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Toward Net-Zero Carbon Emissions for Saudi Arabia Under the Circular Carbon Economy Framework

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Abstract

The issue of energy-related greenhouse gas (GHG) emissions has attracted considerable attention from the Saudi government. The government aims to reduce all GHG emissions to a level consistent with the objectives of the 2015 Paris Agreement. This study estimates the main features of the Saudi economy with net-zero carbon emissions by 2060. It uses Leontief's input–output model to estimate different circular carbon economy (CCE) scenarios in Saudi Arabia from 2020 to 2030 and then from 2030 to 2060, based on a supply and use table for 2018. Moreover, this study estimates the expected size of the green bond market required to finance the transition toward net-zero emissions. In addition, it shows that Saudi gross domestic product will annually grow by 2.6% on average until 2030 and by 2% on average every year until 2060. For the labor market, more than 23 million new jobs are expected to be generated during the study period. This study also predicts that the share of green bonds in the total bond market will be approximately 15% and 30% by 2030 and 2060, respectively. In short, this study predicts and identifies the main features of the Saudi economy with net-zero emissions by 2060, thus helping meet the financial needs of green projects.

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1 Introduction

Emissions of carbon dioxide (CO2) and other greenhouse gases (GHGs) significantly impact the environment and health. Intensive efforts on a global scale are needed to properly address and respond to the negative impact of GHG emissions. In 2021, the 20 largest global economies (G20 countries) alone accounted for 75% of the resources used worldwide and 80% of global GHG emissions. As a result, G20 countries have started to develop national strategies to promote resource efficiency and a circular economy (see the policy guidelines developed by the OECD (2021)). Saudi Arabia, one of the G20 countries, has committed to contributing to global efforts to reduce climate change risk (NDC & Paris Agreement, 2015).

The Saudi economy is dominated by petroleum and associated industries, such as mining and quarrying, construction, and transportation (Kahia et al., 2020; Nurunnabi, 2017). Huge development plans have resulted in increased living standards for Saudi citizens due to the expansion of oil revenue. However, due to its geographical location, Saudi Arabia has a shortage of fresh water. Thus, an enormous amount of energy is needed for cooling and desalination. The resulting patterns of high energy consumption ultimately increase carbon dioxide emissions (Mahmood et al., 2020; World Bank, 2021) . The issue of energy-related CO2 emissions, however, has attracted considerable attention from the Saudi government. One of the aims of Saudi Vision 2030[2] is to

[2] Saudi Vision 2030 is a strategic framework for the country's sustainable development.

eliminate or at least substantially reduce carbon emissions through the adoption of a circular carbon economy (CCE) (Saudi Vision 2030; Vision, 2016). This aim was recently reiterated by Saudi Arabia's Crown Prince, who announced during the inaugural Saudi Green Initiative (2021) forum that the country is committed to reaching net-zero carbon emissions by 2060. The transition to net-zero carbon emissions, moreover, can be viewed as both an opportunity and a challenge. Achieving net-zero carbon emissions is likely to create jobs and boost economic growth as a result of new investments in green projects (Al Yousif, 2021).

In light of the discussion above, this study addresses the following questions:

(i) What main criteria should be met for the Saudi economy to reach net-zero emissions by 2060?

(ii) What are the expected additional sources of finance to fund Saudi Arabia's green projects?

This study aims to provide economic and financial tools for Saudi Arabia's transition to net-zero carbon emissions under the CCE framework. To achieve this transition, long-term plans with a long list of goals and objectives must be formulated. Moreover, it is necessary to build a very strong partnership between the private and public sectors as the main owners of green projects. To this end, the current study estimates the main criteria that should be met for the Saudi economy to achieve net-zero carbon emissions by 2060 using the Leontief input–output (IO) model. The first stage focuses on the main initiatives in Saudi Vision 2030, which are designed to increase diversification of the Saudi economy (making it less dependent on oil production). The second stage focuses on the process of transitioning the Saudi economy toward net-zero carbon emissions by 2060. In addition, this study aims to identify the best green financial instrument to fund projects related to achieving net-zero carbon emissions by 2060. To do so, the study calculates the expected size of the financial gap related to green projects.

Finally, this study seeks to make two important contributions. First, it estimates the main criteria that should be met for the Saudi economy to achieve net-zero carbon emissions by 2060. It should be noted that this study is one of the first attempts in the literature to estimate the changes in Saudi Arabia's main economic variables, such as the size of non-oil GDP, labor market size, and diversification. Second, it helps identify and thus meet the financial needs of green projects. In addition to these contributions, this study identifies three pillars of Saudi Arabia's transformation into a CCE.

The study continues by providing a theoretical background (from both global and Saudi perspectives) on the circular economy (CE), the CCE and the financial gap associated with the CCE (Section 2). Subsequently, we describe our method and materials (Section 3), followed by a results section (Section 4). The study concludes with a summary, a discussion of its contributions and recommendations (Section 5).

2 Theoretical Background

This section has three purposes, the first of which is to provide a global perspective on the CE. The second purpose is to propose and explain the concept of the CCE. The third purpose is to provide an overview of the financial gap associated with the CCE.

2.1 Circular Economy: A Global Perspective

Under the Paris Agreement, several countries have reduced their carbon emissions to net zero (United Nations, 2015). Accordingly, the CE has emerged as a powerful framework for managing and mitigating GHG emissions by providing circular solutions and strategies to enhance the efficiency of existing materials and products. The CE concept works on the principle of a closed-loop circular system rather than an open-loop setup (Ghosh & Ghosh, 2021; Goyal et al., 2021; Korhonen et al., 2018; Su & Urban, 2021). The main difference between linear and circular economic models is that the former adopts a 'take–make–waste' consumption approach, while the latter focuses on reducing, reusing, and recycling existing materials and products.

The CE has the potential to make a significant positive contribution to sustainable economic development. In other words, it provides not only economic value but also environmental and social benefits. Several study papers have focused on how the CE framework can help meet the Paris Agreement objectives in countries such as China (e.g., Fan & Fang, 2020; Song et al., 2021; Su & Urban, 2021; Zhu et al., 2019), the USA (e.g., Ghosh, 2020; Lonca et al., 2020; Saidani et al., 2019), the UK (e.g., Bonsu, 2020; De Lange et al., 2022), and Norway (e.g., Sun et al., 2022).

National governments' policies shall play a crucial role in the adaptation of the CE framework to local economic activities. In China, for instance, policies and strategies related to CE have proven very effective in increasing the efficiency of energy consumption, materials, and water usage (Fan & Fang, 2020). For the European Union and some member states, a roadmap developed by the European Commission (2019) expresses a commitment to substantially improving the efficiency of resource usage of the European economy and enabling the transition toward the CE at both the national and European levels. The resource efficiency roadmap provides directions for policy strategies to transform Europe's economy into a resource-efficient economy by 2050 in four major areas. These are 'sustainable consumption,' 'sustainable production and taxation,' 'innovation and study,' and 'waste as a resource,' which are addressed within the policy objective of 'transforming the economy' to pave the way for the CE. Four roadmaps have been operationalized based on the flagship initiative on resource efficiency, namely a low-carbon economy 2050 roadmap, a roadmap for a resource-efficient Europe, an energy roadmap 2050, and a European transport plan.

In line with the Paris objectives, a recent study has identified several pathways to low-carbon emissions by 2050 in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, the Republic of Korea, Russia, and the United States (Fragkos et al., 2021). According to Fragkos et al. (2021), these low-emission pathways are based on (1) improving energy efficiency across sectors by assimilating more efficient forms of energy and energy-related technologies, (2) diversifying the mix of energy and electricity supply toward clean energy sources, (3) decreasing the carbon intensity of gross domestic product (GDP) by more than 70% from 2015 to 2050, (4) pursuing the electrification of energy services through the promotion of electric vehicles, heat pumps, and the use of electricity in industrial applications, and (5) using a variety of mitigation options, such as nuclear energy, carbon capture and storage, and advanced biofuels. The status of initiation and implementation of policy instruments related to the CE in 32 countries and Europe was presented and discussed by Ghosh and Ghosh (2021).

A sustainable solution for climate change has to focus on three main fundamental factors: energy security, economic development, and social prosperity. The target of decarbonizing fossil fuel-based economies is becoming a major priority worldwide (Alsarhan et al., 2021). Focusing on reducing carbon emissions by targeting fossil fuels is not a sustainable solution (McDonough, 2016). Mitigation by itself has proven to be less sufficient as a policy for addressing carbon pollution (Zhao et al., 2018). Thus, adaptation might be a necessarily additional strategy for reducing the level of carbon emissions by recycling carbon into useful resources. Therefore, efforts to save the worldwide economy from the consequences of climate change must combine mitigation and adaptation (Zhao et al., 2018). The proposed CCE framework, furthermore, is capable of drawing a line between mitigation and adaptation efforts to reduce carbon emissions. The next section will explore the rationale for using the CCE framework to make the world more sustainable and prosperous for all.

2.2 Circular Carbon Economy (CCE)

Before discussing the CCE, it is essential to understand carbon not as an enemy but as a resource. McDonough (2016) argued that carbon should be regarded as a resource for producing raw materials and promoting healthy food in society. Carbon can be found in natural fabrics (such as wool, cotton, and silk) as well as in industrial polymers and diamonds. We concur with McDonough (2016) that carbon should not be perceived as an enemy; rather, it is a useful resource for human life.

McDonough (2016) proposed a new language for looking at carbon, which comprises three stages. The first stage is ‘fugitive carbon,’ which involves producing carbon from burning coal and other fossil fuels. The other two steps focus on strategies for treating carbon as ‘durable carbon’ and ‘living carbon.’ The durable carbon stage relates to reusing or recycling materials that contain large amounts of carbon, while the living carbon stage focuses on carbon from the atmosphere; it involves planting and maintaining the sustainability of forests to support biological cycles. The two latter stages are expected to reduce the amount of carbon in the air. These three stages are reflected in the CCE framework.

The CCE system integrates environmental, economic, and social objectives by using available technologies to reduce CO2 emissions, create new job opportunities, and enhance local economic growth (Williams, 2019). The CCE is the circulation of carbon and energy flows (Mohsin et al., 2019). The CCE framework is built on the 4 'R's; that is, reduce, recycle, reuse, and remove. The first R (reduce) refers to reducing carbon emitted into the air by increasing energy efficiency or using a clean energy source (e.g., renewable energy as part of the mitigation framework). The other three Rs are related to the adaptation framework: recycle, reuse, and remove (Rassool et al., 2021). CCE has attracted much interest in the literature (e.g., Bherwani et al., 2022; Herrador et al., 2022; Kurniawan et al., 2022; Lee et al., 2021; Naims, 2020). The following part of this section reviews the three study themes: the role of CCE in accelerating economic sustainability, the difficulties associated with integrating the CCE framework, and the primary sources of carbon.

Numerous studies have investigated the role of the CCE framework in increasing economic sustainability. Lee et al. (2021) looked at the socio-political domain of carbon recycling (CR) in Germany. They found that CR was associated with significant benefits, including resource conservation, reduced environmental impact, efficiency, technological advantages, productivity, and input flexibility. However, the challenges associated with CR include technical issues, lack of human skills, and infrastructure. Overall, the study recommended engaging in intersectoral cooperation to support regulatory frameworks and funding for research and development (R&D) to enhance the development of CR technologies. Herrador et al. (2022) compared Japanese and South Korean policies and actions related to establishing a carbon economy and identified their main challenges. The authors reported a high level of private-public collaboration in Japan.

Bherwani et al. (2022) used IO analysis and Leontief's inverse matrix to calculate the carbon footprint (CF) and material footprint[3] (MF) of production sectors in India. The study found that the construction and transportation sectors ranked the highest in terms of their CF and MF compared with other production sectors. The study estimated the reduction in the CF and MF resulting from policies implemented in India related to climate change. They found that the average CF reduction was about 2.6% and 10.3% for the construction and transportation sectors, respectively. The decrease in CF for the industrial sector was not significant. The average MF reductions of the construction, industrial, and transportation sectors were 8.3%, 8.5%, and 16%, respectively. The study concluded that energy consumption is the main source of carbon emissions in India.

[3] The term "material footprint" refers to the amount of raw materials that are used to create a final product.

The literature on the CCE has revealed that it is difficult to promote economic sustainability without heavy investment in technological infrastructure (Kurniawan et al., 2022). Kurniawan et al. (2022) found that Petersburg faced a variety of obstacles to achieving carbon neutrality related to recycling waste, such as operational costs, low efficiency, and lack of infrastructure. They found that Petersburg could reduce its carbon emissions by using fewer virgin materials, enabling the city to reduce its carbon emissions by 25% by 2030. In short, investment in technology and R&D is an essential step toward building a less carbon dependent society.

Many studies have focused on the efficiency of energy use with reference to the primary source of carbon. Their insights enable policymakers to develop strategies targeting higher carbon emission activities. Naims (2020) divided the industrial sector into three groups (i.e., equipment manufacturers, high-emitting producers, and producers of materials and fuels). She explored the value of carbon capture and utilization (CCU) innovations for these different groups. The study made a significant contribution by identifying value added by CCU innovation through the various stages of the production system across multiple industries, showing that the value added by CCU innovation differed based on the types of products and activities.

After covering the literature related to the global CCE, the following part of this section reviews the literature on Saudi Arabia’s efforts to instate the CCE framework. Luomi (2020) looked at the recent development of the CCE framework among Gulf

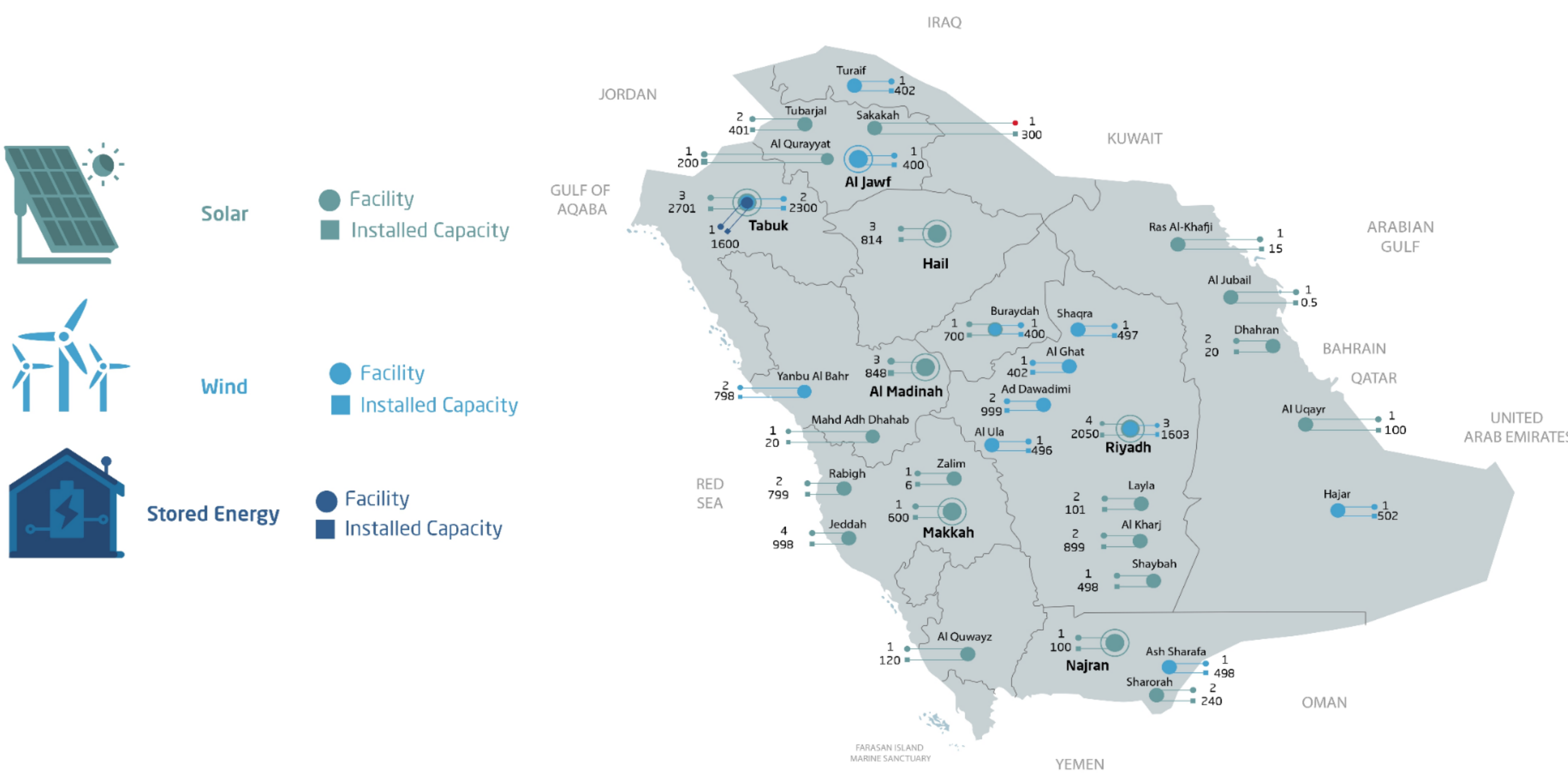
Cooperation Council (GCC)[4] countries and their expected progress in the coming year. With the recent update by many GCC countries to their medium-term GHG emission targets under the Paris Agreement, several countries, including Bahrain, Saudi Arabia and the United Arab Emirates, have announced net-zero emission targets. The latter paper sought to determine how the CCE would help these countries meet their commitments. The study concluded that using the CCE framework would significantly assist these countries in arriving at carbon neutrality, as this framework has a broad scope of technology options. Many of these countries are in the process of reducing their carbon emission, but there is a shortage of investment and finance for the required projects to achieve their goals. Alshehri et al. (2022) of KAPSARC[5] recently concluded that for a country with a high dependence on fossil fuels, adopting the CCE framework is the optimal pathway to meet their nationally determined contributions (NDCs).

Saudi Arabia is willing to increase the efficiency of its domestic electricity consumption and generate energy from more climate-friendly sources, such as solar, wind, and nuclear energy (Wogan et al., 2019). The CCE framework was introduced by Saudi Arabia during the G20 summit (27-28 September 2020) to control and reduce GHG emissions. Furthermore, two additional strategies have been adopted by Saudi Arabia to reduce the level of carbon emissions domestically. The first strategy comprises increasing local energy efficiency consumption through the national energy efficiency program. The

[4] The GCC is an economic and political union that is made up of all Arab states that constitute the Arabian Gulf except Iraq, namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.
[5] The King Abdullah Petroleum Studies and Research Center is a center mandated to advance knowledge and provide services for organizations and authorities in the Saudi energy sector.

second strategy includes investing in technologies that are more environment-friendly (e.g., using natural gas and renewable energy). Figure 1 shows the total number of facilities and installed capacity for three types of energy (i.e., solar, wind, and stored energy) in Saudi cities. It highlights the power-producing facilities in the renewable sector of Saudi Arabia.

Figure 1: Geography of Facilities and Installed Capacities by Energy Types (Solar, Wind, and Stored Energy) in Saudi Arabia



Source: Refinitiv (2022) and authors' calculations.

Note: The data on wind, solar, as well as battery storage were collected in Excel format from the Refinitiv RENEWABLES dashboard and include Facility Name, City, Immediate Owner, Ultimate Owner, Status and Installed Capacity. The authors calculated the data by aggregating the installed capacities for each energy type (solar, wind, and stored energy) data based on the facility city. Then they drew the figure (i.e., infographic) using Adobe Illustrator based on the data that they aggregated from the Refinitiv RENEWABLES dashboard.

2.3 Financial Gap Associated with the CCE

While the need for large investments to transition to a CCE is clear, the mobilization of resources to finance this transition remains unclear. This raises questions about the role that financial systems and governments can play in driving green transitions. Atalla et al. (2022) proposed six ways for the government to move toward a green, net zero future. One way corresponds to encourage businesses and investors to align with climate goals. China, for example, has implemented two policies (i.e., coal resource tax and renewable energy investment scenarios) to take the first step toward achieving carbon neutrality by 2060 (Jia & Lin, 2021). The government can also promote investment in environment-friendly projects by, for instance, establishing green investment banks and introducing green financial instruments.

Lately, it has been well-documented that green bonds play an important role in the transition to a low-emission economy by raising money for low-emission projects (IRENA, 2020). They could offer low-cost access to long-term sources of capital and a more stable and larger investor base, and they can be directly used to finance green projects, assets, or business activities. Harrison et al. (2020) carried out a major survey as part of the Climate Bonds Initiative[6] to identify the main costs and benefits of issuing green bonds and propose guidance for attracting issuers to green financial markets. By interviewing 86 treasurers from 34 countries, the report found that the main benefits of issuing green

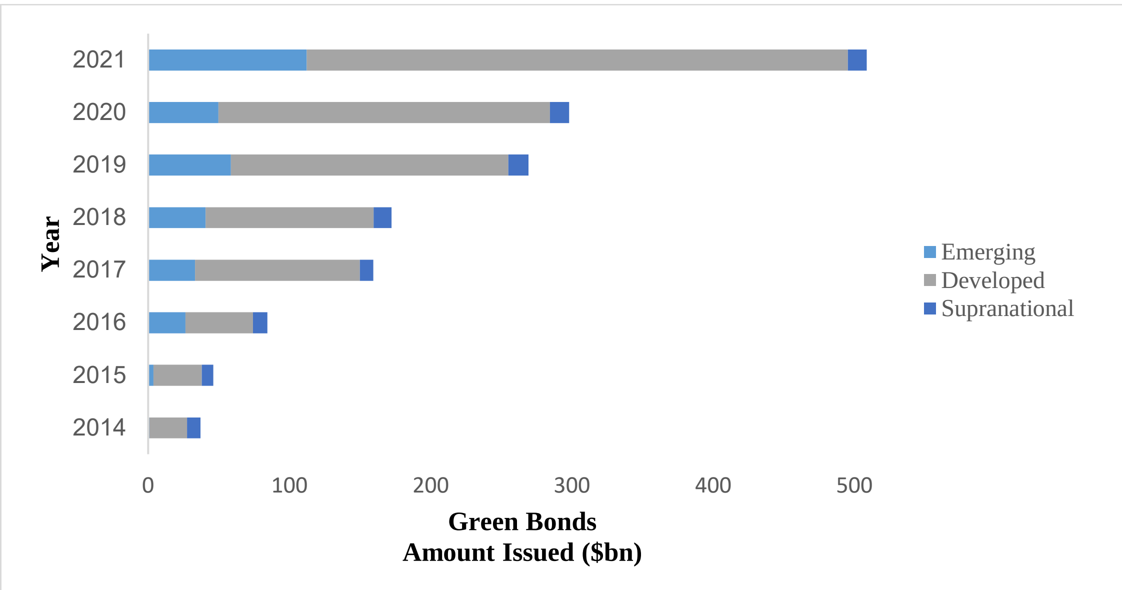
[6] Climate Bonds Initiative is a non-profit organization that promotes investment efforts to help economies move toward low GHG emissions.

bonds were enhancing business risk management and future proofing, attracting new investors and promoting investor engagement, improving the issuer’s reputation and visibility, enhancing internal integration, and promoting better standards to benefit green bond market stakeholders.

Green bonds are fixed-income securities issued to raise capital for green projects, assets, or business activities (Kaminker, 2017). Green bonds are similar to conventional bonds in that they are both debt instruments, but they differ in the use of the funding. Specifically, green bonds finance only environmental impact projects, assets or activities. According to Kaminker (2017), there are six types of green bonds: corporate, project, asset-backed security, supranational, sub-sovereign and agency, municipal, and financial bonds.

The green bond market has grown rapidly in size and importance in the last two decades. Multilateral development banks were the initial developers and supporters of the green bond market (Maino, 2022). In 2007, the European Investment Bank (EIB) issued the first green bond worth EUR 600 million. In 2008, the International Bank for Reconstruction and Development issued its first green bond worth USD 440 million. Since then, corporations and financial institutions have realized the benefits of green bonds and, thus, have continued issuing green bonds. This has led to the rapid growth of the green bond market, which increased from USD 2.6 billion in 2012 to USD 145.1 billion in 2017. By 2021, the green bond market had reached USD 553.39 billion. Whilst developed markets are the largest issuers of green bonds, green bonds are receiving increasing attention in emerging markets. According to the Climate Bond Initiative (2022) database, the value of green bonds issued in emerging markets doubled from USD 26.5 billion in 2016 to USD 58.7 billion in 2019 and doubled again, reaching USD 112.2 billion in 2021. Figure 2 shows the amount of green bonds issued between 2014 and 2022 at the issuer market level.

Figure 2: Issued Amount of Green Bonds in USD billions between 2014 and 2022 at Issuer Market Level



Source: Climate Bond Initiative (2022).

Harrison and Muething (2021)[7] asked 19 sovereign issuers (8 from developed markets and 11 from emerging markets) about their approaches to and experience of issuing sovereign green, social, and sustainability (GSS) bonds as well as their role in

[7] As part of the Climate Bond Initiative.

growing the GSS bond market. The survey findings showed that GSS bonds could expand strategic initiatives, enhance green finance markets, diversify and increase the investor base, and improve visibility and transparency. In 2020, the Saudi Electricity Company (SEC)[8] issued USD 1.3 billion from green bonds to fund renewable energy and energy efficiency projects. In Saudi Arabia, the government and its sovereign wealth fund (Public Investment Fund (PIF)) in 2022 issued green bonds to enhance its efforts toward net-zero emissions by 2060 (Saba, 2022).

Several efforts to standardize, improve and foster the green bond market have been made in response to the challenges and barriers associated with the growth of the green bond market. One such measure is the establishment of green bond market frameworks such as the Green Bond Principles (GBP), issued by the International Capital Market Association (ICMA) (2021), and the EU Green Bond Standard, set by the European Commission (2019). These frameworks aim to promote transparency and disclosure in the market by providing guidelines and recommendations as well as outlining best practices and therefore help to promote and strengthen the green bond market.

In Saudi Arabia, two green finance frameworks have been established: the Green Sukuk Framework (see SEC, 2020) set by the SEC, and the Green Finance Framework (see PIF, 2022) laid out by the PIF. Both frameworks are aligned with the 2018 ICMA Green

[8] SEC is a Saudi supplier of electricity established in 2000 through a merger of existing regional electricity companies. It is a government-backed entity, and it is involved in the electrical generation, transmission and distribution in Saudi Arabia.

Bond Principles. The Green Sukuk Framework aims to increase the standardization and transparency of the green *sukuk* market in line with the company's sustainability strategy to facilitate the transition to a circular and low-carbon economy. The Green Finance Framework provides guidance not only for green *sukuk* but also for green bonds, loans, and other debt instruments. The main aim of the Green Finance Framework is to sustain green finance markets and use green debt instruments as a financing channel to expand funding sources. Specifically, it aims to provide financial guidance to increase investments in environmentally friendly projects that contribute to the establishment of the CCE. The following section discusses the methods and materials used in this study.

2.4 Summary of the Theoretical Background

Recognizing the environmental and health risk posed by GHG emissions, a number of countries have started to introduce policy frameworks to encourage contributions to establishing a CCE. The studies reviewed above indicate that CCE research is evolving to achieve a significant reduction in carbon emissions and fulfill the associated financial needs. Each study represents a unique case for each country based on its resources (i.e., case dependent), low-emission strategies and specific development objectives. The actions taken by Saudi Arabia have a wide-ranging and lasting influence on the region and its trajectory. This is due not only to the country's size but also to the influence of its strategies and leadership in contributing to global efforts to reduce climate change risk. Such influence is exerted through fostering continued interactions and knowledge transfer between MENA countries and adapting the CCE framework to reach Saudi's net-zero emissions goal. For example, Saudi has launched a regional initiative (the Middle East Green Initiative) to foster a shift in and control of carbon emissions and deliver a reforestation program to MENA partners. Consequently, Saudi Arabia plays a wider role in enhancing energy security and stability not only in the MENA region but also in the world. Overall, these factors make Saudi Arabia a unique case setting for this study.

This study focuses on Saudi Arabia as a case study – MENA's largest economy with an ambitious Vision 2030. The actions to which Saudi commits play a critical role in how the region moves toward the CCE framework and may establish Saudi as a regional leader in the low-carbon transition. Hence, this study seeks to make two important contributions. First, it provides new insights into low-emission transition pathways in the Saudi economy by estimating the main features of the Saudi economy with net-zero carbon emissions by 2060, taking into account both mitigation and adaptation as part of the CCE framework and using the Leontief IO methodology. Second, it helps to identify the investment requirements by estimating the expected size of Saudi Arabia's green bond market. In addition to these contributions, this study is expected to benefit policymakers by providing several important implications for the sustainable development agenda.

3 Method and Data

3.1 Method

This paper establishes an IO model and conducts macroeconomic analysis to simulate and analyze scenarios under different CCE hypotheses in Saudi Arabia between 2020 and 2030 and then between 2030 and 2060. The macroeconomic analysis is conducted using Leontief's IO model based on the supply and use table for 2018.

The IO model, first proposed by Leontief (1936), has since been used by numerous scholars to investigate issues related to energy, the environment and economics (Wu et al., 2019). The IO model defines the multipart linkage among fiscal subdivisions and links product manufacturers by substituting goods between economic segments (Jiang et al., 2022). The significant merit of Leontief's IO model is that it can provide a more comprehensive analysis of various direct/indirect influencing factors, particularly the indirect influence of variations in demand in one sector on other sectors (Hoekstra & Van den Bergh, 2003; Jiang et al., 2022). As a result, Leontief's IO model has been effectively used to investigate different issues associated with CE. For instance, Tisserant et al. (2017) used IO data to examine waste treatment and footprints in the CE, covering 48 world regions. He et al. (2022) used an IO table for China in 2012, covering 139 production sectors, as a database for exploring China's low-emission energy transformation pathway. Bherwani et al. (2022) quantified CE strategies in India through IO analysis and the Leontief inverse matrix.

Equation (1), which is based on the Leontief inverse, is stated below (Al Yousif, 2021; Almulhim & Al Yousif, 2022; Jiang et al., 2022):

$$H = \left[H_{ij}\right], H_{ij} = \frac{z_{ij}}{z_i}, \quad (1)$$

where H denotes the matrix coefficient of direct consumption; H_{ij} indicates the input of sector/part j for every component of production value added by segment i; Z_j denotes the total production of segment j; and Z_{ji} refers to the mid-way input matrix from division i to segment j. Let $X = [X_j]$ be the final demand of industry j. The whole output vector is formulated as follows:

$$MZ + X = Z \tag{2}$$

$$\begin{pmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_i \end{pmatrix} = \begin{pmatrix} M_{11} & \cdots & M_{1j} \\ \vdots & \ddots & \vdots \\ M_{i1} & \cdots & M_{ij} \end{pmatrix} \begin{pmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_i \end{pmatrix} + \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \end{pmatrix} \tag{3}$$

$$Z = (I - M)^{-1} X \tag{4}$$

Hence, $(I - M)^{-1}$ is Leontief's inverse matrix, and I refers to the matrix unit. Eq. (4) illustrates that when the demand fluctuations of various sectors in the economy are known, the Leontief inverse matrix can be used to obtain the output fluctuations of all sectors.

3.2 Data and Main Assumptions

All of the data were collected from the General Authority of Statistics (GASTAT, 2020). The most recently available IO tables at GSTAT are the IO tables for 2018, 2019, and 2020. The economy has $n + 1$ sectors, the number of producing sectors for a particular economy, and the final demand sector (see Table 1). All of these IO tables have 20 economic activities, as presented in Table 1.

Table 1: Economic Activities Used in the IO Tables

Code	Sector	Code	Sector
1	Agriculture, forestry and fishing	11	Financial and insurance activities
2	Mining and quarrying	12	Real estate activities
3	Manufacturing	13	Professional, scientific and technical activities
4	Electricity, gas, steam and air conditioning supply	14	Administrative & support service activities
5	Water supply; sewerage, waste management & remediation activities	15	Public administration and defense; compulsory social security
6	Construction	16	Education
7	Wholesale and retail trade; repair of motor vehicles & motorcycles	17	Human health and social work activities
8	Transportation and storage	18	Arts, entertainment and recreation
9	Accommodation and food service activities	19	Other service activities
10	Information and communication	20	Activities of households

Source: GASTAT (2020).

The primary purpose of using IO tables in this study is to estimate the main features of the Saudi economy with net-zero carbon emissions by 2060. The main assumptions used to estimate the Saudi economy's key indicators by 2060 are as follows. The IO table for 2018 is the base table, but we also consider the IO tables for 2019 and 2020, as they reflect certain government structural reforms. We also consider the effects of COVID-19. In addition, we use the Vision 2030 initiatives toward diversification to project the main features of the Saudi economy in 2030. To highlight, one of the adopted main assumptions in our study is that the Saudi economy will be less dependent on oil activities. We consider all Saudi green initiatives that would have a significant contribution to Saudi Arabia's movement toward a low-emission economy. The second step is to build the main features of the Saudi economy in 2060. Currently, information is limited regarding plans or initiatives after 2060. However, Saudi Arabia has been committed to transitioning its economy to net-zero emissions by 2060. This commitment will require a major effort to reduce carbon emissions and minimize the circulation of carbon in the air under the CCE framework.

For the 2030–2060 period, our focus shifts to the types of investments that would significantly contribute to reducing the level of carbon emissions. Saudi Arabia has adopted the CCE framework, which takes into account both mitigation and adaptation (as discussed in Section 2.1). A wide range of additional assumptions are used to calculate the IO tables and other economic factors, such as GDP and new employees, for 2060. For instance, the level of productivity of the local economy is expected to increase. This will increase income, which will in turn enhance local purchasing power and boost economic development. Likewise, this study considers the upward trend in the population level between 2020 and 2030. Since the participation of Saudi women in the Saudi labor force recorded a significant increase to 35.6 percent (by the second quarter of 2022) compared to around 17 percent (by the second quarter of 2011), a significant increase in women's participation in the local economy is also essential to our calculation.

4 Results and Discussion

The macroeconomic analysis is conducted using Leontief's IO model and through Equations (1-4). The IO table for 2018 is used in this analysis as a base year for the estimation of the IO tables for 2030 and 2060. There are two reasons for using the 2018 IO table as a basis; first, this table presumably captures the effects of the most recent structural reforms implemented by the government, and second, 2018 is the current inflation base year for Saudi Arabia. IO tables for 2019 and 2020 are included in our estimation to capture the effects of VAT and COVID-19. Overall, the production level in 2018 was around SAR5 trillion, with a GDP of SAR3 trillion and real GDP calculated at approximately SAR2.6 trillion. Manufacturing, mining and quarrying, wholesale, and construction have the highest levels of output among all 20 sectors of production, accounting for around 60%, as shown in Table 2.

Table 2: Contributions of Selected Production Sectors to Total Output in 2018

Rank	Sector of production	Level of production (million SAR)	Share of total output
1	Manufacturing	1,038,429,011	20.6%
2	Mining and quarrying	1,024,033,940	20.3%%
3	Wholesale and retail trade	613,568,411	12.2%
4	Construction	388,437,742	7.7%
Total output		5,034,039,670.65	

Source: Authors' calculation.

As shown in Table 3, which reports on value added (GDP), mining and quarrying currently makes the most significant contribution to GDP. Manufacturing is the second largest contributor to GDP, at 12.92%. Wholesale and retail trade, real estate activities, and education contribute similarly to the value added. Table 4 shows Saudi's labor market situation in 2018.

Table 3: Contribution of Selected Production Sectors to Total GDP in 2018

Rank	Sector of production	Level of value added (million SAR)	Share of total GDP
1	Mining and quarrying	972,050,359	31.5%
2	Manufacturing	399,044,485	12.9%
3	Wholesale and retail trade	242,681,463	7.9%
4	Real estate activities	203,764,159	6.6%
5	Education	198,901,279	6.44%

6	Construction	144,791,891	4.7%
	Total GDP (current prices)	3,087,548,799	

Source: Authors' calculation.

Table 4: Contribution of Employees for Selected Production Sectors in 2018

Rank	Sector of production	Employees	Share of total employees
1	Public administration	2,300,919.376	16.5%
2	Wholesale and retail trade	1,897,157.715	13.6%
3	Education	1,809,990.853	13.0%
4	Construction	1,607,806.38	11.5%
5	Manufacturing	1,131,940.16	8.1%
	Total employees 2018	13,973,363.25	

Source: Authors' calculation.

4.1 Economic Output Estimations

4.1.1 Economic Output Estimation for 2030

Vision 2030 and the recent Saudi green initiatives are considered important inputs in our process of estimating the IO table for 2030. Overall, the level of production in 2030 is expected to be around SAR6.5 trillion, with a GDP of SAR4.2 trillion and real GDP of around SAR3.01 trillion. Manufacturing, mining and quarrying, wholesale, and construction are expected to have the highest levels of output among all 20 sectors of production, as shown in Table 5.

Table 5: Contributions of Selected Production Sectors to Total Output in 2030

Rank	Sector of production	Level of production (million SAR)	Share of total output 2030	Share of total output 2018
1	Manufacturing	1,605,193,325.86	24.4%	20.6%
2	Mining and quarrying	997,017,618.25	15.6%	20.3%
3	Wholesale and retail	870,501,907.27	13.2%	12.2%
4	Construction	636,706,298.82	9.7%	7.7%
	Total output	6,586,859,928.50		

Source: Authors' calculation.

As part of Vision 2030, the economy will gradually move away from oil dependency. The reduced contribution of the mining and quarrying sector in 2030 does not mean that the growth of this sector will decline. However, the level of development in non-oil economic activities is expected to show rapid growth (exceeding the historical trend). This is due to the anticipated increase in productivity and the size of the Saudi non-oil sector by 2030. For instance, as shown in Table 6, mining and quarrying is expected to contribute 19% to GDP in 2030, compared with 31.5% in 2018. Wholesale and retail trade is expected to be the second largest contributor to GDP, at 18.7%. Manufacturing, real estate activities, and education are estimated to contribute similarly to value added. Service activities are distributed among different economic activities, such as real estate activities, education, retail trade, and tourism. Hence, it is difficult to capture the contribution of the service industry to the Saudi economy. However, this industry is expected to make a big contribution to Saudi's value added, resulting from the Vision 2030 initiatives and the increase in households' living standards. Table 7 illustrates the estimated size of Saudi's labor market by 2030.

Table 6: Contribution of Value Added from Selected Production Sectors in 2030

Rank	Sector of production	Level of GPD (million SAR)	Share of total output 2030	Share of total output 2018
1	Mining and quarrying	797,614,094.60	18.6%	31.5%
2	Wholesale and retail trade	783,451,716.54	18.3%	8.0%
3	Manufacturing	616,839,029.68	14.4	13.0%
4	Construction	445,694,409.17	10.4%	5.0%
	Total GDP (Current prices)	4,290,004,983		

Source: Authors' calculation.

Table 7: Contribution of Employees for Selected Production Sectors in 2030

Rank	Sector of production	Additional employees	Share of total employees by 2030	Share of total employees by 2018
1	Wholesale and retail trade	4,227,461.15	50.0%	13.6%
2	Construction	3,341,298.93	38.8%	11.5%
4	Education	710,900.64	8.3%	13.0%
	Total of new employees	8,602,291.46		

Source: Authors' calculation.

4.1.2 Economic Output Estimation for 2060

In addition to the 2030 assumptions, other factors (i.e., Saudi green initiatives) are embedded to estimate the IO table for 2060. We built our projection based on Vision 2030, which aims to reduce the economy's dependency on government spending and increase the role of the non-oil economic sector. The level of production in 2060 is expected to be around SAR10.5 trillion, with a GDP of SAR6.6 trillion and real GDP expected to be approximately SAR5.5 trillion. Manufacturing, wholesale and trade, construction, and mining and quarrying are expected to show the highest levels of output among all 20 sectors of production as shown in Table 8. These sectors are among all 20 sectors of production due to the continuous implementation of all the initiatives related to the Saudi Vision 2030, which focuses on enhancing local production (e.g., made in KSA), tourism program, and housing program, as well as building new cities (e.g., Neom and Qiddiya). Interestingly, for the first time, mining and quarrying will not be ranked among the top two production sectors by contribution to total output, which reflects Saudi's transition toward a low-emission and diversified economy.

Table 8: Contributions of Selected Production Sectors to Total Output in 2060

Rank	Sector of production	Level of production (million SAR)	Share of total output 2060	Share of total output 2030	Share of total output 2018
1	Manufacturing	3,224,643,534.03	30.6%	24.4%	20.6%
2	Wholesale and retail trade	1,546,560,743.77	14.7%	13.2%	12.2%
3	Construction	1,224,106,847.60	11.6%	9.7%	7.7%
4	Mining and quarrying	981,864,143.85	9.3%	15.6%	20.3%
	Total output	10,532,937,745.92			

Source: Authors' calculation.

As shown in Table 9, regarding value added, by 2060, the wholesale and retail sector will have the largest share of output for the first time, at 21.8%. The manufacturing sector will make the second largest contribution to output, with a share of 16.0%. Table 10 highlights the estimated size of Saudi's labor market by 2060. Figure 3 shows the shifts in the Saudi economy outlook during the three key dates (2018 – 2030 – 2060) for selected production sectors in terms of job creation and contribution of value added.[9]

[9] These estimates are based on currently technologies.

Table 9: Contribution of Value Added from Selected Production Sectors in 2060

Rank	Sector of production	Level of production (million)	Share of total output 2060	Share of total output 2030	Share of total output 2018
1	Wholesale and retail trade	1391904669 1,391,904,669.39	21.1%	18.3%	8.0%
2	Manufacturing	1,239,156,652.69	18.8%	14.4%	13.0%
3	Construction	856,874,793.32	13.0%	10.4%	5.0%
4	Mining and quarrying	785,491,315.08	11.9%	18.6%	31.5%
	Total GDP (Current prices)	6,597,547,506.54			

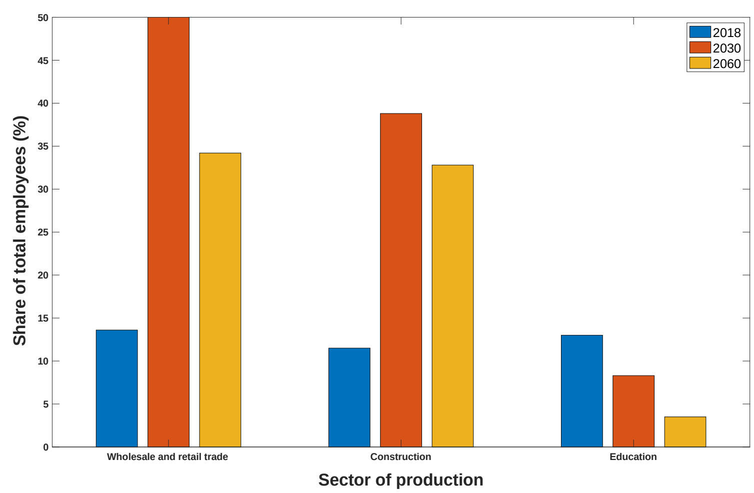
Source: Authors' calculation.

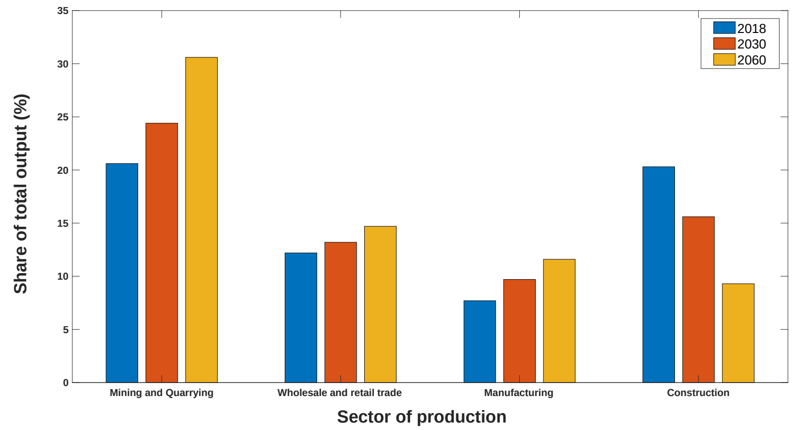
Table 10: Contribution of Employees for Selected Production Sectors in 2060

Rank	Sector of production	Labor	Share of total employees
1	Wholesale and retail trade	4,756,569.37	34.2%
2	Construction	4,565,852.70	32.8%
3	Manufacturing	1,374,068.32	9.9%
4	Public administration	734,762.69	5.3%
5	Education	492,759.30	3.5%
	Total employees 2060	13,925,208.94	

Source: Authors' calculation.

Figure 3: Saudi Economy Outlook for Selected Production Sectors





4.2 Green Bond Estimations

This study explores the transition of the Saudi economy toward a low-emission economy with a high level of diversification (a more sustainable economy). It recommends that Saudi adopts the CCE framework, with its 4 “R”s, as a pathway toward a low-emission economy. However, this transition toward a new structural economy will require huge investment. One barrier associated with investing in green projects is the source of finance (i.e., the financial gap). Both the government and the private sector play a critical role in filling this gap. Green bonds are among the suitable financial instruments to facilitate the transition to a low-emission economy by raising money for low-carbon projects and activities (IRENA, 2020). Luomi et al. (2021) identified several possible elements of a sub-index of CCE enablers. In the sustainable finance and investment component, the indicators include “green, social and sustainability-linked debt (bonds and loans) issued per country of domicile (latest five years)”.

The green financial gap could be defined as a mismatch between the size of the required investment in green projects and the available finance (Climate Bonds Initiative, 2017). The reason for this financial gap may be related to the high cost of technologies associated with green projects, including the large amount of investment in fundamental construction. In addition, the future of investment in green projects is associated with many risks, such as technological failure and changes in countries' political positions. Thus, the global community is working hard to provide financial solutions for green projects, such as green bonds. Although green bonds will not solve the problem of a shortage of financing, they still offer a promising solution to fill the financial gap in green projects.

In 2021, the size of global green bond market was around USD 553.39 billion (Climate Bond Initiative, 2022). According to Climate Bond Initiative (2022) data, Saudi Arabia's green bonds were worth around USD 2.4 billion in 2022, representing around 3.8% of the total Saudi bond market. Taking into account the estimated growth of the bond market in Saudi Arabia for 2030 and 2060, green bonds in Saudi Arabia are expected to be around USD 13.9 and USD 39 billion by the end of 2030 and 2060, respectively. We followed Kaminker (2017) in estimating the growth rate of the global green bond market. In addition, we used the recent development of green bonds in the Saudi economy (i.e., Green Finance Framework) to estimate Saudi's growth. These green bonds are expected to represent around 15% and 30% of the total bonds issued by 2030 and 2060, respectively (see Table 11).

Saudi annual green bonds were estimated based on the following factors. First, the global green bond market has increased by over 50% in the last five years (2015–2020) (Climate Bond Initiative, 2022). Second, the growth rate of the global green, social, and sustainable (GSS) bond market showed an overall upswing of more than 60% in 2021 compared with 2020 (Climate Bond Initiative, 2022) (ibid). Given these figures, and taking into account Saudi's recent green initiatives, we assume that the average growth of the Saudi green bond market during the 10 years from 2020 to 2030 will be around 45% annually and approximately 20% during the 30 years from 2030 to 2060.

Table 11: Estimated Value of Annual Green Bonds Needed for Green Projects (2020, 2030 & 2060)

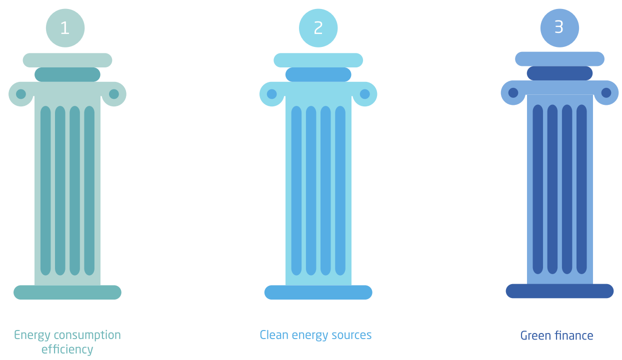
	2020	2030	2060
Bond (billion USD)	70.22794	90	130
Green bonds (billion USD)	2.4	13.9	39
Green bonds (percentage)	3.4%	15%	30%

Source: Authors' calculation.

4.3 Three Pillars for Saudi Arabia's CCE Transition

This study suggests three pillars for Saudi Arabia's transition toward implementing a CCE (see Figure 4). The first pillar is to increase energy consumption efficiency. The second pillar is to enhance clean sources of energy. The third pillar is to promote green finance instruments. This study goes beyond the mitigation agenda (i.e., reducing GHG emissions) to consider the adaptation framework (i.e., recycling reuse) based on the rationale of the CCE framework (i.e., carbon is not an enemy but a resource). These three pillars would hopefully reduce domestic carbon emissions, enhance economic growth, generate more job opportunities and, in turn, increase social prosperity and promote inclusive and sustainable growth.

Figure 4: Three Pillars for Transition Toward the CCE



5 Conclusion and Recommendations

This study examines the comprehensive efforts in Saudi Arabia not only to achieve its 2030 Vision but also to take the first steps toward realizing a net-zero emissions economy by 2060. The purpose of this study is to estimate Saudi's economic outlook in terms of achieving net-zero carbon emissions by 2060. Taking into account both mitigation and adaptation as part of the CCE framework and using the Leontief IO methodology, the study estimates the main economic features and the expected size of Saudi Arabia's green bond market by 2030 and 2060. A transition toward clean and sustainable energy would require strong and sustainable economic growth.

This study estimates the architecture of the Saudi economy in 2030 and 2060. Specifically, the IO tables reveal direct, indirect and induced economic impacts. The direct impact comes from the new investment related to CCE; the indirect impact comes from the new demand generated from these new investments in all sectors of production; and the induced effects are reflected in the new demand for personal goods and services (i.e., schools, hospitals, restaurants) generated by new employees in green projects. Overall, the study's results show that investing in CCE is likely to enhance Saudi Arabia's economic diversification and promote sustainable employment, which is estimated to reach around 22 million jobs by 2060. To date, investment has been directed to sectors with high productivity and high diversification. In addition, this study indicates the potential of green bonds to fill the green financial gap. The findings will be of interest to policymakers, as they offer a useful tool for initiating new policies related to driving the green transition.

Being limited to 20 economic sectors for 2018, this study fails to provide detailed information on sub-sector activities. Another limitation lies in the fact that the study projections depend on the government's strategies and initiatives. However, the risk of unexpected change or disruption may arise. Future research should shed light on the role of the private sector as a vital partner for the Saudi government. Further research could also usefully explore in more depth the sources of finance for green projects in Saudi Arabia.

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