fossil fuels burning, during the same period. The Current GHG emission of the OPEC is around 7.02% from the global total emission in 2013. In general, OPEC countries have been reluctant to accept binding targets, due to financial security and economic stability. Greenhouse gas emissions from developing countries will likely surpass those from developed countries within the first half of this century, highlighting the need for developing country efforts to reduce the risk of climate change. While developing nations have been reluctant to accept binding emissions targets, asking that richer nations take action first, many are undertaking efforts that have significantly reduced the growth of their own greenhouse gas emissions. Some of attempts to document the climate mitigation resulting from using IPCC software done for six key countries (Brazil, China, India, Mexico, South Africa, and Turkey) and to inform policy-making aimed at further mitigation in these and other developing nations. The six countries examined in the study reflect significant regional, economic, demographic, and energy resource diversity. However, there is a global consideration of the climate change effects, individual countries have undertaken different steps in climate change mitigation, which is obvious given the extended negotiations towards the ratification of the Kyoto Protocol. For example, the EU and individual Member States have

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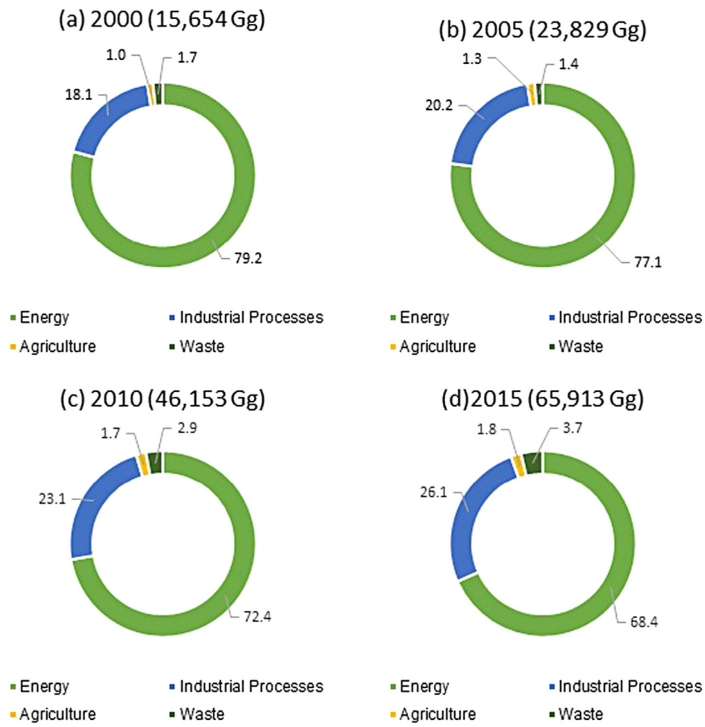

Fig. 1. Shares of Oman's GHG emissions, (a) 2000, (b) 2005, (c) 2010 and (d) 2015.

undertaken several commitments and directed several policies towards the reduction of their emissions.

The sultanate of Oman is a high-income country with economy dominated by hydrocarbon production accounting for 47.2% of GDP in 2014. Of the total, crude oil production contributed 43.8% to GDP while natural gas output accounted for contributed 3.4% of economic output. The average daily production of crude oil has increased gradually from 710,000 bpd in 2007 to 945,000 bpd in 2014. This rebound is due mainly to enhanced oil recovery techniques. The services sector, lead non-oil GDP, accounting for 40.7% of total economic activity, tailed by industry with 18.1%, and agriculture and fishing with 1.3%. Over the past years, the industrial sector has become an essential contributor to GDP, and significant heavy industries have been developed, such as steel, aluminium and petrochemicals (National Statistics Report, 2016).

The sustained economic growth, urban sprawl and industrialization have maintained a continuous rising in energy demand. The consumption of oil and natural gas has doubled and tripled respectively, over the last decade. The power sector has also witnessed a steady growth in line with GDP. The electric power generation is profoundly dependent on natural gas, which accounts for 97.5% and 2.5% for diesel. The power peak demand is projected to raise at about 9% per year, from 5122 MW to 9530 MW in 2021. Energy use is projected to grow from 25 TWh in 2014 to 47 TWh in 2021. The increase in the new home starts and the ongoing public investment in infrastructure projects are the main factors that influences the high growth in the electric power demand (AER , 2016).

Climate change with other multiple stressors poses a serious risks to economy, natural environment and security. The effects of climate change vary across different parts and sectors of Oman. Sectors such, water resources, agriculture, fisheries, tourism infrastructure and urban areas are all sensitive to the adverse effects of climate change. The pivotal role of hydrocarbon makes Oman's economy vulnerable to climate change mitigation. Oman faces the challenge of harmonizing its aspirations for rapid economic growth with a pressing need to address low-carbon, climate-resilient development. In response, it has undertaken domestic efforts to better understand ways to reduce its greenhouse gas emissions. Internationally, Oman has voluntarily agreed to reduce GHG emissions by 2% by 2030 (Ministry of Environment and Climate Affairs, 2015). This pledge requires a set of policies that are reconciled with projected macroeconomic trends. Oman has initiates long term strategies for economic diversification. The vision 2020 and vision 2040. The vision 2020 sets ambitious plans to reduce the impact of oil sector on the economy, mainly based on renewable energy, which highly efficient and integrated with world economy. Al-Mawali et al. (2016), founds that the vision 2020, which started in 1995, does not succeed to achieve their targets and the economy of Oman is still far from being diversified.

Oman understands the need to transition to a low carbon future that reflects new thinking, new frameworks, and new methods. The transition will also need to find practical ways to promote clean energy initiatives, facilitate access to new low-carbon technologies, and develop long-term partnerships to exploit sustainable energy opportunities. Through such actions, Oman seeks to reflect its solidarity with the international community, as well as its long-term commitment to promote greenhouse gas mitigation in a carbon-constrained world.

The main objective of this paper is to provide an objective strategic pathways and regulatory choices, that can serve as a starting point for policy makers when discussing how best to achieve GHG emission reductions in Oman. Therefore, analysis performed in this study greatly focus on the energy sector, since this sector is responsible for the largest share of GHG emissions in the country. This paper is divided in five sections. The first two sections of the paper provide analysis on sectorial GHG emission that was done using IPCC methodology and software of 2006 and GHG projection trend to 2030. Section three of the paper presents details on the primary energy supply and demand. Section four addresses the effective pathways for GHG abatement in Oman, while Section 5 cover the discussions and finally conclusions.

2. Methodology

This paper seeks to analyse and define strategic pathways and regulatory choices for effective GHG reduction in Oman. Three approaches were used to achieve the pragmatic goal of the paper:

- Intergovernmental Panel on Climate Change (IPCC) Software, 2006 was used for the inventory of GHG emission in Oman between 2000 and 2015 (IPCC, 2017). The IPCC inventory Software, 2006 is an international agreed methodology and harmonized standards for the calculation and reporting of National GHG emission and removals for the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2017). The IPCC Inventory Software implements the simplest Tier 1 methods in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. In July 2017, IPCC task force on Greenhouse gas emission realize version 2.54 of the Software which implements Tier 2 methods in the 2006 IPCC Guidelines for most categories under Energy, Industrial Processes and Product Use (IPPU), and Waste Sectors (IPCC, 2017). The IPCC Tier concept is categorized in three different Tiers, according to the quantity of information required, and the level of analytical complexity. IPCC Tier 1 employs defaults emissions factors provided by IPCC guideline, 2006. IPCC Tier 2, applies emissions factors specific to the country. IPCC Tier 3, requires detailed emissions models, measurement and data from Continuous Emissions Monitoring Systems (CEMS). For this paper, IPCC Tier 1 was used form the inventory of GHG emission of Oman.
- A secondary analysis for the existing data was conducted to obtain a fast and robust scene about the energy demand and supply in Oman from 2000 to 2015. Moreover, information about energy efficiency and renewable energy was compiled to examine the factors associated with GHG reduction.
- In addition to secondary analysis, a series of targeted meetings with different stakeholders (Ministry of Environment and Climate Affairs, Ministry of Energy and Public Authority for water and energy, supreme council of planning etc.) were conducted and discussed on possible streamlines that would help the country to enterprise transition to low carbon economy.

3. Sectorial GHG emission trend and projection

Fig. 1 illustrates the shares of total GHG emissions by sector for the years of 2000. 2005, 2010 and 2015. Energy-related activities accounted for the dominant portion of GHG emissions followed by Industrial processes activities. The share of the GHG emission resulting from energy dropped significantly from 79.1% in 2000 to 68.4% in 2015. While, the contribution of the industrial processes to the total GHG emission in Oman has increased steadily from 18.1% in 2000 to 26.1% in 2015.

GHG emission levels have been steadily growing in Oman. Over the period 2000 to 2015, GHG emissions grew at the rate of 10% per year — from 15.654 Gg to about 65,913 Gg. It is important to note that GHG emissions have been growing at a rate significantly above the population growth rate (4.2%/year) and the GDP growth rate (8.9%/year) over the 2000–2015 period (World Bank, 2017). This indicates that Oman's economy has become more carbon intensive, increasing from 0.8 to 0.95 kg CO2 per dollar of output. This was roughly 2.9 times the world average in 2015 (Oak Ridge National Laboratory, 2017). At the same time, the population's consumption patterns are becoming also more carbon intensive, increasing from 6.9 to about 15.7 tonnes CO2-equivalent per person per year. Fig. 2, shows that Oman's GHG emission is projected to reach 94,524 Gg by 2030 and the country is determinates to reduce 1890 Gg from the last year's projection (Ministry of Environment and Climate Affairs, 2015). Given the important role of energy in Oman's GHG emission profile, mitigation pathways focus exclusively on energy and industrial activities.

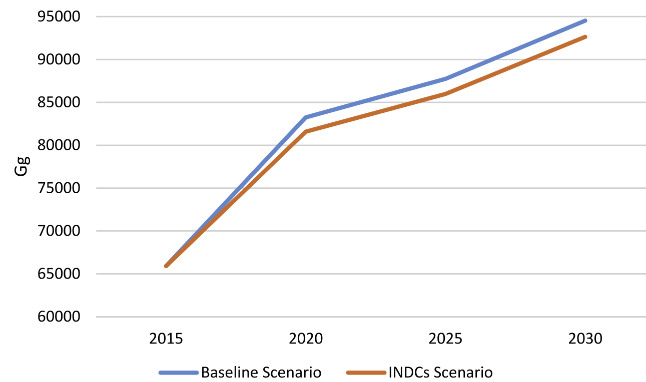

Fig. 2. Oman's GHG emission trends as baseline and INDCs scenarios.

4. Energy supply and demand

Oman's production of oil and natural gas plays an important in the national economy. In 2015, crude oil extraction operations accounted for 49,274 kTOE, most of which was exported — 42,183 kTOE, or 86% of total domestic supply (IEA , 2017). Most of the remaining oil that is consumed in Oman converted into refined oil products – diesel, gasoline, and jet kerosene – for use in the transport sector. Natural gas production shows far different characteristics, with extraction of 28,270 kTOE, most of which is consumed within Oman 19,461 kTOE, or 69% of total domestic supply for power generation and industrial applications (i.e., smelters, refineries).

Fig. 3, shows that from the early 1970s to the present day, total primary energy supply has relied exclusively on diesel oil and natural gas (IEA , 2017). There are no coal, biofuel/waste, renewable, or nuclear resources used in Oman. Total energy supply has grown rapidly between 2000 and 2015, from 7.57 to 25.4 kTOE, or 8.4% per year. Most of this growth is attributed to increasing shares of natural gas in the energy system 2000 to 2015 (IEA , 2017). Currently, there are fourteen (14) power stations in Oman, comprised of open cycle gas turbines and combined cycle units for the co-production of water and desalinated water. Electricity production from these units is dominated by natural gas at over 97%. Fig. 4 and Fig. 5 shows the trend of consumption of Natural Gas and Diesel for electricity generation in Oman between 2000 and 2015 (AER , 2016).

Transmission and distributed losses have declined from 20.8 in 2015 to 9.6% over the period 2000–2015. Total net electricity consumption has increased rapidly during this period, from 6,832 GWh in 2000 to 28,912 GWh in 2015, or 10% per year. Highest growth has been in the industrial sector average 19,4% per year, followed by commercial and public services and residential sector with an annual of 10% and 8.7% respectively (Fig. 6)

Fig. 7, shows trends in the consumption of refined oil products from 2000 to 2015 (IEA , 2017). Gasoline, diesel, and heavy fuel dominated consumption from 2000 through 2004 (2015). Since then, heavy fuel oil has been replaced entirely by natural gas. The transport sector has grown in prominence, accounting in recent years for the highest share of refined oil use, averaging over 70%.

5. Effective pathways for GHG abatement

5.1. Decarbonization of electricity generation

Major renewable energy resources in Oman consist of solar and wind. The total solar energy resources in Oman are huge and could, in theory, fully meet all domestic electricity demands and be available for export as well. High solar energy densities are

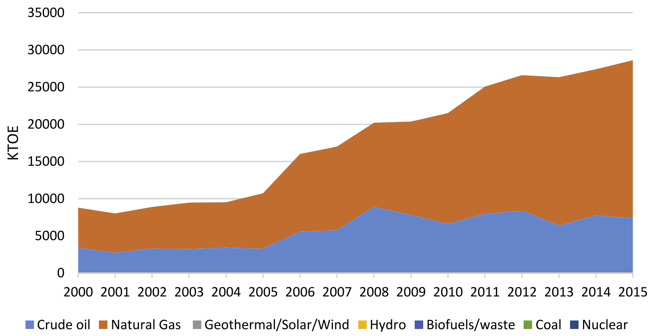

Fig. 3. Energy supply (IEA, 2017).

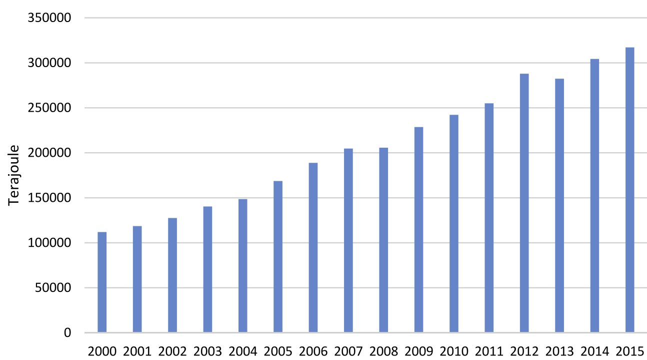

Fig. 4. Natural Gas (Terajoule) consumption for Electricity Generation in Oman (AER, 2016).

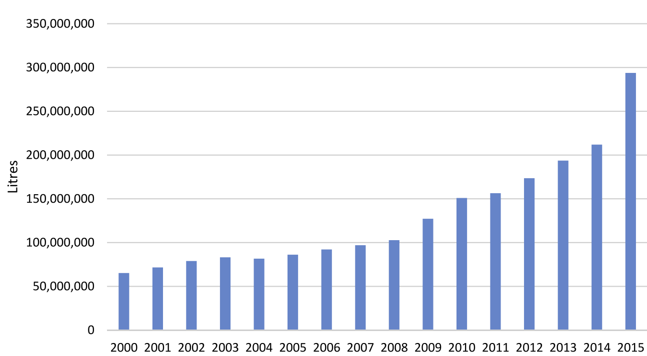

Fig. 5. Diesel consumption (Litres) for Electricity generation Oman (AER, 2016).

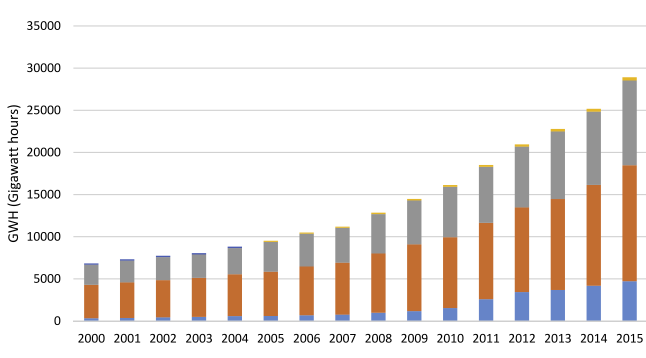

Fig. 6. Electricity consumption by sector in Oman (IEA, 2017).

available in all regions of Oman, ranging from 4.5 to 6.1 kWh/m^2 per day which are some of the highest in the world. The global average daily sunshine duration and solar radiation values for 25

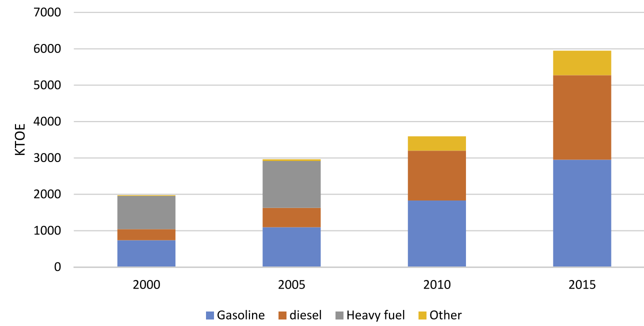

Fig. 7. Consumption of refined oil products (IEA, 2017).

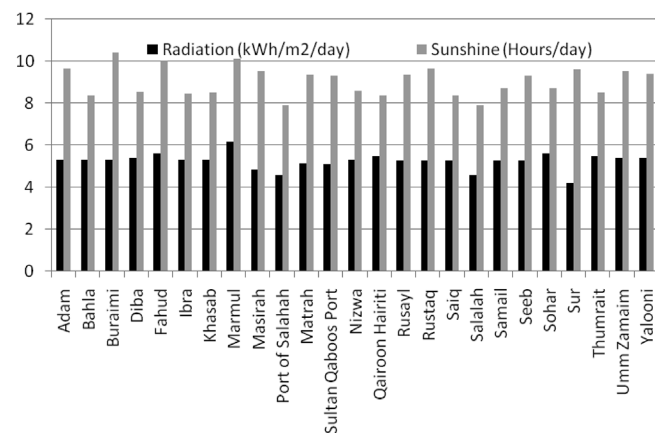

Fig. 8. Global sunshine duration and solar radiation values for 25 meteorological stations in Oman (Al-Badi et al., 2011).

locations in Oman are shown in Fig. 8. The highest solar energy density is found in dessert areas and the lowest are in coastal areas in the south. Photovoltaic and concentrating solar power (CSP) technologies are highly applicable (Authority for Electricity Regulation, 2008; Gastli and Charabi, 2010; Al-Badi et al., 2011; Charabi and Gastli, 2011).

The sultanate of Oman boasts a long coastline that is exposed to strong summer and winter monsoon winds. Average wind speeds are slightly over 5 m/s with an estimated 2463 h of full load per year, making wind power a plentiful resource in Oman (Fig. 9). Several locations are suitable for wind power development, namely locations at Thumrait, Masirah, Joba, Sur and Quiroon Hariti. At the Thumrait and Qayroon Hyriti sites alone, 750 MW of wind power is economically viable, conservatively capable of generating 2300 GWh, or about 7% of Oman's gross electricity production in 2015 (Al-Yahyai et al., 2010).

If Oman's major renewable resources were to be gradually exploited and integrated into the electricity system, the carbon intensity of electricity generation could be significantly decreased. At present, there is no significant penetration of technologies that can exploit these renewable resources such as centralized solar photovoltaics or wind turbine farms. The introduction of even modest amounts of renewable generation could readily achieve Oman's voluntary target to reduce GHG emissions by 2% by 2030.

5.2. *Energy efficiency & conservation*

There is ample scope for improving the efficiency by which energy is consumed in Oman, together with opportunities for conservation. Initial screening has shown that several types of measures in the industrial, commercial, governmental, and residential sectors have great potential in Oman for reducing energy

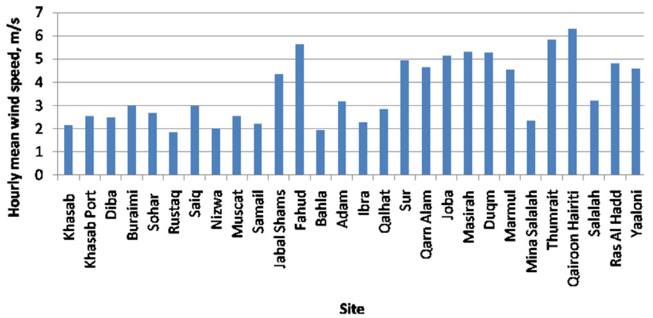

Fig. 9. Hourly measured mean wind speed at 10 m above ground level at 28 meteorological stations (Al-Yahyai et al., 2010).

use. These measures are identified in Table 1, which also indicates their potential penetration level and a feasible rate of improvement (JICA , 2013). The bullets below briefly describe each measure.

- Energy management system: This is a system that calls for energy auditing and integrated management of all energy consuming equipment at large buildings, factories, and other facilities across the industrial, commercial, and government sectors. Participating sites develop an energy efficiency plan and submit periodic reports that track the progress in the implementation of energy efficient devices for all energy end uses.
- Labelling systems: Energy rating labels provide consumers with information on the energy efficiency of a product. There are two main types of labels — comparison labels, which allow consumers to compare the energy consumption of similar products and endorsement labels which offer a seal of approval (e.g., Energy Star). These are relevant for lighting in the commercial and governmental sectors, and for lighting, air conditioning, and refrigeration in the residential sector.
- Building codes: A building code (also building control or building regulations) is a set of rules that specify the standards for constructed objects such as buildings and non-building structures. These codes regulate the design and construction of structures when adopted into law. They are applicable to building design (e.g., insulation) for industrial, commercial, and governmental sectors, and for air conditions for the residential sector.
- Smart meters: A smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system. While they are applicable to all sectors, they have only been considered to be applicable to the residential sector for the period of the assessment.

An analysis of the potential of these measures for reducing electricity consumption shows that the measures can lead to significant savings (JICA , 2013). Each of the measures was considered within a scenario analysis framework for the period 2010 to 2035 that assumes the same historical fuel mix for electricity generation. An overview of the approach is described in the bullets below.

- Baseline scenario: In this scenario, electricity consumption reaches about 60,000 GWh by 2035 from about 28,912 GWh in 2015, or an average growth rate of 3.7% per year. There is no significant penetration of energy efficiency equipment or conservation practices.

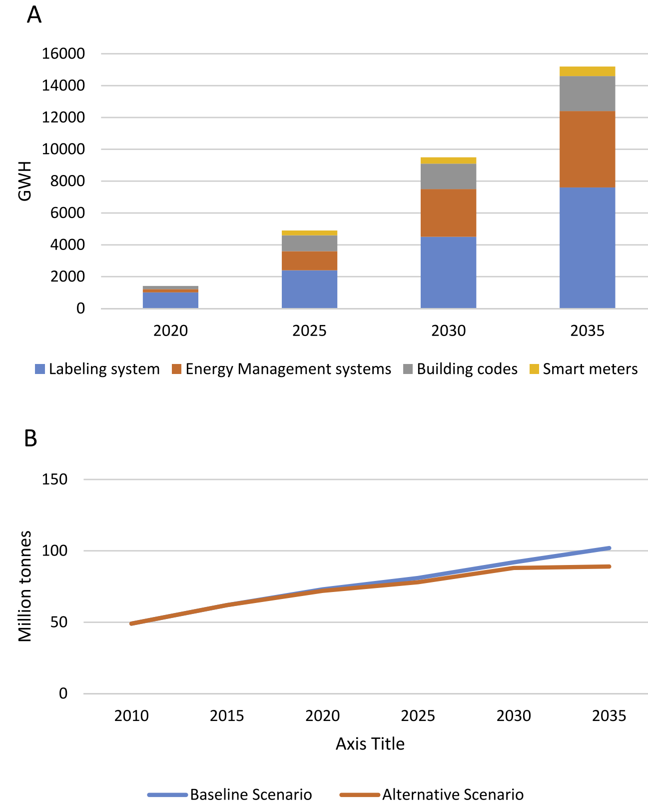

Fig. 10. Electricity savings from the introduction energy efficiency and conservation measures (A) and corresponding GHG reductions (B) (JICA , 2013).

- Alternative scenario: In this scenario, there is a gradual penetration of energy efficiency and conservation measures consistent with the rate of improvement assumptions in Table 1, starting in 2018. The impact of these measures results in a lowering of electricity consumption through 2035.

The results of the analysis are illustrated in Fig. 10. The plot A, shows that by 2035, the implementation of all the measures would lead to electricity savings of about 15,000 GWh, or roughly 25% of electricity consumption in the Baseline scenario. Together, electricity savings from labelling systems and energy management systems account for 81% of the total savings. The plot B of Fig. 10 shows that the GHG reduction benefits from these electricity savings are considerable, resulting in a reduction of approximately 23 million tonnes by 2035, or 21% less that what national emissions would have otherwise been in 2035.

6. Discussions

Since four decades, Oman's economy was largely driven by hydrocarbon and diversification of the economy faces concerns about future energy security as conventional fossil fuel resources dwindle and its young population continues to grow rapidly. The diversifications of the economy away from hydrocarbons requires an ambitious plan to diversify Oman's energy mix while driving economic growth and technological innovation. Specifically, the future energy plan should be built on four core, which will lead to substantial reductions in GHG emissions:

(1) Energy supply

GHG reductions can be achieved through diversification of its energy supply and exploiting Oman's extensive renewable energy resources. Specific measures includes:

Table 1
Major energy efficiency and conservation measures applicable to Oman (JICA , 2013).

#	Sector	Energy efficiency and conservation measure	Potential	Rate of improvement
1	Industry	Energy management system	90%	1% per year
2	Commercial	Energy management system Labelling system for lighting Building codes	60% 22% 40%	1% per year 90% 25%
3	Governmental	Energy management system Labelling system for lighting Building codes	60% 22% 40%	1% per year 9% 25%
4	Residential	Labelling system (Air conditioning, lighting, refrigerators) Building codes Smart meters	12% to 39% 39% 70% to 80%	9% to 23% 28% 2% to 4%

- Create, adopt and implement a comprehensive energy action plan that can facilitate the immediate implementation of renewables;
- Establish an institution that would be responsible for renewable energy and energy development; and
- Establish Small Scale Rooftop and Hybrid Power Generation for local communities that would be backed by a national regulatory body to monitor permitting and building codes/standards.

(2) Energy demand
As discussed earlier, substantial levels of GHG reductions can be achieved by providing an enabling environment for the introduction of energy efficiency and conservation measures. Specific measures are as follows:

- Cut energy-related subsidies that are barriers to promoting energy efficiency and conservation. Removal of subsidies should account for and assist those that may be particularly vulnerable;
- Develop and implement national awareness-raising programmes on the benefits of energy efficiency and conservation, thereby promoting a nationwide change in behaviour to boost the level of energy efficiency in homes and workplaces throughout Oman; and
- Centralize energy policy under a single authority that would be empowered to establish a coordinated energy policy that would treat demand side energy management as a priority.

(3) Research & Development
Diversifying the way in which Oman meets the energy service requirements of its growing population will depend on its institutional research and development capacity to exploit economic opportunities. Specific measures are detailed below:

- Narrow the gap between industry and academia to establish an enhanced R&D culture in order to foster private-partner partnerships and synergies;
- Establish research clusters and incubators with universities across Oman that are linked with promotional entities; and
- Encourage a higher number of Ph.D. students to study and work in Oman as they represent the intellectual value and driving force behind top-level research.

(4) Water–food–energy nexus
Energy is closely linked to water resource management and agricultural development. The "water–food–energy nexus" is a framework that views water and food as part of an integrated system, rather than as independent resources. Energy is required to extract, convey, purify, and deliver water for agricultural productions and other end users in the economy. It is also used to treat municipal and industrial wastewater. Specific measures are indicated in the bullets below:

- Establish an executive authority that focuses on water, energy and food and identifies/quantifies the linkages between them;
- Explore the costs and benefits of renewable energy-based seawater desalination for promoting energy and water security; and
- Enforce building codes and standards for sustainable homes to promote water savings and energy efficiency.

7. Conclusion

The sustained economic growth, urban sprawl and industrialization have maintained a continuous rising energy demand in the Sultanate of Oman. The consumption of oil and natural gas has doubled and tripled respectively over the last decade. The power sector has also witnessed a steady growth in line with gross domestic product (GDP). Oman faces the challenge of harmonizing its aspirations for rapid economic growth with a pressing need to address low-carbon, climate-resilient development. Internationally, Oman has voluntarily agreed to reduce GHG emissions 2% by 2030. For instance, the GHG reduction benefits from electricity savings for the country are considerable, resulting in a reduction of approximately 23 million tonnes by 2035, or 21% less that what national emissions would have otherwise been in 2035. The diversifications of the economy away from hydrocarbons requires an ambitious plan to diversify Oman's energy mix while driving economic growth and technological innovation. Therefore, results presented in this paper provide strategic pathways and regulatory choices that can serve as a starting point for policy makers when discussing how best to achieve GHG emission reductions in Oman.

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