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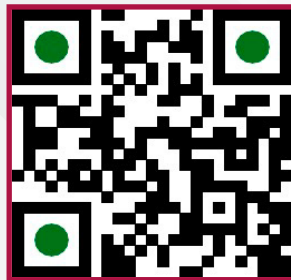
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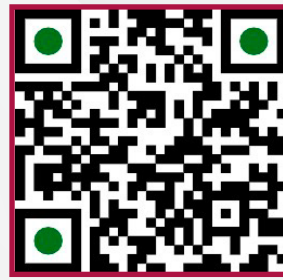
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**Articles of the 22nd Annual Conference of Saudi Economic
Association, September 10-11, 2025, University of Business
and Technology (UBT), Jeddah, Saudi Arabia**



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IN THE NAME OF ALLAH,
MOST GRACIOUS, MOST MERCIFUL

Introduction

The idea of establishing the Saudi Economic Association began as an initiative by the Economics Department at King Saud University in 1982 and the official approval for its establishment was issued by the Scientific Council of the university on 07/04/1985. Since then, SEA is widely considered an umbrella organization for specialists in economics and those interested in economic affairs in the Kingdom of Saudi Arabia. The Association has gained significant importance due to its vital role in providing specialized scientific activities and economic consultancy, as well as its role in raising awareness about all new developments in its field. The Association aims to facilitate the exchange of scientific knowledge and ideas in the economics among the relevant individuals, organizations, and institutions through cooperation with government agencies, the private sector, and research centers. The Saudi Economic Association receives the utmost attention from His Royal Highness Prince Abdulaziz bin Salman bin Abdulaziz Al Saud, the Honorary President of the Association, as well as from officials in the public and private sectors.

SEA has provided various scientific, cultural, and awareness activities since its establishment forty years ago. This included scientific forums of specialists from different institutions, organizing scientific conferences in which scientific papers that discuss contemporary economic developments, as well as the convening of seminars, training courses and workshops that relate to its areas of interest, in addition to the Association's publications such as the semi-annual refereed "Journal of Economic Studies", which began in 1998, and the quarterly "Economy Bulletin", which began in 1990.

The Saudi Economic Association aims to be a leading scientific economic platform at both the Arab and international levels. Therefore, within its research and scientific activities, the association gave a great attention to organizing scientific conferences and forums. These conferences have been considered one of the most prominent contributions of the association since its formation, in view of their importance in raising the level of scientific excellence and in developing the aspects of applied practices, by providing scientific platforms through which experiences are exchanged between economists, academics, and those interested in the field of economics. Moreover, these conferences foster building of bridges of communication, and provide a stimulating environment for researchers and encourage them to conduct specialized research characterized by originality and innovation, in the framework of achieving strategic objectives in line with sustainable development plans and contributing to achieving the Kingdom's Vision 2030, and keeping pace with developments in the global economy.

The 22nd edition of SEA' conference (in September 10th-11th 2025, is part of the Association's series of scientific conferences, under the title "The Economic Impacts of Contemporary Transformations: Prospects and Aspirations".

The theme of the conference and its main objective is in response to the transformations taking place in the global economy, as well as in light of the Kingdom's Vision 2030, which assigned high importance to the economic dimension in order to achieve its goals. This prompted the association to sense the importance of these transformations, hence they became a basis and starting point for this conference. Therefore, it provided an opportunity for researchers, specialists, interested experts, academics and all those related to economics to study these contemporary transformations, analyze them and their impacts, then invest their positives and deal with their challenges, and try to turning them into opportunities for the aim of supporting the sustainable development process that our country seeks under the Kingdom's Vision 2030. The conference will discuss a large number of scientific presentations, including refereed scientific research and valuable working papers, in all the themes of the conference, which are:

- Energy Transformations and their Economic Impact.
- Artificial Intelligence and the Workforce.
- Innovative Development in the field of the Environment.
- Logistics Developments and their Implications for Global Trade.
- Natural Resources and Food Security.

All eighty-nine contributions submitted to the conference were subjected to a rigorous scientific examination and arbitration by a specialized committee in accordance with the procedures and practices followed in international conferences and refereed scientific publishing norms. Sixteen distinguished scientific research papers in the field of economics were accepted according to the approved, precise standards, as well as three working papers in the same field.

In conclusion, I would like to thank all the committees organizing this conference for their great efforts, which lasted for more than twelve months, whether by forming organizational, scientific, and media committees, and the subsequent reception of scientific research papers in the secretariat of the Scientific Committee and its arbitration by members of the Scientific and Specialized Working Papers Committee. I also thank all the members who played a prominent role in coordination, correspondence, and other activities, whether at the Saudi Economic Association at King Saud University or at the University of Business and Technology, in Jeddah.

I also thank the University of Business and Technology in Jeddah for hosting the 22nd annual Conference of the Saudi Economic Association.

May God guide us to the right path.

Chairman of the Board of Directors of the Saudi Economic Association
General Supervisor and Chairman of the Conference Organizing and Scientific Committees
Prof. Ahmed Abdulkarim Al-Mohaimeed

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2	Prof. Ayman Mohamed Zarban	Vice Dean of Graduate Studies at the University of Business and Technology - Jeddah	Moderator of the Research Session: Innovative Development in the field of the Environment
3	Dr. Mamdouh Abdulaziz Al- Faryan	Board Member and Head of the Scientific Committee at The Saudi Economic Association	Moderator of the Research Session: Artificial Intelligence and Workforce
4	Dr. Abdulmohsen Saleh Al Sheikh	Chair of the Partnerships Committee of the Saudi Economic Association, and member of the Board of Directors	Moderator of the Research Session: Logistics Developments and Implications for Global Trade
5	Dr. Talal Hamad Al-Sabhan	Head Department of Economics at King Saud University, Financial Secretary of the Saudi Economic Association, and member of the Board of Directors	Moderator of the Working Papers Session
6	Dr. Hatim Khalid Akeel	Former Vice President for Academic Affairs, the University of Business and Technology, Jeddah	Moderator of the Research Session: Natural Resources and Food Security

Moderators of the Conference Research Sessions

Serial No.	Name	Profession	Capacity of Participation
1	Mr. Amine Mati	Assistant Director, Mission Chief for Saudi Arabia and Head GCC Division, International Monetary Fund	The guest-in-honor of the session presented by the International Monetary Fund, entitled: "The IMF's view on the Saudi Economy"
2	Dr. Said Abdullah Al Shaikh	Director General of the Center for Studies and Consultations at the University of Business and Technology - Jeddah	Moderator of the World Bank Session entitled: "The IMF's view on the Saudi Economy" And Participant in the Discussion Session entitled: "Modern Logistics Structure: Improving Efficiency and Enabling Innovation in the Global Economy"
3	Dr. Ruaa Omar Binsaddig	Dean of Scientific Research at the University of Business and Technology - Jeddah	Moderator of the Discussion entitled: "Modern Logistics Structure: Improving Efficiency and Enabling Innovation in the Global Economy"
4	Prof. Ahmed Abdulkarim Al-Mohaimeed	Chairman of the Board of Directors of the Saudi Economic Association	Participant in the Discussion Session entitled: "Modern Logistics Structure: Improving Efficiency and Enabling Innovation in the Global Economy"
5	Dr. Mohammed Talaat Khoj	Dean of the College of Engineering at the University of Business and Technology	Participant in the Discussion Session entitled: "Modern Logistics Structure: Improving Efficiency and Enabling Innovation in the Global Economy"
6	Dr. Abdulmohsen Saleh Al-Sheikh	Member of the Partnerships Committee of the Saudi Economic Association, and member of its Board of Directors	Participant in the Discussion Session entitled: "Modern Logistics Structure: Improving Efficiency and Enabling Innovation in the Global Economy"

Researchers participating in articles and working papers presentation

Serial No.	Researcher	Institution	Type of participation
1	Eng. Mohammed AL-Sadig AL-Haj	Sulaiman Al Rajhi University, KSA.	Article presentation
2	Dr.Rayan Salem Hammad	Taibah University, Madinah, KSA.	Article presentation
3	Prof. Ali Abdelwahab Naga	Alexandria University, Egypt	Article presentation
4	Dr.Fatma Ahmed Hassan	Princess Nourah bint Abdulrahman University, KSA.	Article presentation
5	Dr.Elwalied Norehuda A. Kunna	Islamic University of Madina, KSA.	Article presentation
6	Mr. Mansour A. Al-Obaid	Ministry of Environment, Water and Agriculture, Riyadh, KSA.	Article presentation
7	Dr.Sana Naseem	Al Yamamah University, Riyadh, KSA	Article presentation
8	Prof. Bashier Al-Abdulrazag	King Saud University, KSA.	Article presentation
9	Prof .Nourah A. Alyousef	Chair of the Economic Center for Research and Consulting - Riyadh	Working paper presentation
10	Dr. Yasir Ali Sallal Al-Malki	Taibah University, KSA.	Working paper presentation
11	Dr. Ghada Othman Al-Sayed	Shaqra University, KSA.	Working paper presentation

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English Section

First: Articles

Economic and Environmental Benefits of Energy Transition in Saudi Arabia: A Case Study of Sakaka Solar Power Plant

Mohammed AL-Sadig M. AL-Haj⁽¹⁾

(Received: Aug 04, 2024 – Accepted for publication: Oct 20, 2024)

Abstract: In the context of global efforts to transition to renewable energy, the Sakaka Solar Power Plant represents a pivotal development in Saudi Arabia's energy landscape, aligning with Vision 2030 goals of economic diversification and environmental sustainability. This study aims to evaluate the economic and environmental impacts of the Sakaka Solar Power Plant, Saudi Arabia's first utility-scale renewable energy project. Using a comprehensive case study approach, data were collected and analyzed utilizing key financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Profitability Index (PI), and Benefit-Cost Ratio (BCR), alongside environmental impact assessments. The results indicate a positive NPV of \$566 million, an IRR of 20.19%, and a payback period of 4.90 years, confirming the project's financial viability and attractiveness to investors. Environmentally, the project contributes to a significant annual reduction of 430,000 tons of carbon emissions, totaling 10.75 million tons over its lifespan. These findings underscore the potential of renewable energy projects in Saudi Arabia to deliver substantial economic returns and environmental benefits. Policy recommendations include enhancing support for renewable energy projects through financial incentives, fostering public-private partnerships, and promoting localization to stimulate economic growth and technological innovation, thereby advancing the objectives of Vision 2030. Additionally, aligning with global trends highlighted by the World Economic Forum (2023), the successful implementation of the Sakaka project demonstrates Saudi Arabia's commitment to fostering effective energy transition.

Key Words: Renewable Energy, Energy Transition, Solar Energy, Sustainability, Energy Economics, Carbon Emissions.

المناخ الاقتصادية والبيئية للتحويل الطاقوي في المملكة العربية السعودية: حالة دراسة محطة سكاكا للطاقة الشمسية

م. محمد الصادق مصطفى الحاج⁽¹⁾

(قُدِّمَ للنشر: 04 أغسطس، 2024م – وقُبِلَ للنشر: 20 أكتوبر، 2024م)

المستخلص: في سياق الجهود العالمية للتحويل إلى الطاقة المتجددة، تمثل محطة سكاكا للطاقة الشمسية تطوراً محورياً في مشهد الطاقة في المملكة العربية السعودية، متماشية مع أهداف رؤية 2030 في تنوع الاقتصاد والاستدامة البيئية. تهدف هذه الدراسة إلى تقييم التأثيرات الاقتصادية والبيئية لمحطة سكاكا للطاقة الشمسية، أول مشروع للطاقة المتجددة على نطاق المرافق في المملكة. باستخدام نهج دراسة حالة شاملة، تم جمع البيانات وتحليلها باستخدام مقاييس مالية رئيسية مثل صافي القيمة الحالية (NPV)، ومعدل العائد الداخلي (IRR)، وفترة الاسترداد، ومؤشر الربحية (PI)، ونسبة الفائدة إلى التكلفة (BCR)، بالإضافة إلى تقييمات التأثير البيئي. تشير النتائج إلى صافي قيمة حالية إيجابية بمقدار 566 مليون دولار، ومعدل عائد داخلي بنسبة 20.19%، وفترة استرداد تبلغ 4.90 سنوات، مما يؤكد جدوى المشروع المالية وجاذبيته للمستثمرين. بيئياً، يسهم المشروع في تقليل انبعاثات الكربون بمعدل سنوي يبلغ 430,000 طن، بإجمالي 10.75 مليون طن على مدار عمره. تؤكد هذه النتائج على قدرة مشاريع الطاقة المتجددة في السعودية على تحقيق عوائد اقتصادية كبيرة وفوائد بيئية ملموسة. تشمل التوصيات السياساتية تعزيز الدعم لمشاريع الطاقة المتجددة من خلال الحوافز المالية، وتعزيز الشراكات بين القطاعين العام والخاص، وتشجيع التوطين لتحفيز النمو الاقتصادي والابتكار التكنولوجي، وبالتالي تعزيز أهداف رؤية 2030. بالإضافة إلى ذلك، وبما يتماشى مع التوجهات العالمية التي أبرزها المنتدى الاقتصادي العالمي (2023)، يُظهر التنفيذ الناجح لمشروع سكاكا التزام المملكة العربية السعودية بتعزيز التحول الفعال للطاقة.

الكلمات المفتاحية: الطاقة المتجددة، التحول في مجال الطاقة، الطاقة الشمسية، الاستدامة، اقتصاديات الطاقة، انبعاثات الكربون.

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1. Introduction:

Innovative renewable energy projects are central to achieving the goals of Vision 2030, as Saudi Arabia seeks to achieve economic and environmental sustainability by diversifying energy sources and promoting a knowledge-based economy. In recent years, investments in renewable energy have garnered increasing global attention, driven by the need to achieve sustainable development policies encompassing economic, social, and environmental dimensions [1]. There is a strong relationship between energy consumption and development, as evidenced during the Industrial Revolution when production technology shifted from human labor to machinery, leading to increased use of coal to generate steam [2]. Numerous studies highlight a significantly positive relationship between global growth and energy demand [3]. Future energy demand is expected to rise due to continued population and economic growth [3]. Saudi Arabia's energy consumption is the highest in the Middle East, with an average oil consumption of approximately 4.3 million barrels per day (bpd) by the end of 2019, compared to an average of 4.1 million bpd in 2018 [4]. By the end of 2018, Saudi Arabia consumed around 289.9 terawatt-hours (TWh) of energy, representing a year-on-year increase of 0.42 percent compared to 2017 [5]. Due to high non-oil economic growth, population fertility, and desalination efforts, domestic energy consumption in Saudi Arabia remains exceptionally high [6].

1.1 Motivation and Objectives of the Study

The transition to renewable energy sources is a strategic imperative for Saudi Arabia as it seeks to achieve the goals of Vision 2030, which emphasizes economic diversification and environmental sustainability. The motivation behind this study is to evaluate the economic and environmental benefits of renewable energy projects, using the Sakaka Solar Power Plant as a case study. The objectives are:

- To assess the financial viability of the Sakaka Solar Power Plant using key economic indicators.
- To evaluate the environmental impact, particularly in terms of carbon emission reductions.
- To compare the Sakaka project with similar international projects to position it within a global context.
- To provide policy recommendations that support the expansion of renewable energy in Saudi Arabia.

1.2 Importance of Renewable Energy Globally and in Saudi Arabia:

1.2.1 Importance of Renewable Energy Globally

In recent years, the world has witnessed a significant shift towards renewable energy sources as part of global efforts to combat climate change and promote environmental sustainability. This shift is driven by the growing recognition that renewable energy provides a long-term solution to the increasing global energy demand without adversely affecting the environment [7]. As more countries adopt policies and programs to support renewable energy, it has become evident that renewables will play a critical role in ensuring a sustainable future for future generations [8]. According to the International Renewable Energy Agency (IRENA), the global total renewable energy capacity reached new levels, with an installed capacity of 2799 gigawatts as of 2023 [9].

The United Nations Sustainable Development Goals (SDGs) emphasize the importance of access to sustainable, modern, reliable, and affordable energy for all (SDG 7) [10]. This global goal includes increasing the share of renewable energy in the global energy mix and improving energy efficiency. Previous analyses of future energy pathways indicate that it is technically possible to simultaneously achieve improved energy access, air quality, and energy security while avoiding dangerous climate change [11]. However, achieving these goals requires rapid policy implementation and fundamental political changes to integrate global concerns, such as climate change, into local and national policy priorities [12]. Integrated policy design is crucial for identifying cost-effective solutions that can achieve multiple goals simultaneously [13].

1.2.2 Importance of Renewable Energy in Saudi Arabia

Saudi Arabia has placed renewable energy at the core of its Vision 2030, aiming to diversify its economy and reduce its reliance on oil [14]. The Kingdom leverages its abundant sunshine to develop large-scale solar energy projects and explore wind energy potentials, benefiting from its vast desert

expanses [15]. By 2024, Saudi Arabia aims to achieve an installed capacity of 27.3 gigawatts of renewable energy, paving the way for a more diverse and sustainable energy mix [16].

1.2.3 The Importance of Transitioning to Renewable Energy for Sustainable Development

Transitioning to renewable energy is not only an environmental or economic necessity but also a strategic imperative for achieving long-term sustainability and economic diversification. This transition is driven by the urgent need to reduce greenhouse gas emissions, as outlined in the Paris Agreement [17]. Economies heavily reliant on oil face significant risks due to oil price volatility and the finite nature of fossil fuel resources, making energy diversification essential for economic stability [4]. Technological advancements have made renewable energy sources such as solar and wind power more feasible and cost-effective [18]. Saudi Arabia is particularly well-suited to benefit from these advancements, given its high solar radiation and vast desert areas suitable for large solar energy projects [19]. Additionally, investing in renewable energy creates new job opportunities, fosters technological innovation, and attracts foreign investments [3].

An essential element of Saudi Vision 2030 is the transformation of the energy sector, with a focus on increasing the share of renewable energy. The Kingdom aims to generate 9.5 gigawatts of renewable energy by 2023, laying the foundation for a more diverse and sustainable energy mix [16].

1.3 Renewable Energy in Saudi Arabia

1.3.1 Economic Benefits of Transitioning to Renewable Energy

The shift to renewable energy in Saudi Arabia significantly drives job creation and economic growth. Solar and wind projects generate thousands of new jobs in engineering, construction, and maintenance, fostering economic diversification and reducing oil dependency [22]. Additionally, Saudi Arabia's strategic location attracts substantial foreign investments, enhancing infrastructure and advancing local technological capabilities through the National Renewable Energy Program (NREP) [20]. The government supports the private sector by implementing incentivizing policies, including financial facilities and tax incentives, which balance cost-efficiency and stimulate market innovation [23]. Furthermore, renewable energy enhances energy security by diversifying energy sources and reducing reliance on oil imports, ensuring stable energy supplies and mitigating the economic impacts of global oil price fluctuations [26].

1.3.2 Environmental Benefits of Renewable Energy

Renewable energy projects play a crucial role in reducing carbon emissions and other pollutants in Saudi Arabia. By replacing fossil fuels with clean energy sources like solar and wind power, the Kingdom can significantly lower carbon dioxide emissions and improve air quality [24]. Additionally, renewable energy helps preserve natural resources by minimizing the consumption of finite resources such as oil and gas, ensuring their sustainability for future generations and supporting ecosystem health [25]. These initiatives are integral to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 7, which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all, thereby promoting balanced economic, social, and environmental development [26].

1.3.3 Energy Sector Transformation in Saudi Arabia under Vision 2030

Under Vision 2030, Saudi Arabia is undergoing a profound transformation of its energy sector to reduce oil dependence and promote renewable energy as a cornerstone of sustainable development [14]. The National Renewable Energy Program (NREP), launched in 2017 alongside the National Transformation Program 2020, aims to install 27.3 gigawatts of renewable energy capacity by 2024, up from an initial target of 9.5 gigawatts [21]. This ambitious program, with an expected investment of approximately 60 billion Saudi riyals, seeks not only to reduce fuel dependency and emissions but also to create job

opportunities, stimulate economic development across all regions, develop advanced renewable technologies, and strengthen public-private partnerships [21].



Figure 1. Saudi Arabia significantly increased its renewable energy targets and long-term visibility.
Reference: Saudi Renewable Energy Program

1.3.4 National Renewable Energy Program (NREP)

The National Renewable Energy Program (NREP) was launched in 2017 under Vision 2030 and the National Transformation Program 2020. It is designed to balance local energy sources and meet the Kingdom's commitments to reducing carbon dioxide emissions. According to the new renewable energy strategy, the solar target for 2023 has been raised from 5.9 GW to 20 GW, aiming to modify renewable energy sources from 9.5 GW to 27.3 GW, representing more than 10% of the Kingdom's total energy production. The investment volume in the National Renewable Energy Program projects is expected to reach around 60 billion Saudi riyals. The NREP aims to diversify energy sources in Saudi Arabia, providing sustainable economic stability in line with Vision 2030 goals. The program's objectives are not limited to reducing fuel dependency and emissions but also aim to provide more job opportunities and stimulate economic development in all regions and cities of the Kingdom. Furthermore, it aims to develop modern renewable energy technologies and strengthen partnerships between the public and private sectors. Accordingly, the Ministry of Energy launched the Renewable Energy Project Development Office (REPDO) to achieve the NREP's goals, unify specialized capacities in energy research, and issue renewable energy tenders. In 2019, REPDO offered more than 2000 MW of solar energy [21].

Overview of NREP Projects:

First Phase: Includes the Sakaka Solar Project (300 MW) and Dumat Al-Jandal Wind Project (400 MW), providing electricity to 115,000 homes and reducing 430,000 tons of carbon emissions annually.

Second Phase: Comprises projects in Qurayyat (200 MW), Madinah (50 MW), Rafha (20 MW), Al-Faisaliah (600 MW), Rabigh (300 MW), Jeddah (300 MW), Mahad Dhahab (20 MW), and Yanbu Wind Project (850 MW), totaling 3.07 GW and expected to generate electricity for 226,500 households by 2023 with private sector investments reaching 5.2 billion Saudi riyals [21].

Third Phase: Involves four photovoltaic projects totaling 1,200 MW, including Layla (80 MW), Wadi Al-Dawasir (120 MW), Saad (300 MW), and Al-Rass (700 MW) [21].

1.3.5 Energy Statistics and Transformations

By the end of 2023, Saudi Arabia's installed renewable energy capacity reached 2.8 gigawatts, with ongoing projects pushing this figure beyond 8 gigawatts [24]. The Ministry of Energy targets generating 50% of the Kingdom's electricity from renewable sources by 2030, supported by significant expansions

in solar and wind projects, investments in energy storage technology, and smart grids [29]. According to the Saudi General Authority for Statistics (Renewable Energy Statistics 2022), renewable projects are expected to generate 43,698 gigawatt-hours annually, supply electricity to 2.6 million homes, and reduce carbon dioxide emissions by approximately 24.8 million tons each year, as illustrated in Figure 2 and Figure 3 [30].

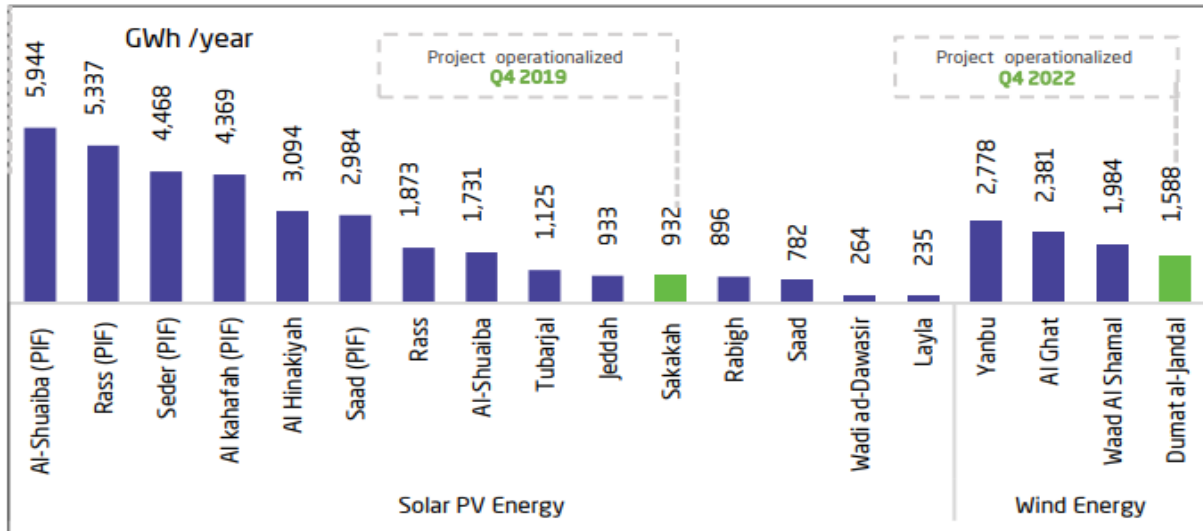


Fig2. Electricity targeted to be generated from renewable energy projects annually. [Reference: Saudi General Authority for Statistics. (2022). Renewable Energy Statistics 2022. Retrieved from [Statistics](#)].

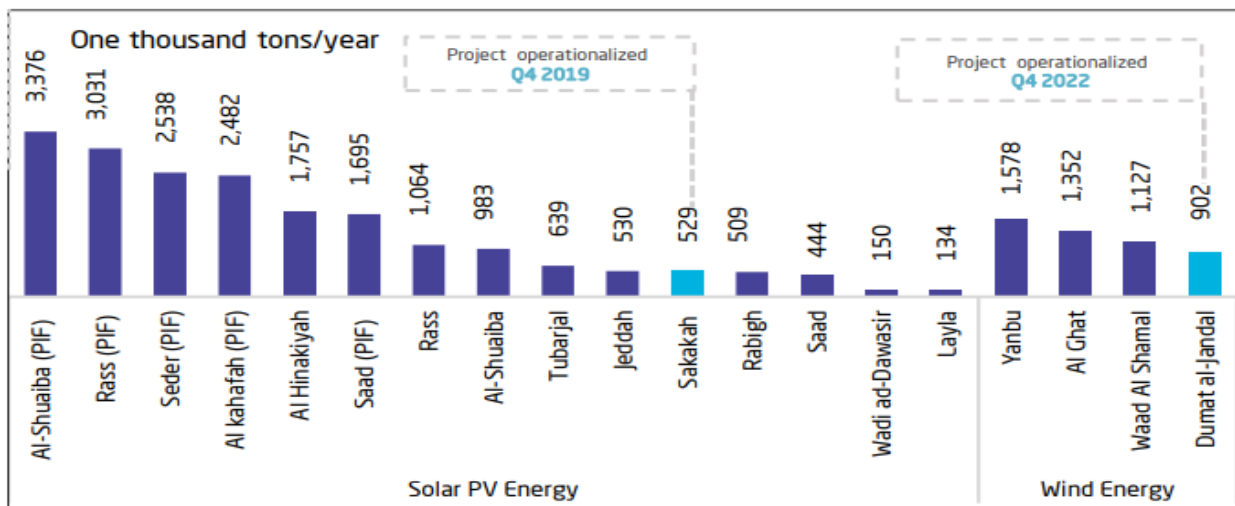


Fig3. Expected environmental impact of projects on reducing carbon dioxide emissions. [Reference: Saudi General Authority for Statistics. (2022). Renewable Energy Statistics 2022. Retrieved from [Statistics](#)].

1.3.6 Localization Strategies and Objectives in Saudi Arabia's Renewable Energy Sector under Vision 2030

Localization of the renewable energy sector is a key objective under Vision 2030. The Ministry of Energy, Industry, and Mineral Resources (MEIM) and the Public Investment Fund (PIF) are promoting local manufacturing to achieve global competitiveness and develop resilient supply chains [23]. Key strategies include:

- **Local Content Requirements:** Mandating that a specific percentage of project costs be spent locally, increasing to 40-45% by 2028 to ensure job creation and skills development

[39]. While beneficial, these requirements may raise the levelized cost of energy and affect economies of scale if not aligned with existing industrial capacities [38].

- **Supply Chain Development:** Addressing challenges such as raw material constraints and global trade disruptions by leveraging Saudi Arabia's abundant mineral resources, domestic demand, and competitive energy costs. Establishing large local markets and production facilities is essential, alongside coordinating market policies across the Middle East and North Africa [38].

- **Practical Measures:** Implementing the "Local Content Compliance Mechanism" to award points for locally produced materials, thereby incentivizing local manufacturing and enhancing the renewable energy ecosystem [38].

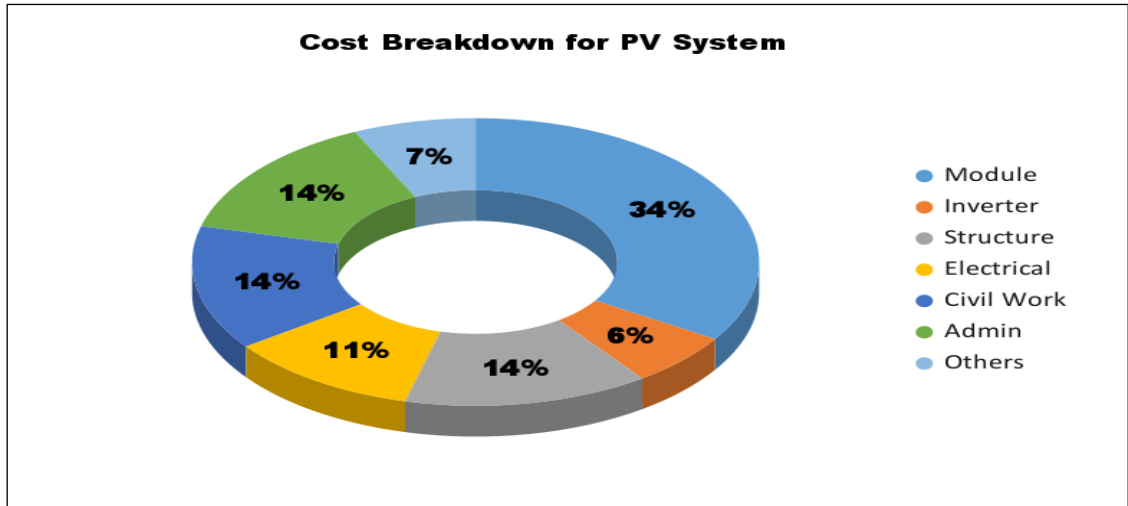


Fig4. Cost Breakdown for PV System. [Reference: AlOtaibi, Z.S., Khonkar, H.I., AlAmoudi, A.O. et al. Current status and future perspectives for localizing the solar photovoltaic industry in the Kingdom of Saudi Arabia. *Energy Transit* 4, 1–9 (2020). <https://doi.org/10.1007/s41825-019-00020-y>].

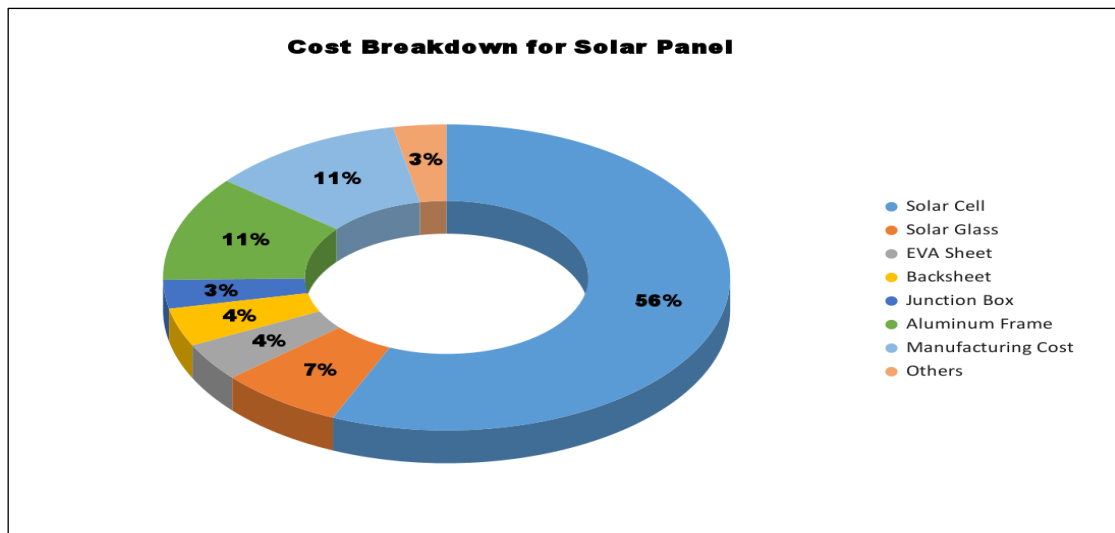


Fig5. Cost Breakdown for Solar Panel. [Reference: AlOtaibi, Z.S., Khonkar, H.I., AlAmoudi, A.O. et al. Current status and future perspectives for localizing the solar photovoltaic industry in the Kingdom of Saudi Arabia. *Energy Transit* 4, 1–9 (2020). <https://doi.org/10.1007/s41825-019-00020-y>].

The Importance of the Domestic Market

A crucial factor in developing renewable energy industries is the domestic market's ability to expand into regional and global markets. Saudi Arabia's abundant wind and solar resources, coupled with its strategic location as a trade hub linking Africa, Europe, and Asia, provide significant opportunities to boost investment in local industries and develop the regional market, especially in the Middle East and North Africa [38]. To achieve the goal of 40 GW by 2030, Saudi Arabia must increase its current solar capacity by approximately 110-fold. Large-scale projects such as the 300 MW Sakaka plant must achieve more than 30% local content, which could increase by 19% if all modules were manufactured within the Kingdom rather than imported [39].

Government Initiatives and Incentives

Saudi Arabia is committed to transforming its energy system and building local capacity under Vision 2030, offering various policy-related incentives to boost trade, attract foreign direct investment, develop technology infrastructure, encourage local employment, and enhance local capabilities. For example, support mechanisms have been launched for manufacturers to access export financing through the Saudi Export Development Authority and the Saudi Export-Import Bank [38].

Ministry of Investment's Role

The Ministry of Investment is actively facilitating opportunities in the green energy sector by developing cross-governmental sectoral ecosystems and supporting companies in their investment processes. Saudi companies are gradually establishing themselves in local supply chains, laying the foundation for Saudi-Chinese cooperation [39]. For instance, Desert Technologies established the first solar PV manufacturing plant in Saudi Arabia in 2011, with a production capacity of 300 megawatts per year, and has started exporting its products globally. The Kingdom is expanding its production to include energy storage solutions and electric vehicle charging systems. In 2021, Alfanar acquired India's Servion to accelerate the localization of wind energy manufacturing and participate in the development of the Indian market [38].

1.4 Previous Studies and Research Gaps

Extensive research has been conducted on the economic and environmental impacts of renewable energy in Saudi Arabia, highlighting both opportunities and challenges in the sector. Alghamdi et al. (2022) explored the supply chain readiness for solar photovoltaic (PV) expansion in Saudi Arabia, emphasizing the importance of local content policies and the need for robust supply chain infrastructures to support large-scale solar projects [40]. Their study underscores the critical role of government incentives and regulatory frameworks in fostering a conducive environment for renewable energy investments. Similarly, Khaled Abdalla Moh'd Al-Tamimi et al. (2023) examined the broader economic implications of renewable energy adoption in Saudi Arabia, demonstrating that renewable projects significantly contribute to job creation, economic diversification, and enhanced energy security [41]. This research provides valuable insights into the macroeconomic benefits of transitioning to renewable energy sources, aligning with the strategic objectives of Vision 2030.

In the realm of technical and economic feasibility, a study by Al-Otaibi et al. (2019) assessed the viability of utility-scale solar energy conversion systems in Saudi Arabia. The research highlighted the favorable solar irradiance conditions and declining costs of photovoltaic technologies as key factors supporting the expansion of solar energy [42]. Additionally, a recent article published in *Energy Policy* (2024) delved into the integration challenges of renewable energy into Saudi Arabia's existing energy infrastructure, identifying technical bottlenecks and proposing solutions to enhance grid stability and energy storage capabilities [43].

Despite the significant advancements, several research gaps remain. Firstly, while existing studies have extensively covered the economic benefits and technical feasibility of renewable energy projects, there is a paucity of comprehensive analyses that concurrently evaluate both economic and environmental impacts within a unified framework. Most studies tend to focus on one aspect, thereby overlooking the synergistic effects that can be harnessed from an integrated approach. Secondly, there is limited research on the long-term sustainability and lifecycle impacts of renewable energy projects in

Saudi Arabia, particularly concerning resource utilization and waste management. Lastly, comparative analyses between Saudi Arabian projects and international counterparts are scarce, which hinders the ability to benchmark performance and identify best practices that could be adapted to the local context.

This study aims to address these gaps by providing a holistic assessment of the Sakaka Solar Power Plant, integrating both economic and environmental evaluations. By employing a comprehensive methodology that includes Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Profitability Index (PI), and Benefit-Cost Ratio (BCR), alongside an Environmental Impact Assessment (EIA) and Life Cycle Analysis (LCA), this research seeks to offer a more nuanced understanding of the multifaceted benefits of renewable energy projects. Furthermore, the comparative analysis with international projects such as the Tengger Desert and Ivanpah Solar Power Plants will position the Sakaka project within a global context, highlighting its unique contributions and areas for improvement.

2. Methodology

The study is grounded in the principles of environmental economics and sustainable development. Economic indicators such as NPV and IRR are used to assess financial viability, while environmental impact assessments consider the project's contribution to sustainability goals.

2.1 Methodology Overview

This methodology is designed to thoroughly evaluate both the economic and environmental impacts of the Sakaka Solar Power Plant. The analysis consists of several key steps:

1. **Case Study Analysis:** Understanding the specific details of the Sakaka project.
2. **Data Collection:** Gathering data from credible sources about the project's technical specifications, financial metrics, and environmental benefits.
3. **Data Analysis:**
 - **Economic Analysis:** Performing a Cost-Benefit Analysis (CBA) including NPV, IRR, payback period, PI, and BCR.
 - **Environmental Analysis:** Conducting an Environmental Impact Assessment (EIA) and Life Cycle Analysis (LCA).
4. **Comparative Analysis:** Comparing the Sakaka project with similar international projects.
5. **Conclusions and Recommendations:** Summarizing findings and providing actionable recommendations.

Justification of Statistical Methods

The statistical methods used, such as NPV and IRR calculations, are standard in financial analysis for evaluating investment projects [19]. Sensitivity analysis is employed to assess the robustness of the results under different scenarios, enhancing the reliability of the conclusions.

2.2 Case Study

The Sakaka Independent Photovoltaic Solar Power Plant, with a capacity of 300 MW, is the first utility-scale renewable energy project in Saudi Arabia. The project was awarded to ACWA Power at a record-breaking tariff of 2.3417 cents per kWh. The plant spans 6 square kilometers in the Al Jouf region, with an investment of \$302 million [20].

2.2.1 Data Collection

Data for the Sakaka Solar Power Station case study was sourced from three primary references and includes: [31,32,33].

- **Capacity:** 300 MW
- **Cost:** \$302 million
- **Levelized Cost of Electricity (LCOE):** 2.3417 cents per kWh
- **Operation Year:** 2020
- **Reduced Emissions:** 430,000 tons annually

2.2.2 Data Analysis

Economic Analysis:

The economic analysis utilizes several financial metrics to assess the project's viability:

Cost-Benefit Analysis (CBA):

1. Initial Costs: \$302 million

2. Estimated Annual Revenue:

$$\text{Annual Revenue} = \text{Capacity} \times \text{Annual Hours} \times \text{Electricity Price}$$

$$\text{Annual Revenue} = 300 \text{ MW} \times 8760 \text{ hours} \times 0.023417 \text{ USD/kWh} = 61,608,852 \text{ USD}$$

3. Net Present Value (NPV):

$$\text{NPV} = \sum (B_t - C_t) / (1 + r)^t$$

Where:

- B_t is the annual revenue.
- C_t is the annual costs.
- r is the discount rate.
- t is the number of years.

Internal Rate of Return (IRR):

$$\text{IRR} = \text{Discount rate where NPV} = 0$$

Payback Period:

$$\text{Payback Period} = \text{Initial Investment} / \text{Annual Revenue}$$

Profitability Index (PI):

$$\text{PI} = (\text{NPV} + \text{Initial Investment}) / \text{Initial Investment}$$

Benefit-Cost Ratio (BCR):

$$\text{BCR} = \sum (B_t / (1 + r)^t) / \sum (C_t / (1 + r)^t)$$

Simple Rate of Return:

$$\text{Simple Rate of Return} = (\text{Annual Revenue} - \text{Annual Costs} / \text{Initial Investment}) \times 100\%$$

$$\text{Simple Rate of Return} = (\text{Initial Investment} / (\text{Annual Revenue} - \text{Annual Costs})) \times 100\%$$

- **Explanation:** This measures the percentage return on the initial investment, indicating the project's efficiency.

Environmental Analysis:

Emission Reductions:

$$\text{Total Emission Reductions} = \text{Annual Reductions} \times \text{Project Duration}$$

Life Cycle Analysis (LCA):

- **Production:** Use of sustainable materials and technologies.
- **Operation:** Reduction of carbon emissions and provision of clean energy.
- **Disposal:** Waste management and recycling after the project lifespan.

2.2.3 Analysis Using MATLAB

After collecting the data for the project and developing the equations that will be relied upon in the economic and environmental analysis, they will be applied to the MATLAB program. Figure 6 shows the code used and the equations.

```

MATLAB Drive > lk.m
1 % Project data
2 investment = 302000000; % Initial investment in USD
3 annual_revenue = 61608852; % Annual revenue in USD
4 discount_rate = 0.05; % Discount rate
5 years = 25; % Project duration
6
7 % Calculate NPV
8 NPV = sum(annual_revenue ./ (1 + discount_rate) .^ (1:years)) - investment;
9
10 % Calculate IRR
11 cash_flows = [-investment, repmat(annual_revenue, 1, years)]; % Annual cash flows
12 IRR = irr(cash_flows);
13
14 % Calculate Payback Period
15 payback_period = investment / annual_revenue;
16
17 % Calculate Profitability Index
18 PI = (NPV + investment) / investment;
19
20 % Calculate BCR
21 BCR = sum(annual_revenue ./ (1 + discount_rate) .^ (1:years)) / investment;
22
23 % Display results
24 disp(['NPV: $', num2str(NPV)]);
25 disp(['IRR: ', num2str(IRR * 100), '%']);
26 disp(['Payback Period: ', num2str(payback_period), ' years']);
27 disp(['Profitability Index: ', num2str(PI)]);
28 disp(['Benefit-Cost Ratio: ', num2str(BCR)]);
29
30 % Plot cash flows
31 years_array = 0:years;
32 cash_flows_array = [-investment, repmat(annual_revenue, 1, years)];
33 figure;
34 bar(years_array, cash_flows_array);
35 xlabel('Years');
36 ylabel('Cash Flows ($)');
37 title('Cash Flows over the Project Lifetime');
38 grid on;
39
40 % Calculate emission reductions
41 CO2_reduction_per_year = 430000; % tons annually
42 total_CO2_reduction = CO2_reduction_per_year * years;
43 disp(['Total CO2 Reduction: ', num2str(total_CO2_reduction), ' tons']);
44
45 % Plot NPV over time
46 npv_values = cumsum(cash_flows_array ./ (1 + discount_rate) .^ (0:years));
47 figure;
48 plot(years_array, npv_values, '-o');
49 xlabel('Years');
50 ylabel('Net Present Value ($)');
51 title('NPV over Project Lifetime');
52 grid on;
53

```

Fig6.Code used in MATLAB program.

Table 1 shows the results of the calculations, which were calculated using MATLAB. Figure 7 also shows the cash flow of the project for a period of 25 years with a discount rate of 5% and figure 8 shows Net present value for 25 years.

Table1. Analysis and calculation results.

Parameter	Result
Net Present Value (NPV)	\$566311744.8657
Internal Rate of Return (IRR)	20.1949%
Payback Period	4.9019 years
Profitability Index (PI)	2.8752
Benefit-Cost Ratio (BCR)	2.8752
Total CO2 Reduction	10750000 tons

Net Present Value (NPV): \$566,311,744.87

- **Analysis:** The positive and substantial NPV indicates that the project is highly profitable over the 25-year period. The project generates significant financial returns that exceed the initial investment costs.

Internal Rate of Return (IRR): 20.1949%

- **Analysis:** The IRR is significantly higher than the assumed discount rate (5%), suggesting that the project offers a good return on investment. This high rate is a strong indicator for attracting investors.

Payback Period: 4.9019 years

- **Analysis:** A relatively short payback period (less than 5 years) indicates that the project recoups its costs quickly. This is a significant advantage for investment projects, as it reduces the risks associated with long-term investments.

Profitability Index (PI): 2.8752

- **Analysis:** A PI greater than 1 indicates that the project is profitable and generates good returns compared to its costs. Specifically, for every dollar invested in the project, the investor receives a return of \$2.8752.

Benefit-Cost Ratio (BCR): 2.8752

- **Analysis:** A BCR greater than 1 also indicates that the benefits of the project far outweigh its costs. This makes the project attractive for investment.

Simple Rate of Return: 20.39%

- **Analysis:** This high percentage reflects the project's efficiency in delivering returns on the initial investment.

Total CO2 Reduction: 10,750,000 tons

- **Analysis:** A substantial reduction in CO2 emissions contributes significantly to improving air quality and reducing the environmental footprint. This environmental aspect enhances the project's value and supports sustainability goals.

Sensitivity Analysis

- **NPV over Time:**

- **Analysis:** The NPV plot shows a steady increase over the project lifespan, indicating growing project value and positive financial stability.

- **Impact of Discount Rate and Electricity Prices:**

- **Analysis:** Sensitivity to these variables underscores the project's resilience and adaptability under different economic conditions, reinforcing its robust financial outlook.

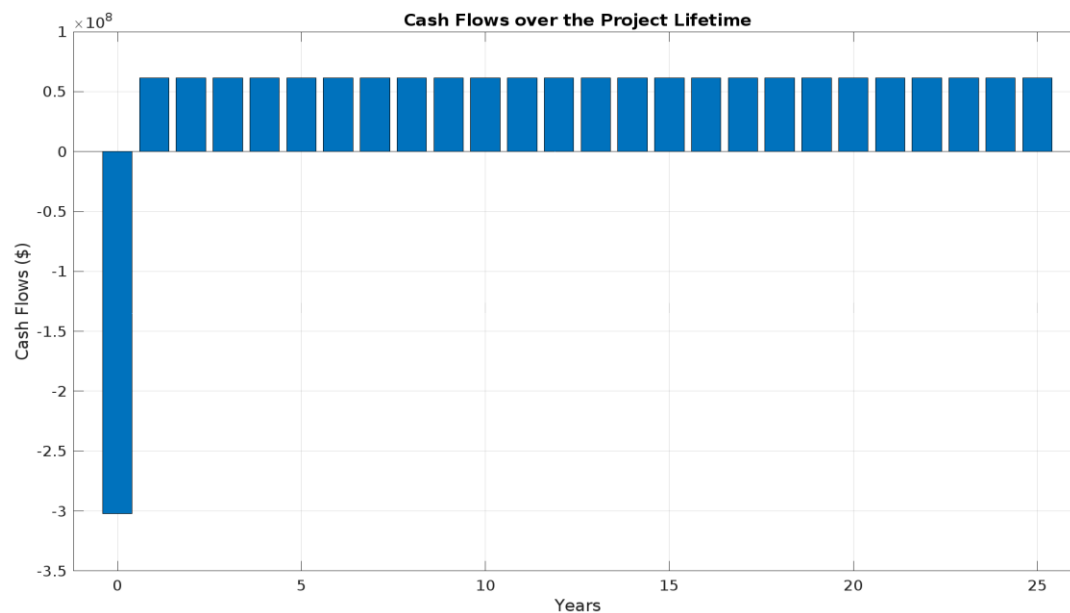


Fig7. cash flow of the project from the MATLAB program.

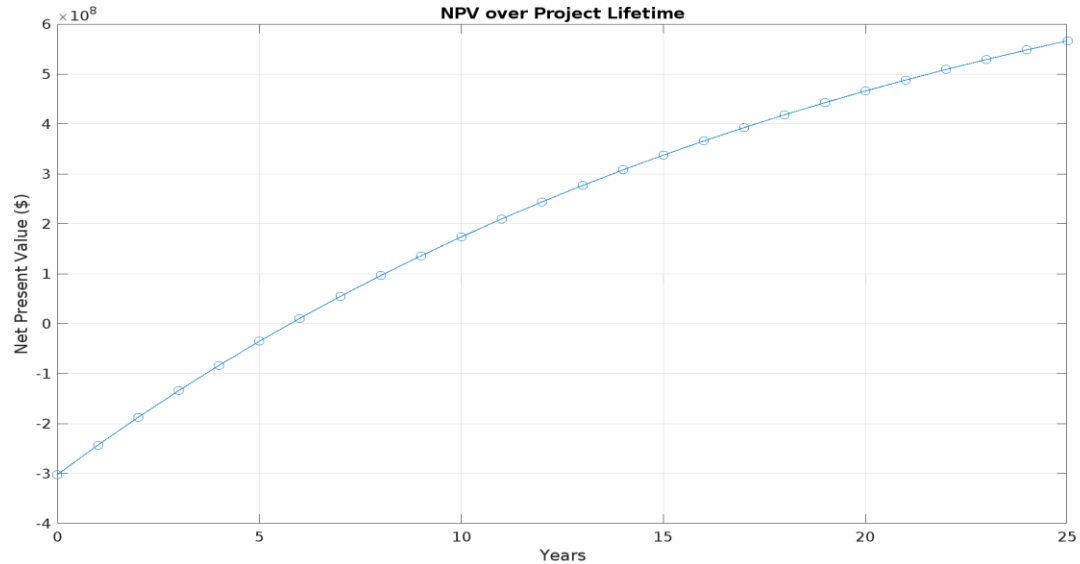


Fig8. Net Present Value of the project from the MATLAB program.

Cash Flows over the Project Lifetime:

- **Analysis:** The graph shows positive annual cash flows following the significant initial investment. This pattern reflects steady and stable cash flows throughout the project's lifespan, indicating good financial stability.

- **Recommendation:** Maintaining this financial stability can help attract more investments and funding for future projects.

Sensitivity Analysis:

- **NPV over Time:**

- **Analysis:** The NPV plot shows a steady increase over the project lifespan, indicating growing project value and positive financial stability.

- **Impact of Discount Rate and Electricity Prices:**

- **Analysis:** Sensitivity to these variables underscores the project's resilience and adaptability under different economic conditions, reinforcing its robust financial outlook.

2.2.4 Conclusion and Recommendations

3 **Economic Viability:** The Sakaka Solar Power Plant is financially viable, with strong NPV, IRR, and profitability metrics. Continued monitoring of electricity prices and discount rates is recommended to sustain financial stability.

4 **Environmental Impact:** The project's significant CO₂ emissions reduction aligns with sustainability goals, further enhancing its environmental value.

5 **Future Prospects:** This successful model can be replicated in similar ventures, with recommendations to optimize cost-efficiency and maximize environmental benefits.

- **Additional Economic Analysis**

Long-term Economic Impact Analysis

1. **Job Creation:** The project created approximately 400 jobs during construction and supports permanent local jobs during operation.

2. **Expected Financial Returns:** Using NPV, IRR, Profitability Index, and Payback Period.

3. **Impact on Local Economic Growth:** Enhances local economy by improving infrastructure and providing clean, sustainable energy.

Life Cycle Analysis (LCA)

Evaluating Environmental Impact from Production to Disposal:

- **Production:** Use of sustainable materials and technologies.
- **Operation:** Reduction of carbon emissions and provision of clean energy.
- **Disposal:** Waste management and recycling after the project's lifespan.

• Additional Environmental Analysis

1. **Studying the Project's Impact on Biodiversity and Natural Resources:** Analyze how the project affects local wildlife and plants.
2. **Estimating Additional Environmental Benefits:** Such as improved air quality and reduced reliance on fossil fuels.

2.3 Comparative Analysis

2.3.1 Selecting Similar Global Projects:

- Ivanpah Solar Power Plant (USA) [34].
- Tengger Desert Solar Power Plant (China) [35,36].

Table 2 below presents a detailed comparison between these three prominent solar power projects, highlighting their capacity, cost, and CO2 emission reductions.

Table2. comparison between the three projects.

Project	Capacity (MW)	Cost (USD)	CO2 Reduction (Metric tons annually)
Sakaka Solar Power Plant	300	302 million	430,000
Tengger Desert Solar Power Plant (China)	1,547	2.2 billion	3.29 million
Ivanpah Solar Power Plant (USA)	392	2.2 billion	500,000

2.3.2 Comparative Analysis:

Capacity

- Tengger Desert Solar Power Plant leads in capacity with 1,547 MW, making it one of the largest solar power projects globally.
- Ivanpah Solar Power Plant follows with 392 MW, which is a significant capacity for a solar thermal power station.
- Sakaka Solar Power Plant has a smaller capacity of 300 MW compared to the other two, yet it marks a crucial step in Saudi Arabia's renewable energy journey.

Cost

- Tengger Desert Solar Power Plant and Ivanpah Solar Power Plant both have a high cost of 2.2 billion USD, reflecting their large scale and advanced technologies.
- Sakaka Solar Power Plant is relatively more cost-effective at 302 million USD, demonstrating a lower cost per megawatt ratio compared to its counterparts.

CO2 Emission Reductions

- Tengger Desert Solar Power Plant achieves the most significant CO2 reduction, with an impressive 3.29 million metric tons annually. This highlights its efficiency and impact on reducing greenhouse gas emissions.
- Ivanpah Solar Power Plant reduces CO2 emissions by 500,000 metric tons annually, benefiting from its innovative solar thermal technology.
- Sakaka Solar Power Plant contributes to a CO2 reduction of 430,000 metric tons annually, supporting Saudi Arabia's sustainability goals and its Vision 2030 objectives.

Each of these solar power projects exemplifies a unique approach to harnessing solar energy, with distinct characteristics and impacts:

- Tengger Desert Solar Power Plant stands out for its large scale and remarkable emission reductions, representing China's commitment to renewable energy.
- Ivanpah Solar Power Plant showcases advanced solar thermal technology, achieving significant emissions reductions but at a higher cost.

- Sakaka Solar Power Plant is a testament to Saudi Arabia's growing investment in solar energy, balancing cost-effectiveness with substantial environmental benefits.

2.3.3 Conclusions and Recommendations

Conclusions

Economic Viability: The Sakaka Solar Power Plant is financially viable, with a positive NPV, high IRR, and a short payback period. The project demonstrates strong profitability and attractiveness to investors.

Environmental Impact: The project contributes significantly to reducing carbon emissions, supporting Saudi Arabia's sustainability goals and commitments under international agreements.

Strategic Significance: Sakaka serves as a model for future renewable energy projects in the region, showcasing the potential for economic and environmental benefits.

Recommendations and Policy Implications

- **Enhance Government Support:** Increase financial incentives, subsidies, and tax breaks to encourage investment in renewable energy projects.
- **Promote Public-Private Partnerships:** Facilitate collaborations to leverage expertise, share risks, and mobilize capital.
- **Encourage Localization:** Implement policies to develop local manufacturing of renewable energy components, creating jobs and stimulating economic growth.
- **Invest in Research and Development:** Support innovation to improve technology efficiency and reduce costs.
- **Strengthen Regulatory Framework:** Establish clear and stable policies to provide certainty for investors and developers.
- **Increase Public Awareness:** Educate the public on the benefits of renewable energy to build societal support.

Scientific Contribution and Originality

This study provides a comprehensive analysis combining economic and environmental evaluations of the Sakaka Solar Power Plant, filling a gap in existing literature. It offers valuable insights for policymakers, investors, and researchers interested in the renewable energy sector.

3. Conclusion

The Sakaka Solar Power Plant stands as a landmark in Saudi Arabia's renewable energy journey, offering compelling insights into the economic and environmental benefits of transitioning to renewable energy sources. The financial analysis reveals that the project is not only viable but also highly profitable, with an NPV of \$566 million and an IRR of 20.19%, which significantly exceeds the benchmark discount rate of 5%. The project's short payback period of 4.90 years highlights its efficiency in recouping investments, while the PI and BCR values indicate substantial returns on investment.

Environmentally, the Sakaka Solar Power Plant contributes to a significant reduction in carbon emissions, with a projected decrease of 10.75 million tons over its lifespan. This reduction supports Saudi Arabia's Vision 2030 goals of decreasing the carbon footprint and promoting sustainability. The project's use of photovoltaic technology exemplifies Saudi Arabia's commitment to leveraging its abundant solar resources, setting a precedent for future renewable energy projects in the region.

Comparative analysis with other global solar projects, such as the Tengger Desert and Ivanpah Solar Power Plants, underscores the Sakaka project's competitive advantage in cost-effectiveness and environmental impact. While it may have a smaller capacity, its strategic significance in Saudi Arabia's energy diversification strategy cannot be overstated.

In conclusion, the Sakaka Solar Power Plant is a testament to Saudi Arabia's proactive approach to achieving sustainable development through renewable energy. The project's success demonstrates the potential for similar initiatives to contribute to economic growth, job creation, and environmental conservation. Moving forward, Saudi Arabia can build on the Sakaka model to expand its renewable energy capacity, reduce reliance on fossil fuels, and foster a more sustainable and diversified economy.

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The Importance of ESG Integration for Financial Stability: A Study of Energy-Intensive Companies in Saudi Arabia

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Abstract: This study assesses the financial strength and ESG (Environmental, Social, and Governance) commitments of a selected group of energy-intensive companies listed on the Saudi Stock Exchange (Tadawul). Altman's Z-score is employed to identify firms with minimal or no bankruptcy risk. ESG-related activities are evaluated through a manual review of each company's annual board reports, in accordance with the guidelines issued by the Saudi Capital Market Authority (CMA). We utilize human experience and AI applications to search board annual reports for companies under analysis. We identify and score ESG activities under each factor. The results indicate a weak positive correlation between financial stability and ESG integration. We used visual inspection, Spearman's correlation, and robust checks to understand this relationship better. Based on further investigation, we apply a scatter plot to visualize the relationship, which illustrates clusters rather than a distinctive correlation pattern. As a result, we apply hierarchical clustering analysis that suggests three different data clusters that we could link to the company's efforts for financial stability and ESG integration. These findings provide valuable insights for investors and risk managers in evaluating risk-return trade-offs. Moreover, the results can support policymakers and stakeholders in formulating environmentally responsible, sustainable strategies by introducing effective regulatory frameworks and fostering public trust.

Keywords: energy sector, environment, financial, governance, hierarchical clustering, social.

أهمية تكامل المعايير البيئية والاجتماعية والحوكمة لتحقيق الاستقرار المالي: دراسة للشركات السعودية كثيفة الاستهلاك للطاقة

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المستخلص: تُقيّم هذه الدراسة الوضع المالي، ومدى علاقته بالالتزام بمعايير البيئة والمجتمع والحوكمة (ESG) في عددٍ من الشركات المدرجة ضمن القطاعات كثيفة الاستهلاك للطاقة بسوق الأسهم السعودي (تداول)، وقد تم استخدام نموذج "ألتمان Z-Score" لتحديد الشركات الأقل عرضة للإفلاس، كما تم قياس الالتزام بالمعايير المعتمدة من هيئة السوق المالية من خلال تحليل تقارير مجالس الإدارات باستخدام مزيج من الخبرة البشرية وتقنيات الذكاء الاصطناعي، مع تصنيف الأنشطة والمبادرات المرتبطة بمعايير أعلاه، وقد أظهرت النتائج عبر التحليل البصري، ومعامل ارتباط سبيرمان، واختبار النشاط، وجود علاقة طردية ضعيفة. ولتفسير طبيعة العلاقة بعمق، تم استخدام مخطط الانتشار، الذي كشف عن تجمعات بدلاً من علاقة خطية؛ مما أتاح تطبيق نموذج تحليل هرمي بين انقسام العينة إلى ثلاث مجموعات، وفقاً لدرجات السعي نحو الاستقرار المالي والالتزام البيئي. تشير النتائج إلى أن الالتزام بمعايير ESG قد يرتبط بأنماط متباينة من الأداء المالي، ما يساعد المستثمرين، ومديري المخاطر، على فهم العلاقة بين العائد والمخاطر، ويدعم صانعي السياسات في تعزيز الممارسات المستدامة، وبناء الثقة المجتمعية.

الكلمات المفتاحية: قطاع الطاقة، بيئة، حوكمة، تحليل هرمي، اجتماعي.

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1. Introduction

Many investors and stakeholders now expect corporate performance to extend beyond traditional financial results, placing increasing emphasis on long-term environmental, social, and governance (ESG) goals. While corporate social responsibility (CSR) is a well-established concept among publicly traded companies and often considered a subset of the broader ESG framework, the full integration of ESG factors into corporate strategy and operations remains limited. Despite ongoing skepticism among some executives regarding the tangible benefits of ESG adoption, the potential for positive, transformative impact is becoming increasingly evident. In the 2019 annual meeting of Berkshire Hathaway, legendary investor Warren Buffet expressed his view on ESG, "We'll Never Waste Time and Money on ESG Reporting." However, many stockholders and stakeholders increasingly value plans and decisions regarding long-term sustainability. For instance, in recent years, Larry Fink, Chairman and CEO of BlackRock, the world's largest asset manager, stated that the ESG matrix would play a significant role in valuing a company, thereby underlining the crucial role of ESG in corporate valuation. BlackRock is embracing transition investing and focusing on transitioning to a low-carbon economy¹. Given the investment community's increasing awareness, we observe the growing significance of ESG in the financial world, a trend that our research aims to analyze. We assess the financial strength and ESG commitment of a selected group of energy-intensive companies listed on the Saudi Stock Exchange by estimating each company's financial stability and ESG scores.

This analysis is particularly relevant in the context of energy-intensive companies, where the intersection of financial stability and ESG integration is becoming increasingly critical. The transition to a low-carbon economy refers to the global shift towards reducing carbon emissions and adopting sustainable energy practices and consumptions. This growing trend of ESG integration is becoming more urgent, emphasizing the need for companies to adapt to this change and gain the potential benefits of a more sustainable financial future, such as improved brand reputation, reduced risk, and increased investor interest. Our research aims to uncover the tangible benefits of ESG integration, offering reassurance to investors, risk managers, policymakers, and other stakeholders regarding the value of investing in ESG-oriented firms. It also encourages broader ESG adoption across industries.

The energy sector serves as a prime example of how businesses must focus on the collective expectations of stakeholders to guide future projects. With the global shift toward green and renewable energy, energy-intensive firms are under increasing pressure to integrate ESG factors into their strategic planning. As a result, these companies must assess and forecast the impact of ESG integration on their long-term financial health. The trend toward green and renewable energy is not just a passing phenomenon but a global movement driven by growing awareness and concerns about climate change and the need for sustainable energy solutions. This movement presents an opportunity for energy companies to be part of a more significant, positive change and contribute to a more sustainable future. For instance, traditional project-based financing models may soon be supplanted by mechanisms such as energy performance contracts (EPCs), which promote investments in energy efficiency (Ning et al 2023).

As a newly developed financing mechanism, green finance serves, in addition to its financing role, as an additional means of diversification to an investment portfolio. Hence, a class of assets attracts impacts-seeking investors and a growing number of traditional investors. They would be keen to tap into a new class of assets with a unique set of unsystematic risks to offset other traditional unsystematic risks. The urgency of this global movement is visible, and companies need to act swiftly to adapt. International investors have committed billions of dollars to investments in green and low-carbon initiatives announced in recent years. The alignment of financial portfolios with targeted and sustainable goals, consisting of buying and holding green assets and selling brown assets², aligns with the European Union (EU) Sustainable Finance Taxonomy and Sustainable Finance Action Plan (Caldecott et al., 2024).

¹ <https://www.blackrock.com/sg/en/investment-strategies/sustainable-transition-investing>.

² Brown assets: Investment that could potentially be harmful to the empowerment.

The successful implementation of green finance projects such as concessional loans, green bonds, Energy Saving Insurance (ESI), contingent grants, and performance contracts heavily relies on the role of financial intermediaries. These intermediaries are crucial in developing, underwriting, and marketing financial products/arrangements that accommodate a business's long-term sustainable financial needs. They also need to evaluate and mitigate expected risks within the venture. Given that green energy projects operate in an environment with particular risks and expectations, financial intermediaries must alter the risk and reward paradox accordingly to account more accurately for these risks. Grishunin et al. (2023) specify that the top three most severe risks expected globally are environment-related: climate action failure, extreme weather, and biodiversity loss. This function of risk adjustment underscores the vital role of financial intermediaries in achieving long-term sustainability, providing a solid support system for these ventures, and reassuring stakeholders about the sustainability of these projects.

For companies to participate in green finance, several criteria and conditions must be met (e.g., successfully launching a green bond). The International Finance Corporation (IFC) has developed a green bond issuing framework for issuing social, sustainability, and sustainability-linked bonds. The framework consists of four principles: 1) Use of Proceeds, 2) Project Evaluation and Selection, 3) Management of Proceeds, and 4) Reporting. It also emphasizes the role of external examiners and evaluators in ensuring long-term sustainability throughout the life of the green-financed project. Although these principles are voluntary, 95% of global issuers apply them (see page 5 of the referenced report). The international trend can be recognized by the share numbers and performance of multi-national indexes, as shown in Table 1.

Table 1: Multi-national indexes and their respected annual performance as of July 29, 2024:

Index	Target	Performance (%)
Bloomberg Barclays MSCI Green Bond Index	Fixed-income securities issued to fund projects of direct environmental benefits	4.5
S&P Green Bond Select Index	Global green bonds.	3.8
Solactive Green Bond Index	Green bonds that meet specific criteria	4.2
MSCI Global Bond Index	Global green bonds issued by sovereign, quasi-sovereign, and corporate issuers	4.0
Source: Bloomberg Professional Services		

Nationally, and in alignment with Saudi Arabia's Vision 2030, the Saudi Ministry of Finance has taken a significant step by issuing a Green Financing Framework. This framework, developed following the Green Bond Principles of the IFC, highlights the Saudi government's commitment to sustainable finance. It consists of the four abovementioned principles and a fifth External Review principle. Notably, it specified that these principles also apply to issuing Sukuk, a bond-like financial instrument aligned with Islamic principles. The Saudi Capital Market Authority (CMA) launched the Sukuk/Bonds Market index on June 19, 2011. As of July 29, 2024, the index closed at 895.59 points, and the Sukuk issuance by the end of 2023 amounted to SAR 758.8 billion, equivalent to US\$ 202.34 billion. The Saudi Stock Exchange has also launched two specialized indexes: the Corporate Sukuk/Bonds Index and the Government Sukuk /Bond Index. Internationally, On the international front, in September 2021, FTSE Russell announced the inclusion of the local currency Saudi Arabian government Sukuk, in the FTSE Emerging Markets Government Bond Index (EMGBI)³.

In a 2023 report, the International Renewable Energy Agency (IRENA) estimates that energy infrastructure investment that would contribute to achieving the target of limiting global temperature increase to below 1.5 degrees, as specified by the Paris Climate Agreement, would reach US\$ 150 trillion for the period from 2023-2050. Furthermore, investments must exceed US\$ 5 trillion annually

³ Ministry of Finance, Saudi Arabia and Tadawul.

between 2023 and 2030 to meet the expected target⁴. Thus, major international stock exchanges have launched trading on green finance products. Table 2 lists international financial markets that list and trade green financial products and the launching date for each.

Table 2: Global Stock Exchanges that have launched sections of green or sustainable bonds

Name of Stock Exchange	Type of Dedicated Section	Launch Date
Oslo Stock Exchange	Green bonds	2015-01-01
Stockholm Stock Exchange	Sustainable bonds	2015-06-01
London Stock Exchange	Green bonds	2015-07-01
Shanghai Stock Exchange	Green bonds	2016-03-01
Mexico Stock Exchange	Green Bond	2016-08-01
Luxembourg Stock Exchange	Luxembourg Green Exchange	2016-09-01
Borsa Italiana	Borsa Italiana	2017-03-01
Taipei Exchange	Sustainable bonds	2017-05-01
Johannesburg Stock Exchange	Green bonds	2017-10-01
Japan Exchange Group	Green and Social bonds	2018-01-01
Vienna Exchange	Green and Social bonds	2018-03-01
Nasdaq (Multiple stock exchanges)	Sustainable bonds	2018-05-01
Swiss Stock Exchange	Green and Sustainability bonds	2018-07-01
The International Stock Exchange	Sustainable bonds	2018-11-01
Frankfurt Stock Exchange	Green bonds	2018-11-01
Santiago Stock Exchange	Green and social bonds	2019-07-01
Euronext (Multiple stock exchanges)	Green, Sustainable, and Social bonds	2019-11-01
Bombay Stock Exchange	Green bonds	2019-06-01
Argentina Stock Exchange BYMA	Green, Sustainable, and Social bonds	2019-07-01
Brazil Stock Exchange	Green bond	2019-06-01
Nigerian Stock Exchange	Sustainable bonds	2019-10-01
Hong Kong Exchange	Green, Sustainable, and Social bonds	2020-06-01
Korea Exchange	Green, Sustainable, and Social bonds	2020-06-01
Toronto Stock Exchange	Sustainable bonds	2020-11-01
Singapore Stock Exchange	Green, Sustainable, and Social bonds	2020-06-01
Bolsas y Mercados Españoles (BME)	Green, Sustainable, and Social bonds	2022-11-01
Astana International Exchange (AIX)	ESG bonds	2022-12-01
Source: Climate Bonds Initiative		

As of 2023, the global green debt issuance market reached a record high of US\$870 billion, with the potential to grow strongly in 2024. This growth is a testament to the increasing importance

⁴ The Global Landscape of Renewable Energy Finance, IRENA, 2023.

and potential of green finance in the global market, providing a promising outlook for the future of sustainable finance. Grishunin et al. (2023) estimate that financial institutions account for 45% of green issues, followed by utilities and industrials, with 30% and 10%, respectively. In terms of countries issuing green bonds, China is in the first place, issuing almost US\$ 85 billion, followed by Germany and the US, issuing US\$ 68 and US\$ 60 billion, respectively.

Emerging markets also have seen an unprecedented %45 growth in green, social, sustainability, and sustainability-linked (GSSS) bonds to a record high of US\$ 209 billion. GSSS bonds fund projects with a positive social or environmental impact and are regularly re-evaluated to ensure meeting these intended targets. In the case of the GCC countries, we can group green debt issuance into the following two categories: First is sovereign bond issuance, in which Saudi Arabia has a considerable lead in green bond issuance. As of the end of 2023, Saudi Arabia issued US\$ 16 billion, followed by the UAE, which raised over US\$ 3.6 billion. Next, Qatar and Bahrain issued US\$ 2.5 and US\$ 2 billion each. Second is corporate bond ESG-related issuance, which reached US\$ 14.7 billion. The leading issuer is the Saudi Public Investment Fund (PIF), which totaled US\$ 9 billion—followed by Masdar, Abu Dhabi's clean energy company, which raised US\$1 billion⁵.

Energy investment is expected to surpass US\$ 3 trillion globally by the end of 2024, with about US\$ 2 trillion projected toward clean energy investment. In Saudi Arabia, energy investment is expected to exceed US\$ 175 billion by the end of 2024, with increasing funding demand for clean energy projects⁶. Such high demand for funding and investment puts Saudi energy-related companies under increasing pressure to be financially and technically well-equipped to contribute to achieving several ambitious Saudi Vision 2030 goals. These goals include specific targets such as achieving net zero emissions, protecting land by planting 600 million trees, and using renewable energy to produce 50% of local energy needs. In addition, the energy-intensive industries are significant participants in four critical programs of the vision: Saudi Green Initiative (SGI), National Industry Development and Logistics Program, Renewable Energy Projects, and Technological and Economic Strategies.

The study assesses the financial strength and ESG commitments of a selected group of energy-intensive companies listed on the Saudi Stock Exchange (Tadawul). The companies are selected based on the specifications issued by EU Energy-intensive industries' Masterplan of Competitive Transformation⁷. According to the masterplan plan, energy-intensive industries are characterized by high energy consumption, significant carbon emissions, infrastructure dependency, technological pathways for reduction, global competitive pressure, long-term investment, and Circular Economy Integration. Hence, the masterplan has identified 33 industries as energy-intensive. To compile our sample, we cross-reference these industries to their counterparts in the Saudi Stock Exchange.

We apply the Altman (1968) Z-score to measure the financial health of 63 publicly traded Saudi companies across six energy-related sectors. Next, we utilize human/AI interaction to measure the ESG-related rating by reviewing these companies' board annual reports. Our sample of companies is classified as follows: Energy sector: 7 companies, Materials/Industrial: 18 companies, Materials/Petrochemical: 11 companies, Materials/Cement: 14 companies, Transportation: 7 companies, and Utilities: 6 companies. Our data set consists of companies' financial statements for the last four years (2020 - 2021- 2022- 2023). The Altman Z-score helps us assess the financial stability of these companies by answering the question of whether a particular company is facing financial distress or not. At the same time, the ESG-related rating provides insights into their commitment to environmental, social, and governance principles. We organized the remainder of the paper: Section 2 provides a literature review. Section 3 introduces the methodology, including model specifications, and states hypotheses. Section 4 provides results and discussion. Finally, section 5 presents the conclusion and future research recommendations.

⁵ Sources: Abu Dhabi Commercial Bank and Qatar National Bank

⁶ Source: International Energy Association, www.iea.org

⁷ Report by the High-Level Group on Energy-intensive Industries, European Union, 2019

2. Literature review

A growing body of literature has investigated the interplay between ESG practices and corporate financial performance, highlighting how sustainability efforts can affect both operational efficiency and financial resilience. Researchers across various sectors and regions have employed varied methodologies to evaluate how ESG integration affects investment decisions, firm value, and risk management. The following studies provide insights into how ESG considerations are increasingly shaping financial strategies and outcomes.

Iazzolino et al. (2023) explore the influence of ESG factors on companies' financial efficiency across several European sectors by applying Data Envelopment Analysis (DEA). Results suggest ESG factors are affecting financial efficiency across different sectors. Furthermore, the study gives potential investors insights into constructing efficient and sustainable portfolios. Lisian et al. (2022) studied the impact of ESG-related policies on the financial performance of 691 companies in North America. They apply regression models and the Pearson correlation coefficients.

MacNeil and Esser (2022) examine how ESG investing evolved from Corporate Social Responsibility (CSR). The main idea investigated is that the risk and return business model has limitations. Thus, they propose an alternative "entity" model to emphasize corporate governance and board decision-making in promoting sustainability. They argue that investors' focus, through capital allocation, has shifted from ethical responsibility to financial performance.

Lupu et al. (2024) examine the impact of ESG factors on the financial stability of several European banks using a cross-quantilegram statistical method. They explore the dependencies of various distribution levels of ESG scores on financial stability measures such as Marginal Expected Shortfall (MES) and Value-at-risk (Var). the study reveals a significant but varied impact of ESG components on financial resilience.

Ben Abdallah, S. (2020) investigates the relationship between sustainability practices and financial stability in 61 European banks using a panel vector autoregressive (PVAR) model and a Granger causality test. The results indicate the possible existence of a bidirectional causality between sustainability and bank stability. It shows that sustainability positively impacts banks' stability but not vice versa.

Several recent studies have focused on ESG practices and financial sustainability within the Saudi market, reflecting the region's growing interest in aligning with global sustainability standards. Almubarak et al. (2023) examine the relationship between ESG corporate practices and financial sustainability in local companies. They examine how companies reformed governance during the COVID-19 pandemic and its influence on this relationship.

By using publicly available historical prices from the Saudi Stock Exchange, which spans 2013 and 2021, the study found a positive relationship between financial sustainability and ESG disclosure. Chebbi et al. (2022) examine the association between board composition (i.e., terms of size, gender, and independence) and ESG disclosure. It suggests that board size and independence positively impact ESG disclosure.

On the other hand, gender diversity has a positive but insignificant relationship with ESG disclosure. Qasem et al. (2024) examine the relationship between institutional investors' ownership and its impact on the ESG reporting of 206 publicly listed Saudi companies. The study applies ordinary least squares regression (OLS) on data spans from 2010 to 2019. It finds a positive relationship between institutional ownership and ESG reporting. Furthermore, the significance of this relationship varies with each of the three pillars of ESG. Conversely, they found no significant positive relationship between private ownership and ESG reporting.

In the context of financial development within the GCC countries, several recent studies have examined the interplay between environmental factors and financial systems. Hasanov et al. (2023) utilized a panel data time series analysis to investigate the effects of carbon emissions, alongside other economic factors, on financial development. They conclude that the authorities in the GCC countries should jointly work on climate initiatives to boost financial development. Studies are not limited to empirical analysis; in a comprehensive literature review and semi-structured interviews,

Alhejaili (2024) examines the integration of climate change risk and sustainable goals in the Saudi financial markets. He identified several mechanisms for promoting sustainability in the Saudi financial sector. Radhi et al. (2024) examine the transformative impact of ESG disclosures on conventional and Islamic banks' financial and operational performance in GCC countries. By conducting literature reviews, they can identify the complex relationship between ESG disclosures and financial performance, indicating that some banks negatively impact while others positively correlate.

This study contributes to the growing body of literature on ESG integration by exploring its impact on corporate financial performance and long-term sustainability. Specifically, it examines the relationship between financial stability and ESG factor integration in a sample of 63 Saudi energy-intensive companies. We measure financial stability using the Altman Z-score. On the other hand, given that most of the companies under study have yet to publish ESG reports formally, and only a handful of ESG reports and sections appear in annual board reports, we utilize a human/AI technology approach. We apply this human/AI interaction to search and rate ESG-related initiatives and programs for each company. To our knowledge, this is the first study to apply a human-AI interaction model to assess ESG integration within the context of the Saudi market. By generating ESG scores through empirical analysis of publicly available data, this research enhances our understanding of how both financially stable and unstable companies are engaging with ESG principles. The findings offer valuable insights for investors, policymakers, and corporate leaders aiming to evaluate sustainability practices within the framework of financial resilience.

3. Methodology

This section outlines the methodological approach employed to examine the relationship between financial stability and ESG integration in Saudi energy-intensive companies. Our goal is to estimate whether there is a correlation between the two scores or not. We state that financially stable firms' management and corporate culture are more likely to integrate ESG factors in their strategic planning and operational activities. In other words, we are testing the null hypothesis that there is no significant correlation between financial stability (i.e., measured by Z-score) and the integration of ESG factors:

H0: ESG integration is not correlated with the firm's financial stability

Ha: ESG integration is correlated with the firm's financial stability

We identify companies with high Z-scores and ESG-related scores, which suggest higher chances of successfully obtaining green finance funds. Combining Z-score and ESG-related scores would provide empirical evidence of the degree of correlation between financial stability and environmental, social, and governance factors. Therefore, we divide our study into three stages. First, by reviewing financial statements, we obtain the Z-score of 63 energy-intensive companies using Altman's Z-score. The Z-score has eight inputs: Total Assets, Total Liabilities, Current Assets, Current Liabilities, EBIT, Retained Earnings, Net Sales, and Market capitalization. Altman (1968) states the Z-score equation as follows:

$$\text{Altman Z-score} = 1.2a + 1.4b + 3.3c + 0.6d + 0.99e \quad (1)$$

a = Working capital / Total Assets

b = Returned Earning / Total Assets

c = Earnings Before Interest and Taxes (EBIT) / Total Assets

d = Market Value of Equity / Total Assets

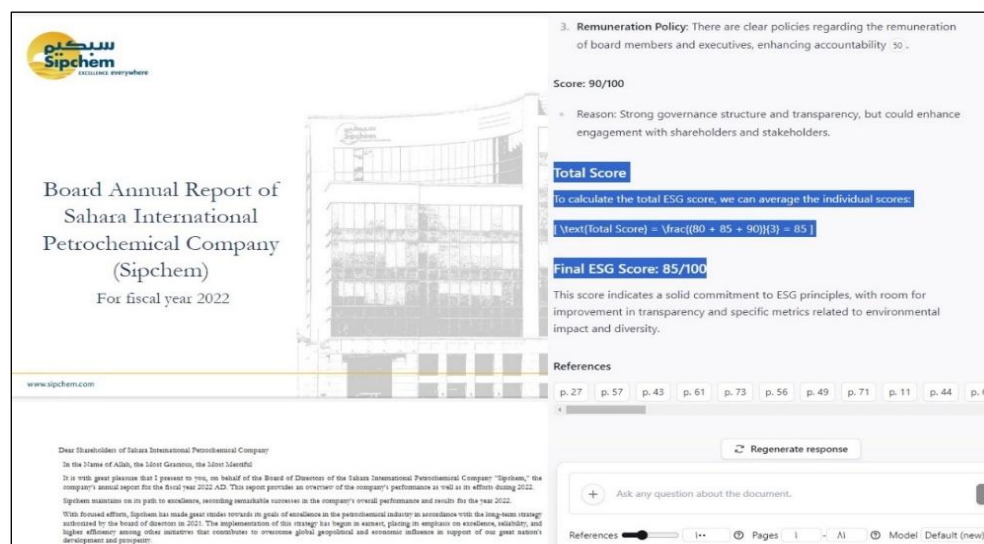
e = Sales / Total Assets

Second, through a partnership with the UN Sustainable Stock Exchange Initiatives, CMA has issued ESG Disclosure Guidelines to help issuers (and underwriters) navigate through promoting the ESG framework and its impact on sustainable investment. For the most part, listed companies still

need to do better in publishing ESG reports on the Saudi Stock Exchange website. They may need help adopting and integrating ESG, mainly concerning data availability, resource constraints, and sector-specific factors. Nevertheless, by reviewing annual board reports, we could still find initiatives and programs and categorize them into one or more ESG factors. We have encountered several professional ESG rating agencies, but they cover only major Saudi companies. As a result, to avoid any bias in treatment, we disregard external ratings for major companies in our sample and rely on human/AI interaction to subject all companies to the exact steps of analysis and treatment.

To ensure the accuracy and relevance of ESG-related activities, we reviewed outputs generated by AI applications in alignment with internationally recognized standards, specifically the MSCI ESG Ratings and the Sustainability Accounting Standards Board (SASB) frameworks.⁸ Once we establish a company's financial strength, we identify its level of ESG commitment through joint hybrid efforts between human expertise and AI applications. We start by developing an evaluation form for each company, consisting of the company's name, Tadawul's trading symbol, industry, and sector. Then, we divide the evaluation form into four columns corresponding to 2020 to 2023. In each column, we specify three sections representing ESG's three pillars. Finally, we manually review annual reports for our sample of companies to identify ESG's and ESG-related activities. Once we have completed the evaluation forms, we utilize the Coral AI application to upload four annual reports for each company. The AI application goes through four stages of processing: First, scanning and extracting related ESG information by reviewing environmental, social responsibility, and governance sections. Second, analyzing text using Natural Language Processing (NLP) to identify key terms and phrases to measure each against ESG factors. Third, benchmarking and scoring each item against industry standards specified by MSCI ESG Ratings and SASB Standards. Finally, the AI application generates a full report with detailed scoring for each factor and a total grade. Figure 1: Provide a screenshot of the inputs (Sipchem for the fiscal year 2022 and the following two questions: "Can you review ESG-related activities and score each out of 100? and a total score out of 100?") and outputs of the Coral AI application on the left side of the image stating detailed analysis for ESG activities and a total score of 85 out of 100.

Figure 1: Outputs of the Coral AI application.



Finally, we combined the Z-score and ESG scores for each company. Given that the minimum Z-score for a safe financial position is > 2.99 and the minimal risk of bankruptcy is a Z-score between 1.8 and 2.99, we decided to accept companies of Z-score 1.8 and above, which means companies of no or minimum bankruptcy risk are potential candidates for pairing. In the case of ESG scores, we use rating criteria specified by MSCI in which the highest rating is AAA, equal to a score of 100;

⁸ MSCI ESG Ratings and SASB Standards are two leading ESG frameworks for evaluating and ranking corporate ESG activities.

AA, equal to 90; A, equal to 80; and the lowest acceptable rating of BBB, equal to 70 is "passing grade." These thresholds can vary according to industry standards and economic conditions.

4. Results and discussion

This section presents the findings of our empirical analysis, focusing on the relationship between financial stability, as measured by Altman's Z-score, and ESG integration scores derived from hybrid human-AI evaluation. By categorizing firms based on their financial health and ESG performance, we aim to identify companies that are both financially sound and committed to long-term sustainability. In calculating Z-scores, we obtained 34 out of the 63 companies' samples with a Z-score of 2.99 and above, indicating a safe financial position, and we expect no risk of bankruptcy. In addition, 12 companies out of the total sample exhibit Z-scores between 1.8 and 2.99, which we classified as having minimal risk of bankruptcy. These two groups account for 65.62% of the sample and are to be cross-matched with the ESG ratings of at least BBB, equivalent to 0.70 and above. For ESG ratings, we have rated 55 companies as having the acceptable rating of BBB equal to the passing grade of 70 or above. Next, we paired Z-scores of 1.8 and above with ESG ratings of 0.70 and above to identify companies that exhibit financial soundness and have the potential for long-term sustainability. Table 2 provides Z-scores and ESG ratings organized by sector, firm name, Tadawul's trading symbol, and Z-scores and ESG ratings, respectively. We highlight firms that meet the two criteria of Z-scores of at least 1.8 and ESG rating of 0.70 by a gray background.

Table 2: Firms included in the study, including their trading symbols, calculated Z-score, and ESG score.

Sect.	Firm	Symb ol	Z- Score	ES G	Sect.	Firm	Symb ol	Z- Score	ES G
Energy	SARCO (1)	2030	0.48	0.58	Materials Cement	NAJRAN CEMENT (37)	3002	3.55	0.85
	SAUDI ARAMCO (2)	2222	8.62	0.88		CITY CEMENT (38)	3003	17.63	0.83
	PETRO RABIGH (3)	2380	0.44	0.85		NORTHERN CEMENT (39)	3004	0.74	0.80
	ARABIAN DRILL (4)	2381	3.47	0.80		SAUDI CEMENT (40)	3030	5.91	0.85
	ADES (5)	2382	1.21	0.85		QACCO (41)	3040	18.92	0.83
	BAHRI (6)	4030	1.06	0.86		SPCC (42)	3050	7.23	0.82
	ALDREES (7)	4200	2.80	0.85		YCC (43)	3060	6.19	0.80
Materials Industrial	TAKWEEN (8)	1201	0.43	0.70		EPCCO (44)	3080	6.21	0.80
	MEPCO (9)	1202	3.18	0.80		TCC (45)	3090	2.38	0.80
	MA'ADEN (10)	1211	2.30	0.90		JOUF CEMENT (46)	3091	1.04	0.80
	ASLAK (11)	1301	8.79	0.75		RIYADH CEM (47)	3092	13.30	0.85
	ALYAMAMAH (12)	1304	2.33	0.85		YANBU CEMENT (48)	3020	2.70	0.85
	SSP (13)	1320	4.16	0.80		ACC (49)	3010	4.91	0.87
	EAST PIPES (14)	1321	4.90	0.80		UACC (50)	3005	2.24	0.78
	AMAK (15)	1322	6.52	0.82	Trans	SISCO HOLD (51)	2190	0.84	0.83
	TASNEE (16)	2060	0.95	0.80		SGS (52)	4031	2.45	0.85
	NGC (17)	2090	12.92	0.78		SAPTCO (53)	4040	0.81	0.57
	ZOUJAJ (18)	2150	7.99	0.88		BUDGET SAUDI (54)	4260	4.43	0.82
	ALUJAIN (19)	2170	2.75	0.50		THEEB (55)	4261	2.08	0.85
	FIPCO (20)	2180	3.43	0.50		LUMI (56)	4262	0.95	0.70
	APC (21)	2200	0.99	0.77		SAL (57)	4263	5.62	0.75
	MAADANIYAH (22)	2220	4.22	0.63	Utilities	GASCO (58)	2080	4.92	0.85
	ZAMIL INDUST (23)	2240	0.76	0.85		AWPT (59)	2081	4.54	0.85
	SIIG (24)	2250	17.98	0.85		ACWA POWER (60)	2082	2.98	0.82
	SVCP (25)	2360	16.51	0.60		MARAFIQ (61)	2083	6.20	0.86
Materials Petrochemical	CHEMANOL (26)	2001	2.33	0.83		MIAHONA (62)	2084	5.82	0.50
	SABIC (27)	2010	2.96	0.81		SAUDI ELECTRICITY (63)	5110	0.51	0.83
	SABIC AGRI-NU (28)	2020	9.38	0.85					
	NAMA CHEMIC (29)	2210	0.88	0.83					
	LUBEREF (30)	2223	4.39	0.85					
	YANSAB (31)	2290	5.41	0.85					
	SPM (32)	2300	1.86	0.75					
	SIPCHEM (33)	2310	3.09	0.85					
	ADVANCED (34)	2330	1.96	0.87					
	SAUDI KAYAN (35)	2350	1.09	0.85					
	BCI (36)	1210	2.31	0.80					

Note: Numbers in parentheses are in clusters in Figure 3.

By examining the results in Table 2, we find that all six sectors have shown pass and no pass of the two-threshold criteria. Thus, we suspect no particular sector is immune to the impact of ESG integration and that selection bias is less likely. However, the energy sector has shown less passing of the two criteria than the other sectors. Only three companies acquired high Z and ESG scores, which is 42.86% of the companies in the energy sector, showing evidence of a degree of correlation between ESG integration and financial stability. On the other hand, the Materials/Cement sector has shown the highest degree of correlation between a high Z-score and a high ESG score. Twelve out of fourteen companies have passed the two-threshold criteria, which is 85.71% of the total companies in the sector. Passing percentages for other sectors are as follows: Materials/Industrial is 55.56%, Materials/Petrochemicals 81.82%, transportation is 57.14%, and finally, Utilities is 66.67%.

Additionally, we grouped the results of combining pairs of Z-scores and ESG ratings into the following: First, a group of High Z-scores and high ESG ratings. Second, a group of high Z-scores and low ESG ratings. Third, a group of low Z-scores and high ESG ratings. Finally, a group of low Z-scores and low ESG ratings. Table 3. shows the allocation of these Z-score and ESG-rating pairs among the four specified groups. We apply three methods of examination: visual inspection, Spearman's correlation, and robustness checks to determine the statistical significance of the results. To revisit these statistical tools, see Smith and Johnson (2018) and Ronchetti (2020).

Through visual inspection, we clearly show that in the first group (high Z-score and high ESG ratings), 42 companies out of the 63 met the two criteria of Z-scores of at least 1.8 and ESG rating of 0.70, which represents 66.67% of the total sample. Hence, these numbers may indicate a degree of correlation between the Z-score and ESG score.

Table 3: Results of the allocation of the pairs of Z-score and ESG score listed by trading symbols.

	High	Z-score	Low
High	2222 2381 4200 1202 1211 1301 1304 1320 1321 1322 2090 2150 2250 2001 2010 2020 2223 2290 2300 2310 2330 1210 3002 3003 3030 3040 3050 3060 3080 3090 3092 3020 3010 3005 4031 4260 4261 4263 2080 2081 2082 2083		2060 2380 2382 4030 2350 3091 2190 2200 2240 2350 3004 4262 5110
ESG			
Low		2170 2180 2220 2360 2084	2030 1201 2210 4040

Subsequently, we check for robustness to validate the stability of results by testing two scenarios. First, we increase thresholds by 10%, the Z-score increases from 1.8 to 1.98, and the ESG score increases from 0.70 to 0.77. Second, we decrease the thresholds by 10%, the Z-scorer from 1.8 to 1.62, and the ESG score from 0.70 to 0.63. In the case of the first scenario, we found out that tightening the threshold causes the number of passing companies to decrease. Thus, companies with high Z-scores and ESG scores decreased from 42 to 39 (down %7.14). Likewise, in the second scenario, loosening thresholds by 10% causes the number of passing companies to go from 42 to 43 (up % 4.76). We examine the sensitivity of results by varying thresholds and provide supporting evidence of a positive relationship between ESG integration and financial stability. We summarize the robustness check results in Table 4.

Table 4: Results of robust checks:

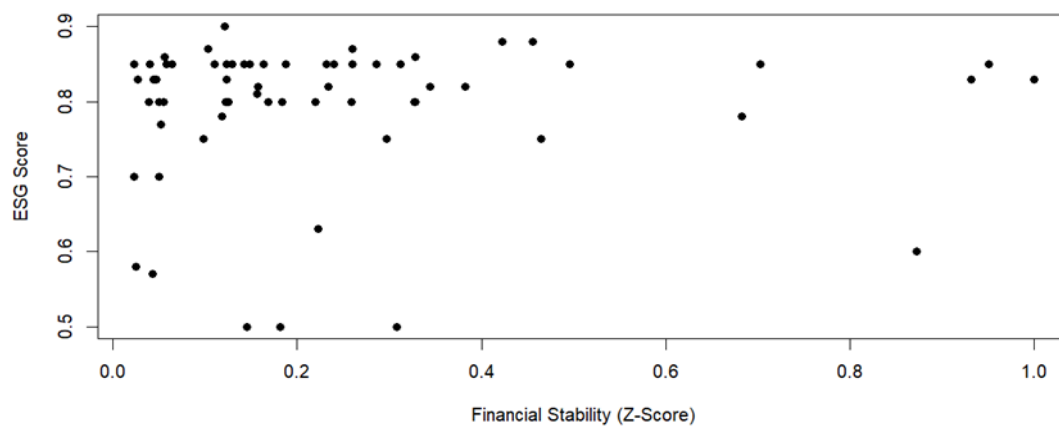
	Z-score	ESG-score	Result
Scenario 1	1.98	0.77	39 Decreased by 7.14 %
Scenario 2	1.62	0.63	43 Increased by 4.76 %
Base	1.8	0.70	Passing companies (42 out of 63)

Furthermore, we ran Spearman's correlation between Z-scores and ESG scores of companies in the first group and obtained a value of 0.26, which suggests a weak positive relationship. Therefore, a correlation value of 0.26 is insufficient to assume a moderate correlation; however,

considering the relatively large number of pairs in the High Z-score/High ESG score category (i.e., as indicated in Table 3), we further investigate all pairs of scores using a scatter plot. Given that the Z-scores in the X-axis are open-ended and have no ceiling and the ESG scores in the Y-axis scaled from 0.01 to 0.99, we have to normalize the Z-score by using the min-max normalization method to make both sides comparable. Hence, we divide each Z-score by the maximum Z-value of 18.92 obtained for QACC (see Appendix 1).

By looking into the spread of pairs in the scatter, as illustrated in Figure 2, we suspect the relationship is a cluster rather than a recognizable correlation. The scatter plot suggests that the relationship between Z-scores and ESG scores spreads across the graph without forming any apparent pattern or trend (i.e., we could not identify a solid linear relationship). Since we did not identify upward or downward sloping, we take a closer inspection and see that a higher density of observations located between scaled Z-scores of 0.01 to 0.5 and ESG scores of 0.7 to 0.9, indicating the possibility of most companies seeking to achieve the highest possible ESG scores using financial resources sufficient to achieve financial stability. Thus, we applied hierarchical clustering analysis to identify companies with similar clustering patterns, analyze sector-related patterns, and detect any possible outliers.

Figure 2: Scatter Plot of pairs of Z and ESG scores.

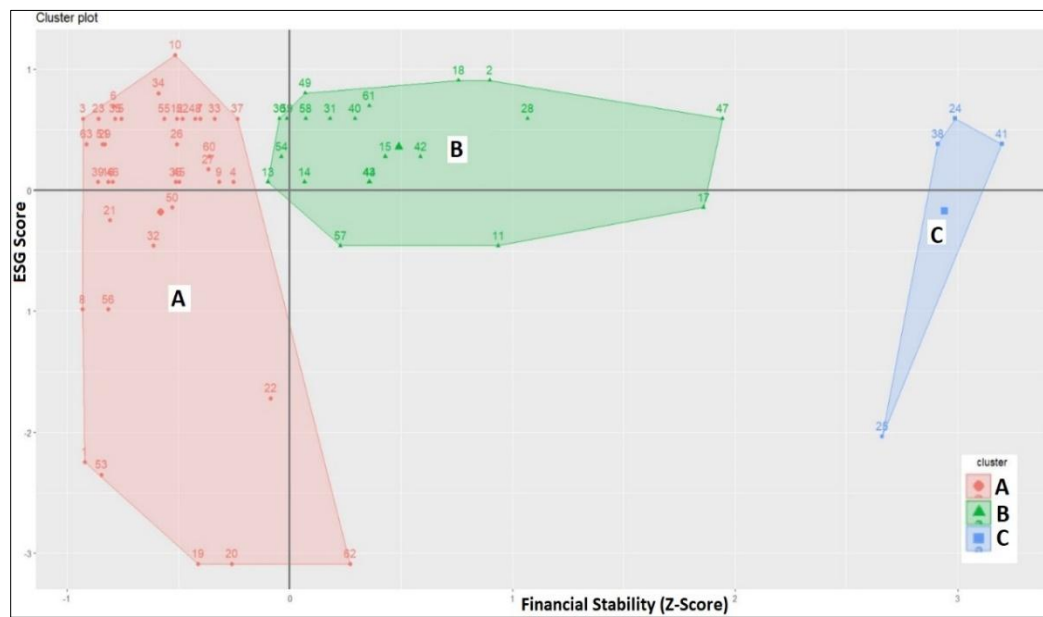


We applied a plotting dendrogram to identify the number of clusters we suspect in Figure 2. We draw a line at 0.75 (four clusters) and another line at 1 (three clusters) in the Height axis⁹ of the clustering dendrogram to compare and contrast significant gaps (Appendix 2). Next, we calculate the silhouette average width for both lines, which ranges from -1 to 1, with the optimal size being as close to 1 as possible. In practical terms, a width above 0.5 is considered good, and anything above 0.7 is considered very strong. In our two cases, we received 0.57 and 0.64, respectively, suggesting that three clusters would be a more meaningful level of clustering than four clusters, as illustrated in Figure 3. Then, we map how far each cluster is from the passing scores of both axes. By dividing Figure 3 into four quadrants, each represents combinations of Z-scores and ESG scores. The clusters are color-coded by the programming¹⁰. However, we decided to code clusters (A, B, and C) to ensure easier identification, given that color printers are not always available.

⁹ Height is the y-axis in the Hierarchical Clustering Dendrogram, which measures the distance (or dissimilarity) between clusters at the merge points

¹⁰language R, and packages are available upon request.

Figure 3: Scatter Plot of pairs of Z and ESG scores.



Note 1: In the x and y-axes, the zero value represents the passing Z-score of 1.8 and the passing score of 0.70 for ESG scores; we adjusted other scores accordingly.

Note 2: Numbers in clusters represent companies in Table 2.

We analyze clusters and recognize that no specific cluster is sector-specific; in other words, no sector can be identified as dominant in one of the following clusters. First, the red cluster (A) is in the two right quadrants, with all 36 companies (except one) not achieving the minimum passing score of financial stability (1.80). In this cluster, companies have low Z-scores and varying ESG scores (25 out of 36 companies are above the ESG threshold of 0.70). Companies in this cluster are likely facing financial hardship. Long-term survival is in question; thus, ESG integration may not be a priority. In other words, a company in this category may need more funds and resources to achieve (or sustain) ESG integration. In addition, companies in this cluster may need help attracting new investments or meeting sustainable growth requirements.

Second, the green cluster (B) at the top between the right and left quadrants contains 21 companies. Most companies surpass the passing score on the Z-score and ESG score, except four companies that did not pass the Z-score threshold and three that did not pass the ESG threshold score. However, these companies are close to the passing thresholds in both cases. This cluster of companies suggests that companies are looking to reach a particular level of considerable financial stability but would not be eager to increase their financial stability beyond a certain level. Any additional financial stability beyond what is required to cope with market and industry conditions would likely cause missing out on future profits.

These results are in line with the findings of several other studies, such as Kim et al. (2021), which found a positive correlation between ESG factors and corporate financial performance, and MacNeil and Esser (2022), who argue that ESG has shifted the focus of investors and capital allocation from corporate ethical responsibility toward financial performance. However, we further claim that the green cluster (B) offers an optimal area for companies to achieve and stay on. Given that any additional investment in financial stability and ESG would likely have diminishing returns (see Atz et al., (2021).

Third, the purple cluster (C) is mainly in the upper left quadrant above the ESG, with three companies passing the threshold and only one company below the threshold in the middle of the lower left quadrant. Companies in this cluster would look like outliers; however, the R package used "factoextra" is programmed to perform a silhouette plot but does not identify outliers. Nevertheless, the cluster under investigation (i.e., cluster C) produces an even higher silhouette average width of 0.67, as shown in Appendix 2.

In many cases, the direction of causality is straightforward and obvious and can easily be deducted (i.e., prices and sales). These are clear-cut examples of cause and effect (unidirectional). However, in the case of financial strength causing ESG commitment, a company with vast financial resources can invest generously in ESG initiatives. Additionally, enhanced financial resources provide top executives with the mindset to foster the implementation of ESG. In the case of ESG integration causing financial strength, companies with robust ESG implementation may enhance their financial stability by improving operational efficiency and risk management. They can also tap into a relatively less costly green finance market. For instance, debt holders would lower interest rates on loans for environmentally friendly projects. We perceive the possibility of a bidirectional relationship between ESG integration and financial strength. However, given that we have small-size observations, our choices of empirical causality tests are limited.

Nevertheless, we apply the Bayesian model, one of the few capable of handling small samples. In both cases (i.e., financial stability causes ESG integration and vice versa), we find neither has significant causal effects on the other, even though the model converged well. The estimates are checked for reliability, but the most likely explanation is that other factors significantly influence the relationship, laying the foundation for future research.

Long-term sustainable goals significantly affect corporate financial decisions (i.e., capital budgeting). An environment-friendly operation would benefit from relatively low-cost debt provided or supported by formal and informal bodies. For instance, two-thirds of the green bonds issued by the Association of Southeast Asian Nations are used for financing renewable energy and energy efficiency projects (SU et al., 2022). Furthermore, in 2023, the EU countries and the UK's collective issuance of green bonds reached US\$190 billion, in addition to 135 billion for social bonds¹¹. In addition, concessional loans, Energy Saving Insurance (ESI), contingent grants, and performance contracts are examples of financing mechanisms that promote funding clean energy projects and decrease their weighted average cost of capital¹². Hence, investors and fund managers would value companies in terms of current and future financial performance (i.e., sustainability), ensuring the company's long-term economic, social, and environmental health. A project, or an asset maintained by the owner and operated correctly and up to standard, is expected to serve longer and more efficiently. This logic would be the driving force behind convincing potential lenders and investors to fund environmentally friendly projects.

Our results would help policymakers and stakeholders make environmentally friendly and sustainable decisions. ESG integration drives community awareness and encourages policymakers to introduce regulations to achieve long-term economic, social, and environmental goals. Once regulations are implemented, the investment community generally values how transparency and reporting standards are disclosed. Free access to such information would help build public trust and maintain continuous investments in green projects.

5. Conclusion:

This section summarizes the key findings of our study and reflects on the implications of our analysis. By employing various statistical techniques, we sought to explore the relationship between financial stability and ESG integration in Saudi energy-intensive companies. The findings provide valuable insights, and we conclude by suggesting potential areas for further investigation.

We employed a combination of visual inspection, Spearman's correlation, and robust checks to explore the relationship between financial stability and ESG scores. Spearman's correlation indicated a weak positive relationship, prompting further investigation into this connection. To better understand the distribution of the data, we created a scatter plot, which revealed clusters rather than a clear linear correlation. Following this, we performed hierarchical clustering analysis using a dendrogram to determine the optimal number of clusters.

¹¹ Bloomberg Professional Services, (2024).

¹² Deloitte. *Financing the Green Energy Transition: A US\$ 50 trillion catch*, November, 2023

In addition, we apply the Bayesian model to test for a bidirectional relationship between financial stability and ESG scores. We find neither has a significant causal effect on the other, even though the model converges well. We suspect that other factors significantly influence the relationship. In future research, once we obtain additional financial data, we could use regression models, time series analysis, or structural equations to empirically test the impact of financial strength on ESG integration and vice versa.

Integrating ESG factors provides significant benefits for investors, mutual fund managers, and risk managers, enabling them to enhance risk-adjusted returns and better estimate risk-reward trade-offs. In the context of portfolio management, especially within international finance, ESG considerations serve as a valuable tool to filter investment options and offer guidelines for optimizing portfolio performance.

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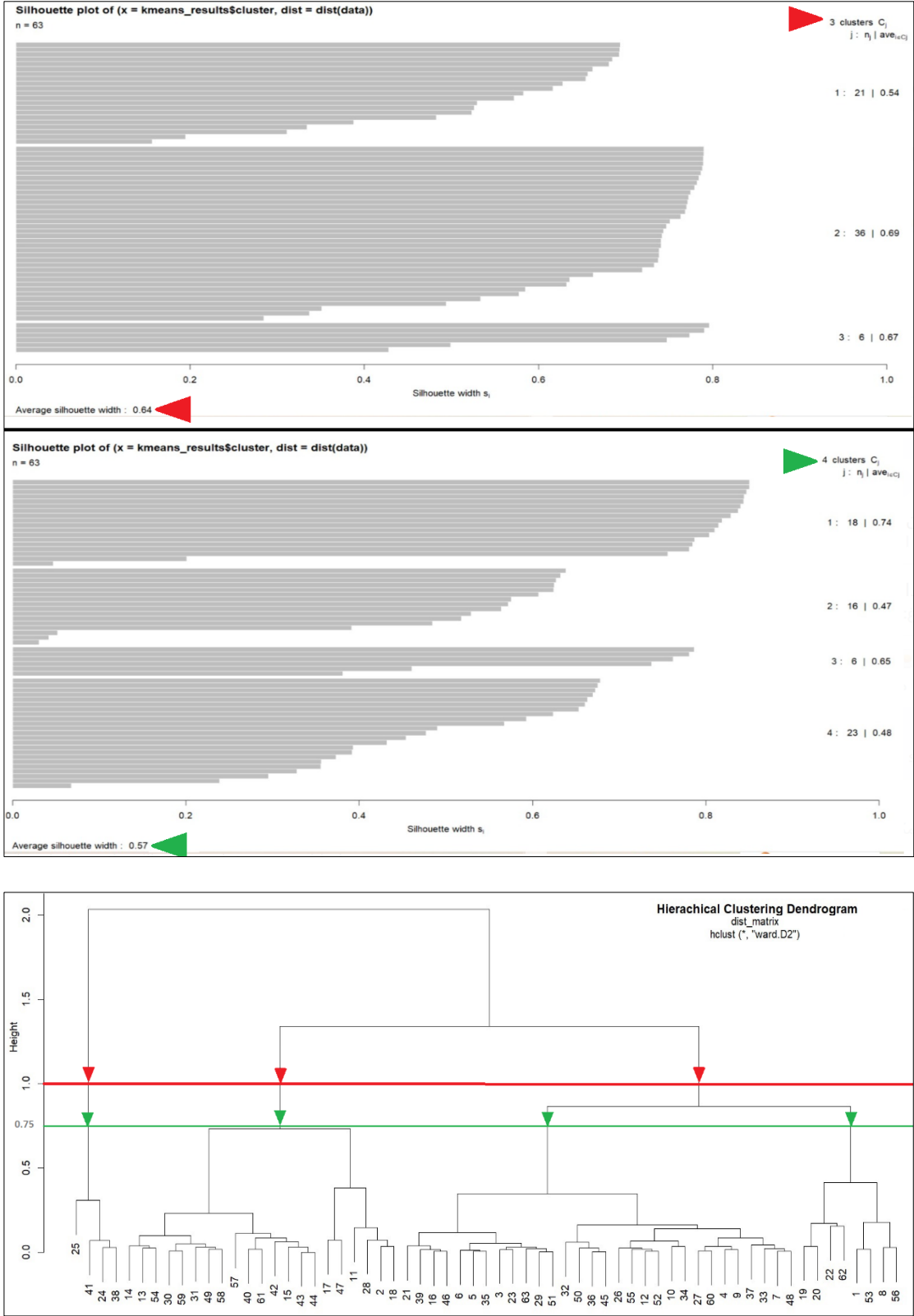
Appendixes:

Appendix 1: Z-score calculations:

	Company	Symb	Z-	Sales	Mkt. V.	T. Liab	EBIT	R.	W. Cap	T. Assets
Energy	SARCO	2030	0.48	19,864	1,458	6,620	15,522	34,957	39,108	474,610
	SAUDI ARAMCO	2222	8.62	1,609,595	7,653,988	802,093	892,262	1,259,773	394,480	2,338,174
	PETRO RABIGH	2380	0.44	45,941,97	16,249,12	55,618,3	-	-3,493,786	-	66,696,57
	ARABIAN	2381	3.47	2,886,589	13,867,01	3,865,61	550,170	3,894,581	1,741,25	9,254,561
	ADES	2382	1.21	3,586,022	18,078,96	13,084,4	504,965	1,553,808	-662,694	17,454,00
	BAHRI	4030	1.06	7,995,289	4,340,152	11,119,0	1,363,44	3,174,866	1,422,15	22,552,38
	ALDREES	4200	2.80	11,959,77	8,484,750	5,327,97	238,336	258,706	-936,661	6,443,421
Mat_Ind	TAKWEEN	1201	0.43	900,198	729,220	1,193,03	-46,350	-229,986	-253,373	1,726,377
	MEPCO	1202	3.18	986,751	2,106,880	622,394	100,799	308,128	349,380	1,888,087
	MAADEN	1211	2.30	31,003,69	143,770,8	56,504,8	6,257,50	12,148,13	13,256,1	108,566,5
	ASLAK	1301	8.79	887,057	868,259	87,929	49,139	14,935	321,491	505,864
	ALYAMAMAH	1304	2.33	1,573,853	2,027,982	1,008,78	-2,536	47,020	298,890	1,751,159
	SSP	1320	4.16	880,356	1,401,032	763,692	1,023,30	63,925	43,992	1,434,753
	EAST PIPES	1321	4.90	1,261,904	1,881,600	471,829	169,465	343,957	493,796	1,151,986
	AMAK	1322	6.52	524,834	3,088,323	334,153	115,811	28,011	324,625	1,363,190
	TASNEE	2060	0.95	3,553,443	9,383,527	10,440,8	1,053,27	1,500,239	837,572	24,778,12
	NGC	2090	12.92	64,665	881,473	39,309	11,103	-319,354	95,936	432,075
	ZOUJAJ	2150	7.99	119,980	1,209,733	102,407	65,366	255,524	13,087	785,631
	ALUJAIN	2170	2.75	1,237,345	2,898,096	1,402,87	388,322	2,095,588	678,263	4,150,839
	FIPCO	2180	3.43	236,078	562,407	157,996	8,853	34,198	56,649	292,455
	APC	2200	0.99	354,852	785,610	635,815	24,168	-68,539	-115,656	797,219
	MAADANIYAH	2220	4.22	235,018	787,296	129,416	-29,096	-68,330	171,628	434,970
	ZAMIL INDUST	2240	0.76	4,094,686	1,373,000	4,996,60	-187,267	42,332	4,613	5,903,397
	SIIG	2250	17.98	336,390	16,397,16	563,176	604,157	940,955	1,753,19	11,204,11
Mat_Petro	SVCP	2360	16.51	83,254	847,500	31,899	-24,834	22,971	106,334	279,870
	CHEMANOL	2001	2.33	865,714	1,698,148	682,431	23,962	183,232	224,059	1,746,701
	SABIC	2010	2.96	158,209,4	275,400,0	99,729,9	16,488,4	27,939,02	52,697,2	241,302,8
	SABIC AGRI-	2020	9.38	11,575,45	60,713,50	5,163,52	6,337,55	6,820,658	10,058,9	23,195,75
	NAMA	2210	0.88	506,042	764,870	700,812	-41,439	60,093	-167,221	1,100,832
	LUBEREF	2223	4.39	8,650,468	19,507,50	3,847,70	348,479	1,023,615	298,840	8,540,134
	YANSAB	2290	5.41	5,905,346	26,305,31	3,847,70	440,784	6,053,956	4,634,10	16,272,20
	SPM	2300	1.86	702,961	903,342	670,009	80,698	76,179	16,965	1,031,838
	SIPCHEM	2310	3.09	8,651,913	24,219,14	7,016,83	2,766,76	2,309,265	2,270,79	23,129,52
	ADVANCED	2330	1.96	2,679,346	11,786,63	4,973,02	395,848	320,654	198,837	8,633,623
	SAUDI KAYAN	2350	1.09	10,112,38	20,520,00	13,399,3	-	-1,434,638	238,221	29,276,95
	BCI	1210	2.31	651,542	960,162	516,950	66,011	241,696	177,833	1,179,790
Mat_Cemt	NAJRAN CEMENT	3002	3.55	478,997	2,279,020	461,721	124,332	143,016	306,481	2,459,169
	CITY CEMENT	3003	17.63	428,621	2,990,960	107,374	132,674	207,389	509,230	1,914,103
	NORTHERN	3004	0.74	638,739	204,084	1,174,61	128,336	282,880	-79,338	2,138,232
	SAUDI CEMENT	3030	5.91	1,449,556	8,177,850	1,009,20	401,289	314,236	215,592	3,315,169
	QACCO	3040	18.92	437,195	7,412,980	256,193	219,975	492,181	947,042	1,915,370
	SPCC	3050	7.23	1,228,009	7,667,800	764,656	323,039	1,152,851	798,304	4,010,286
	YCC	3060	6.19	887,372	5,703,075	632,604	186,942	387,530	503,580	3,392,313
	EPCCO	3080	6.21	854,879	3,683,380	437,742	213,050	516,841	862,379	2,837,362
	TCC	3090	2.38	268,649	1,371,960	400,388	28,080	26,816	118,906	1,683,835
	JOUF CEMENT	3091	1.04	266,657	1,363,273	833,996	3,542	-60,991	-64,250	2,005,584
	RIYADH CEMENT	3092	13.30	629,997	3,981,600	193,184	208,912	118,369	230,529	1,871,554
	YC	3020	2.70	919,278	6,057,787	1,703,50	317,514	1,031,332	124,785	6,242,323
	ACC	3010	4.91	935,421	3,517,500	545,360	190,136	710,003	726,475	3,288,875
	UACC	3005	2.24	223,043	1,081,575	446,072	44,310	176,489	270,059	1,191,903
Trans	SISCO HOLDING	2190	0.84	1,238,691	2,263,891	3,102,23	130,401	184,048	218,325	5,353,218
	SGS	4031	2.45	2,023,436	5,664,816	2,148,72	-513	-121,417	1,652,93	4,414,793
	SAPTCO	4040	0.81	1,332,783	2,362,500	3,454,73	-109,063	-268,117	984,514	4,442,690
	BUDGET SAUDI	4260	4.43	1,152,915	4,145,814	763,441	258,206	798,946	-146,203	2,513,091
	THEEB	4261	2.08	961,021	2,801,880	1,236,81	154,979	186,114	-306,630	1,889,765
	LUMI	4262	0.95	976,398	5,302,000	1,488,90	158,549	249,441	-	2,685,571
	SAL	4263	5.62	1,250,755	15,552,00	2,146,74	419,520	232,369	993,007	3,256,566
	GASCO	2080	4.92	2,178,853	3,894,750	668,620	223,807	272,575	128,470	2,414,196

Utilities	AWPT	2081	4.54	1,096,209	3,795,750	806,807	130,878	148,096	341,230	1,241,822
	ACWA POWER	2082	2.98	13,184,57	127,597,1	31,532,8	1,430,21	2,303,272	5,345,81	49,428,94
	MARAFIQ	2083	6.20	6,354,875	144,100,0	15,758,4	657,551	5,082,092	1,086,93	23,722,06
	MLAHONA	2084	5.82	286,595	3,482,257	619,953	500,296	181,328	150,238	968,428
	SAUDI ELECTRIC	5110	0.51	72,494,19	88,248,45	232,937,	12,203,4	37,084,47	21,21,92	487,681,5

Appendix 2: Determining the number of clusters using Hierarchical Clustering Dendrogram:



Aging Population and Economic Growth in Saudi Arabia: Evidence from ARDL Approach

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Abstract: Globally, there is a significant debate on the Aging population matter among the researchers and government authorities, however, its adverse impacts, specifically economic impacts, are a controversial issue. This paper intends to assess the long and short run impacts of population aging on the economic growth of Kingdom of Saudi Arabia (KSA). Using annual data for the period 1981-2021 and applying the "Autoregressive Distributed Lag (ARDL)" framework, we show that population aging is indeed detrimental for the long run growth performance of KSA. On the other hand, age dependency has impacted the growth performance positively. Moreover, human capital and domestic investment have positively impacted economic growth which is consistent with prior theoretical and empirical literature. Furthermore, inflation rate has negatively influenced economic growth while trade openness has not had the desirable significant impact on economic growth. Moreover, the short run analysis shows that economic growth positively responds to changes in trade and domestic investment and negatively to changes in inflation rate. Finally, the causality analysis displayed several one-way and two-way causal relationships among the variables including the bidirectionality between population aging and economic growth. Our results have important policy implications for the policymakers of the economy of KSA.

Keywords: Ageing population, Saudi Arabia, Economic Growth, NARDL, Cointegration
JEL classification: J10; O11, C72; C91, D63, J11.

الشيخوخة السكانية والنمو الاقتصادي في المملكة العربية السعودية: دليل من منهجية ARDL

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المستخلص: عالميًا، هناك جدل كبير حول مسألة شيخوخة السكان بين الباحثين والسلطات الحكومية، ومع ذلك، فإن آثارها السلبية، وخاصة الآثار الاقتصادية، تُعتبر قضية مثيرة للجدل. تهدف هذه الورقة إلى تقييم الآثار القصيرة والطويلة المدى لشيخوخة السكان على النمو الاقتصادي في المملكة العربية السعودية. باستخدام بيانات سنوية للفترة من 1981 إلى 2021 وتطبيق إطار "نموذج الانحدار الذاتي وفترات الإبطاء (ARDL)"، نُظهر أن شيخوخة السكان تُعتبر ضارة بالفعل لأداء النمو على المدى الطويل في المملكة. من ناحية أخرى، كان للاعتماد على العمر تأثير إيجابي على أداء النمو. علاوة على ذلك، كان لرأس المال البشري والاستثمار المحلي تأثير إيجابي على النمو الاقتصادي، وهو ما يتماشى مع الأدبيات النظرية والتجريبية السابقة. بالإضافة إلى ذلك، أثر معدل التضخم سلبًا على النمو الاقتصادي، في حين أن الانفتاح التجاري لم يكن له التأثير الكبير المرغوب على النمو الاقتصادي. كما تُظهر التحليلات على المدى القصير أن النمو الاقتصادي يستجيب إيجابيًا للتغيرات في التجارة والاستثمار المحلي وسلبًا للتغيرات في معدل التضخم. أخيرًا، عرض تحليل السببية العديد من العلاقات السببية ذات الاتجاه الواحد والاتجاهين بين المتغيرات، بما في ذلك العلاقة ثنائية الاتجاه بين شيخوخة السكان والنمو الاقتصادي. وتقدم نتائجنا دلالات سياسية مهمة لصانعي السياسات في اقتصاد المملكة العربية السعودية.

الكلمات المفتاحية: شيخوخة السكان، المملكة العربية السعودية، النمو الاقتصادي، نموذج الانحدار الذاتي وفترات الإبطاء، التكامل المشترك.

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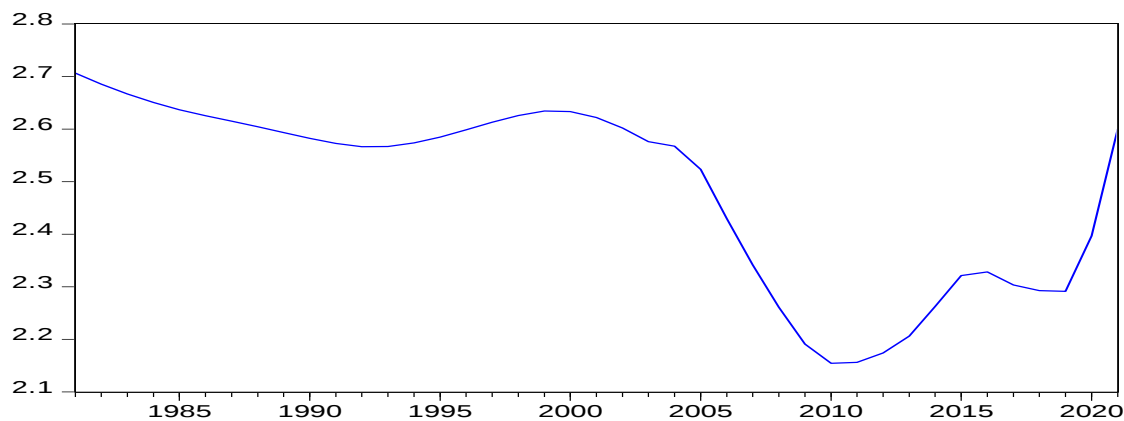
1 - Introduction

The global economy is experiencing an aging population phenomenon in recent times. According to Ismail et al. (2021) population aging is defined as “the increase in number and percentage of older population aged 60 years and above, and at the same time, decreasing in number and percentage of the young population aged 15 yr old and below”. According to the World Health Organization (WHO), the ageing society is defined as “one where more than 7% of the population is in the aged of 65 years or above, an aged society as one in which this age group accounts for more than 14% of the total population, and a hyper-aged society as one wherein this rate is greater than 20%”. Currently, the world population is around 8 billion people and most of the economies are suffering from the aging population. Several factors could be responsible for the ageing population problem. Bloom et al. (2010) commented that the increase life expectancy, falling fertility rates and variation in birth and death rates have significantly changes the global age structure. The aging population has several adverse consequences as the aged population is relatively less productive compared to the younger population. The recent research of Maestas et al. (2023) highlighted that each 10 percent increase in the population in the age bracket of 60 plus population will decrease income per person by 5.5 percent. Lee and Shin (2021) identified six distinct channels by which population aging impacts the growth performance of the economy. Therefore, the aging population phenomena has created serious concerns among the policymakers and government authorities worldwide.

The ageing population constitutes a matter of concern at all levels related to the expected adverse impacts on key economic variables. For instance, population ageing adversely impacts growth performance, savings, investment, consumption, labor markets and transfer payments. However, empirical research on the consequences of an ageing population on economic growth is still a controversial subject among researchers due to diverse empirical findings reported in the literature. In general, some researchers have concluded that ageing population adversely affects economic growth (Park and Son, 2021; Mohd et al., 2021; Rahman et al., 2020; Wen-Hsin et al., 2019; Abeywardhana, 2019; Moradi & Nilgun, 2020; Tach & Duc, 2021; Valeriy et al., 2019). Another strand of applied research concluded that ageing population positively affects economic growth (Moradi & Nilgun, 2020; Rahman et al., 2020). Moreover, researchers argue that the negative relation between the two variables is a result of labor supply shortage and the slowdown of productivity (Park and Son, 2021; Hsu et al., 2019; Miri et al., 2019; Mamun et al., 2020; Ademola, 2018; Mikiko, 2015; Moradi and Nilgun, 2020; Wen-Hsin et al., 2019). Futagami and Nakajima (2001) rightly pointed out that it is indeed not necessary that population aging decelerate economic growth. It seems that the research studies on the linkages between population ageing and economic growth are yet to reach an acceptable conclusion. It implies that extensive research is indeed needed to establish an explicit relationship between population aging and economic growth. Particularly, in the context of resource-rich economy of Saudi Arabia (KSA, hereafter), research evidence on the linkages between population aging and economic growth are indeed scarce. While it is a fact that KSA is going through age transformation period and hence it is of significant importance to quantify the exact impacts of population aging on economic growth.

Like all other economies, the problem of population ageing has become a serious concern in KSA in recent years. Ageing population has created significant concerns among the authorities of the KSA economy as it may create hurdles to achieve the targets of the vision 2023. The percentage of aged population “(population ages 65 and above (% of total population))” was 2.706 percent in 1981. Over the years, the aged population has declined, and it reached to the lowest point in 2011. However, since 2011, an upward trend is observed in the aged population. The observed increase in the aged population has created serious concerns among the authorities of KSA as the aged population has numerous undesirable repercussions. An overview of population ageing is provided in the following Figure 1.

Figure 1. Population Ageing in Saudi Arabia
Population ages 65 and above (% of total population)



The main motivations for pursuing this study, taking Saudi Arabia as a case study, are in two folds. Firstly, this topic is highly essential as the empirical investigation on this matter is relatively scarce in the ageing population-growth nexus in the literature (Rahman et al., 2020), and especially in the KSA. While it is a fact that KSA economy is going through demographic transformation including population aging as demonstrated by recent research (Salam, 2023). Secondly, it focuses on the KSA because Saudi government is pursuing an ambitious economic plan to achieve high economic growth rates over the coming period (2030 Vision). The vision 2030 is indeed a comprehensive plan for the transformation of KSA economy and hence all sectors are expected to play a dominant role to push the KSA economy in the right direction.

This study applies the ARDL model to annual time series data for the 1981-2021 period to examine the short-run and long-run relationships between ageing population and economic growth in response to within the endogenous growth model framework developed by (Romer, 1990). The motivation for the current study stems from the lack of research on the KSA economy with respect to the impact of population ageing on economic growth. In addition, the findings are expected to provide the KSA government and the policymakers with a clear understanding of the impacts and consequence of the ageing population on the Saudi economy. Thereby, it helps them to prioritize the areas for improvement for future economic growth. Therefore, the research hypothesis is that the ageing population has a negative impact on economic growth in KSA. Besides, population ageing is also responsible for several socioeconomic issues as well in addition to its adverse consequences on the overall growth performance of economies.

This research contributes to literature in three ways. Firstly, it contributes to the ageing-growth literature, which is relatively scarce in KSA. Secondly, we apply the advanced cointegration testing of “autoregressive distributed lag (ARDL)” to assess both the short run and long run influence of population ageing on economic growth. Thirdly, our study is interested in uncovering the direction of relationship between population aging and economic growth as prior literature is silent on the issue of causality. To the best of our knowledge, no study has investigated the asymmetric relationship between ageing population and economic growth in KSA. Our results would have significant policy implications for the authorities of KSA.

The organization of the article is as follows. Section 2 presents theoretical and empirical literature. Section 3 includes model derivation, data and methodology. Section 4 includes results and discussions. The causality findings are reported in the penultimate section. Section 5 presents concluding remarks and implications of the research.

2.0 Review of theoretical and Empirical Literature

2.1 Theoretical Background

Based on the argument of the economic theory, an ageing population is expected to hinder the economic process in the economy. In his lifecycle hypothesis (LCH), Modigliani and Brumberg (1954) showed a support to the notion that aging population can have a negative impact on the

performance of the economy, and hence, economic growth. The theme of the LCH is that population tends to save at early stages of their working life. This behavior would increase the national saving, and indirectly through investment activities economic growth. However, as the population ages over time, and some relative proportion of the population reaches their retirement age and their incomes fall, then according to LCH, there will be a reduction in aggregate national savings.

On the hand, Solow's growth theory indicates that as population is ageing, it becomes relatively difficult for the economy to sustain stable or steady state economic growth. In addition, the theory argues that only when population structure is constant, the steady state growth can be achieved. However, this condition, with an ageing population, is relatively out of reach, since the population structure is varying over time. Hence, Solow's growth theory predicts that ageing population negatively impacted economic growth (Mohd et al., 2021).

Another explanation of the impact of ageing population, is the Malthusian catastrophe theorem, which describes that the population growth exceeds the required needs to survive. The bottom line of his theory is that population tends to grow at a faster rate than the human needs, such as the basis needs. In addition, it argued that poverty will prevail because the growth in agricultural resources is outweighed by the uncontrolled population growth.

A new strand of economic theory known as endogenous growth theory led by Romer (1986) asserted that population growth is a vital factor for long-term economic growth. This argument is based on the idea that larger (populated) countries are expected to have highly skilled and professional people and large size markets for competitive and innovative firms. In addition, Romer (1988) pointed out that the low rate of both mortality and fertility would lead to population ageing while leaving the population size constant.

The endogenous growth model (Lucas, 1988; Romer, 1986) emphasized the vital role of labor. Physical capital and human capital in sustaining economic growth. These factors are seen to be main determinants of productivity growth and in turn economic growth. Nevertheless, aging population increase and the reduction in fertility rate hinder economic growth through the decrease in the quality of labor force. The forces behind such an outcome lies in the notion that ageing population increases the burden of working-age population (Rahman et al, 2020).

2.2 Empirical Literature

The potential impacts of population on major economic factors have attracted much attention of both policymakers and researchers in developing and developed countries, and specifically, economic growth. Accordingly, a huge body of theoretical models and applied research has been conducted to investigate the nexus relationship between ageing population and major economic factors, specifically, economic growth. However, the results were ambiguous, bouncing from negative to positive impacts due to various types of data employed, single country or group of countries. Additionally, research mainly relied on the linearity relationship assumption between ageing population and economic growth when applying various estimation methods to time series and panel data for single/multi-country levels (Moradi & Nilgun, 2020).

Related to the nature of such a relationship, two opposing views have been introduced, the pessimistic and optimistic. The pessimistic view advocates the negative impact of ageing population growth. Their argument based on the assumption that the increase in the share of old age group in population leads to a sharp reduction in the labor force and national saving rates of the country, thus, lessening the investment and national output (Thach & Duc, 2021). This view has been supported by the majority of the empirical work which concluded that ageing population negatively affect economic growth in a country (Mohd et al., 2021; Thach & Duc, 2021; Moradi and Nilgun, 2020; Rahman et al., 2020; Abeywardhana, 2019; Wen-Hsin et al., 2019; Acemoglu & Restrepo, 2017; Valeriy et al., 2019; Maestas et a., 2023). In this Regard, it has been argued that as ageing population increases, the consumption declines in current periods because people opt to save for future consumption. Consequently, consumption for durable goods, housing, and new products declines, which may exert a negative impact on economic growth. In addition, they argue that documented

that the responsiveness of growth towards population ageing is dependent on estimation methods (Nagarajan, Teixeira, and Silva 2016). Moreover, the view argues that ageing population increase causes a diversion of government public investment from infrastructure toward health care and public pension on the expense of development expenditures, especially, the elders are coming from professional and semi-professional (Nagarajan, Teixeira, & Silva, 2017; Teixeira et al., 2016; Acemoglu & Restrepo, 2017; Rahman et al., 2020). which in turn negatively affects capital accumulation and productivity growth (Ademola, 2018). For example, the transportation systems, public facilities, and housing areas may be changed consistently with the varying needs of the elderly who demand safe and clean environment (Rahman et al., 2020; Nagarajan et al., 2017).

Moreover, depending on the government's fiscal position, the government may resort to external substantial financial resources mainly to finance its infrastructure expenditure (Ramhan et al., 2020; Teixeira et al., 2017). In contrast to the pessimistic view, the optimistic view posits that a positive effect is associated with ageing population growth. Accordingly, the reduction in fertility rates and longevity would bring about a high savings where elders save more for their retirement. Thereby, provide more resources for investment which would boost investment in R&D which is a crucial engine for economic growth [Ademola, 2018]. Also, empirical research provides evidence on the positive or neutral impacts (Ismail et al., 2016; Tach & Duc, 2021, Blake and Mayhew 2006).

Some applied research goes deeply in investigating the impact of ageing populations on the various sources of economic growth. They attempted to explore the transmission channels through which the effects are transmitted to economic growth ¹. Focusing on 35 OECD countries, Lee & Kwanho (2021) focused on six transmission channels by which ageing population affect growth. Their empirical findings provide evidence about the negative consequences of both "higher old dependency ratio" and "old population share" on growth. They indicated that among all the six channels, lowering TFP accounts for the highest negative effect of population aging on growth. Recent research (Wen-Hsin et al. 2019) also supported the negative effect of population ageing on TFP.

Hsu et al. (2019) demonstrated that ageing population can affect economic growth through negatively affecting supply. Guo et al. (2016) using a mathematical representation of the consumption function, they derived a critical value as benchmark for the propensity to consume through which ageing population affects economic growth. They concluded that an ageing population could have positive and negative effects on EG depending on the value of MPC. If the marginal propensity to consume is greater than the critical value, then population ageing has an indirect negative impact on economic growth, whereas, if the MPC is less than the critical value, then ageing population positively affecting EG through the increase in per capita capital.

Capital formation due to affecting saving rates and leading to positively affect economic growth (Hsu et al., 2019). Recently, Hsu et al. (2019). give support to this argument. However, the previous empirical literature was criticized by assuming the relationship between economic growth and ageing population is linear one. Lee and Shin (2019) claimed that previous research assumed that relationship between population ageing, and economic growth is linear, however, he criticized this assumption which leads to incorrect impact of population ageing on economic growth. Their empirical findings demonstrate a negative nonlinear impact of ageing population (quadratic term) on economic growth of 142 countries for the period 1960-2014 using panel data analysis which supports his hypotheses.

From a policy perspective, a considerable body of research demonstrated that policy measures can mitigate the adverse negative impacts of population ageing on economic growth. Park and Son (2021) reported that the extent of population ageing effect varies among countries according to the classification of the income level. They argued that high- and middle-income countries are less affected by population ageing than low-income level countries. They advocate that due to the policy measures such high level of human capital formation and the engagement in high and advanced R&S technologies to mitigate the negative impacts of ageing population on growth.

¹ For more detailed survey, see Nagarajan, R., Aurora, A.C. Teixeira, and Sandra, S. (2013)

From the applied methodology side, the research methodology focused on the impact of Ageing population measures by various measures such as the old dependency ratio, the share of population aged above 65 years. While the GDP growth was utilized as proxy to economic growth. A strand of the applied studies investigates the nexus relationship between the two variables using the ARDL bounce test to cointegration, since it has some advantages over the other cointegration approaches and (Miri et al., 2019; Mohd et al., 2021; Moradi and Nilgun, 2020; Shairilizwan, 2020), or OLS estimation (Mikiko, 2015; Wen-Hsin et al. (2019) Valeriy et al. (2019). On the country-group level, the applied research utilized the panel data analyzes approaches to examine the nexus relation in developing and developed countries, the GMM approach (Thach et al., 2021; Rahman et al., 2020; Abeywardhana, 2019; Park and Son, 2021). Others applied the VECM approach (Ademola, 2018). Their findings provide evidence on the negative impact of an ageing population on economic growth. Thach et al. (2021) examined the effect of ageing populations on economic growth of developing countries over the period 1971-2015 by applying the panel quantile regression framework to account for the differences in the distribution of age groups.

Mikiko (2015) found that the old dependency has no effect on GDP when investigating the impact of ageing population on economic growth of Japan over the period 1975-2011 by using the OLS estimation approach. Miri et al. (2019) analyze the effect of age population structure on economic growth of Iran over the period 1987-2017 by applying the ARDL model. Their empirical findings revealed that aged population group over 64 years old negatively and significantly effect on economic growth in the long term. They concluded that the increase in the share of age population would slow down economic growth of Iran in the long run. They argued that ageing population reduces the marginal propensity to save, thus, causes a reduction in capital formation which in turn negatively affects economic growth.

Mohd et al., (2021) examined the impact of ageing population on economic growth in Malaysia for the period 1981-2019 employing the ARDL bounds testing approach to cointegration. Their findings revealed a significant negative impact of ageing population on economic growth in Malaysia. As for physical capital, Human capital, and labor force, the empirical findings showed positive impacts on economic growth. Moradi and Nilgun (2020) examined the short-run and long-run impacts of ageing population on economic in Turkey for 1978-2018 period by applying the ARDL model. The empirical findings showed that population aging has a negative short-run or long-run effects on Turkey's economic growth. Rahman et al. (2020) investigated the effect of ageing population in 32 countries of upper-middle income countries for the period 199-2018 by applying system GMM. The empirical findings revealed a negative impact of ageing population on EG in these countries. Shairilizwan (2020) investigated the linkage between economic growth and ageing in Malaysia for the period 1990 to 2017 by applying the ARDL bounds test to cointegration. She pointed out that the ageing measured as the people over 55 years old. Abeywardhana (2019) examined the impact of ageing population economic growth in South Asia by means of descriptive analysis. The analytical results revealed that economic growth (GDP) depends on ageing structure, that ageing population has a negative impact on economic growth.

Hsu et al. (2019) attempted to link ageing to saving, investment and growth by analyzing data of Japan. The outcome provides some policy implication to mitigate the negative effect of ageing population such as child welfare programs, promote R&D, and increase expenditure on HC investment because it improves labor quality and productivity, and among others. Wen-Hsin et al. (2019) examined the impact of ageing population and workforce on economic growth in Taiwan using quarterly data from 1981–2017 by applying the ordinary Least Squares Method (OLS). The empirical findings revealed a significant positive impact of workforce on the rate of economic growth, the old-age dependency ratio has a significantly negative effect, and human capital has positive effect on total factor productivity (TFP) growth.

Ademola (2018) applied the VECM framework to assess the linkages between ageing and growth of Nigeria over the period 1975-2015 using ARDL. The outcome indicated that the elderly population is detrimental for growth. Moreover, he argues that expanding the retirement age and increasing expenditure on human capital investment would cure the problem. Valeriy et al. (2019) also assessed the influence of ageing on growth of Ukraine over the period 2000-2017 by applying

the linear regression. Their analysis confirmed the positive influence of ageing on economic growth and labor productivity.

Moreover, Mamun et al. (2020) explored the short and long-run consequences of ageing population on growth of Bangladesh for the period 1972-2015. Their results endorsed that population ageing improves growth. Therefore, they argued that the elderly population does not hinder EG of Bangladesh provided that per capita capital formation exceeds per capita ageing population. Park and Son (2021) attempted to assess the threshold influence of aging population on growth by utilizing a sample of 98 economies. The empirical findings estimated the ageing population threshold lies between 10.1% and 10.9%, which beyond that ageing population negatively affects EG of middle-income countries.

3.0 Econometric Model, Data and Methodology

3.1 Econometric Modeling

The paper is aimed at assessing the role of population aging on the growth performance. However, the growth process of economies responds to several factors other than population aging. For instance, human capital and physical capital are the main factors of growth performance as evident from prior research studies as well as theoretical literature. Following the previous research (Mohd et al., 2021; Rahman et al., 2020; Shairilizwan, 2020; Moradi & Nilgun, 2020; Lee and Kwanho, 2021) the study's economic model specification is constructed based on the Romer's endogenous theory which emphasizes the significance of the human capital as a vital determinant factor of economic growth. Similarly, physical capital in the form of domestic investment also matters for economic performance. It is also a fact that open economies perform better as compared to closed economies (Dollar, 1992, Edwards, 1998). The following function form is specified for analysis.

$$y_t = f(popag^a, popdpr^b, edu^c, inv^d, open^e, inf^f) \quad (1)$$

where (Y_t) is the "growth of per capita GDP" ($POPAG^a$) is an exogenous variable representing the aging population. The control variables include dependency ratio ($POPDPH^b$), human capital (EDU^c), domestic investment (INV^d), openness to trade ($OPEN^e$) and inflation rate (INF^f). The "ratio of the gross capital formation to GDP" is a proxy physical capital investment (Brida, Gómez, & Seijas, 2017). We transform equation using logarithms transformation to the estimable form to address the non-linearities among the variables as shown by expression 2.

$$\ln y_t = \beta_0 + \beta_1 \ln popag_t + \beta_2 \ln popdpr_t + \beta_3 \ln edu_t + \beta_4 \ln inv_t + \beta_5 \ln open_t + \beta_6 \ln inf_t + U_{i,t} \quad (2)$$

All data from 1981 to 2021 were acquired from the "World Development Indicator (WDI)" except the human capital index which is retrieved from the "Penn World Table (PWT)". In the appendix part, the study provides a complete description of variables used in the study.

3.2 Estimation Strategies

The suitable technique for dealing with time series data is to adopt the cointegration technique. The reason for using cointegration is that time series variables are not stationary due to their upward trend. Researchers have proposed several techniques of cointegration, among which the "Engle & Granger, 1987; Johansen & Juselius, 1990" got significant attention from researchers due to their significant benefits. However, the mentioned tests are only valid in case all variables share the same integration order. The same order of integration of variables may not be possible in applied research in most of the cases. Hence, the scope and application of the mentioned tests is limited. Pesaran et al. (2001) suggested a new and interesting approach called "Autoregressive Lag Model (ARDL)" which has some benefits.

$$\begin{aligned} \ln y_t = & \beta_0 + \sum_{i=1}^{n_1} \beta_{1i} \Delta \ln y_{t-i} + \sum_{i=0}^{n_2} \beta_{2i} \Delta \ln \text{popag}_{t-i} + \sum_{i=0}^{n_3} \beta_{3i} \Delta \ln \text{popdpr}_{t-i} + \\ & \sum_{i=0}^{n_4} \beta_{4i} \Delta \ln \text{edu}_{t-i} + \sum_{i=0}^{n_5} \beta_{5i} \Delta \ln \text{inv}_{t-i} + \sum_{i=0}^{n_6} \beta_{6i} \Delta \ln \text{open}_{t-i} + \sum_{i=0}^{n_7} \beta_{7i} \Delta \ln \text{inf}_{t-i} + \theta_1 \ln y_{t-1} + \\ & \theta_2 \ln \text{popag}_{t-1} + \theta_3 \ln \text{popdpr}_{t-1} + \theta_4 \ln \text{edu}_{t-1} + \theta_5 \ln \text{inv}_{t-1} + \theta_6 \ln \text{open}_{t-1} + \\ & \theta_7 \ln \text{inf}_{t-1} + \varepsilon_t \quad (3) \end{aligned}$$

Equation 3 is the ARDL form of equation 2. In equation 3, the unknown parameters " $(\beta_1 - \beta_7)$ " measures short run influence of independent variables on dependent variable. Likewise, the parameters " $(\theta_1 - \theta_7)$ " indicates the short run influence of independent variables on dependent variable. In the ARDL methodology, the presence of cointegration can be assessed by testing the "null hypothesis ($\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = \theta_7 = 0$)" against the "alternative hypothesis ($\theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq \theta_7 \neq 0$)". The F-test values will be compared with the values of Narayan (2005). Cointegration will be accepted if the value of the F-test is higher than the upper limit and vice versa. The second step in the ARDL methodology is to estimate the "error correction model (ECM)". The ECM model is useful as it highlights the adjustment speed and demonstrates the short run relationships. The ECM version of equation 3 is presented below.

$$\begin{aligned} \ln y_t = & \beta_0 + \sum_{i=1}^{n_1} \beta_{1i} \Delta \ln y_{t-i} + \sum_{i=0}^{n_2} \beta_{2i} \Delta \ln \text{popag}_{t-i} + \sum_{i=0}^{n_3} \beta_{3i} \Delta \ln \text{popdpr}_{t-i} + \\ & \sum_{i=0}^{n_4} \beta_{4i} \Delta \ln \text{edu}_{t-i} + \sum_{i=0}^{n_5} \beta_{5i} \Delta \ln \text{inv}_{t-i} + \sum_{i=0}^{n_6} \beta_{6i} \Delta \ln \text{open}_{t-i} + \sum_{i=0}^{n_7} \beta_{7i} \Delta \ln \text{inf}_{t-i} + \\ & \theta_1 \text{ECT}_{t-1} + \varepsilon_t \quad (4) \end{aligned}$$

In expression 4, the term (ECT) measures the speed of adjustment. Other variables measure the short run relationship. In the ideal situation, the term ECT should possess a negative with statistical significance.

4.0 Estimation Results and Discussion

4.1 Unit root Results

In Table 1, the study reported the result of unit root which are acquired with the help of the "Augmented Dickey Fuller Test (ADF)". It is found that that at level, except inflation, all variables are non-stationary. However, at first difference, the issue of non-stationarity is resolved for all selected variables. The order of integration of variables selected for the study is not uniform. The diversity in integration order is the valid justification for employing the ARDL technique.

Table 1. Unit root findings

Variables	Level	Difference	Conclusion
$\ln y_t$	-1.033	-5.678***	I (1)
$\ln \text{popag}_t$	-1.714	-4.064***	I (1)
$\ln \text{popdpr}_t$	-1.367	-3.789**	I (1)
$\ln \text{inv}_t$	-2.243	-6.557***	I (1)
$\ln \text{edu}_t$	-1.996	-4.193***	I (1)
$\ln \text{inf}_t$	-3.603**	-9.256***	I (0)
$\ln \text{open}_t$	-1.832	-5.111***	I (1)

Note: The asterisk (***, **) indicates significance level at 1 and 5 percent level".

4.2 Descriptive Analysis

The study has reported descriptives statistics in Table 2. The descriptives showed that the mean value of "GDP per capita" is 18824.28 "constant 2015 US\$". KSA experienced the highest level of GDP per capita (33070.590) in 1981. Similarly, the lowest value of GDP per capita (15670.730) is recorded in 1987. Since then, the KSA has recorded a persistent increase in GDP per capita.

The age dependency "(Age dependency ratio, old (% of working-age population))" statistics show that on average 4.057 persons are dependent. The maximum (5.173) and minimum (3.131) values of age dependency are experienced by KSA in 1981 and 2013 respectively. On the other hand, the average value of population aging "(Population ages 65 and above (% of total population))" is 2.486 percent while its deviation is 0.173. The maximum and minimum values of population aging are observed in the years 1981 and 2010 respectively. Moreover, the human index takes a mean value

of 2.259 while its standard deviation is only 0.305. Finally, the maximum and minimum values of human capital index are witnessed in the years in 1981 and 2019 respectively.

As far as inflation is concerned, the descriptives indicated a mean value of 1.451 % while its standard deviation is only 2.647. The highest inflation of (9.879 %) is recorded in 2008 while the lowest inflation of (-3.203 %) is in 1987. Overall, the inflation statistics are an indication of improved macroeconomic stability as prices have remained stable during the study period. The investment statistics “(Gross fixed capital formation (% of GDP))” shows that average domestic investment in KSA is 21.647 % which is reasonable. The highest (29.356 %) and lowest value (17.308 %) of domestic investment have happened in 2015 and 1996 respectively. Finally, trade liberalization journey of KSA is remarkable as evident from the descriptives. The trade openness index “(Trade (% of GDP))” takes an average value of 72.325 % which is indeed remarkable. The highest value and lowest values of openness are observed by KSA in 2008 and 2020 respectively.

Table 2. Descriptive Statistics

Descriptives	y_t	$popdpr_t$	$popag_t$	edu_t	inf_t	inv_t	$open_t$
Mean	18824.28	4.057	2.486	2.259	1.451	21.647	72.325
Maximum	33070.59	5.173	2.706	2.713	9.870	29.356	96.102
Minimum	15670.73	3.131	2.154	1.737	-3.203	17.308	49.713
Std. Dev.	2869.481	0.662	0.173	0.305	2.647	2.940	11.767
Observations	41	41	41	41	41	41	41

4.3 ARDL Results

The cointegration results are shown in Table 3. The calculated F-test value is 5.387 which exceeds the upper limit in all significance levels. Therefore, we accept the alternative hypothesis and reject the null hypothesis which believes that variables are not cointegrated. Hence, the presence of cointegration is accepted among the variables.

Table 3. Cointegration Results

“Dependent Variable”	Bound Test	Decision
$lny_t, lnpopag_t, lnpopdpr_t, lnedu_t, lninv_t, lnopen_t, inf_t$	5.387***	“H ₁ Accepted”
“Critical Level”	“I (0)”	“I (1)”
1%	2.88	3.99
5%	2.27	3.28
10%	1.99	2.94

4.4 Discussion on Long Run Results

The study presented the findings of long run relationships in Table 4. According to results, populating aging is indeed harmful for the long run growth of KSA. The Coefficient of population aging is negative as well significant. Therefore, population aging is posing a serious threat for the future growth of the KSA. Our results are supported by the recent research of Maestas et al. (2023) who highlighted that each 10 percent increase in population aging will decrease income per person by 5.5 percent. Therefore, the current aging population needs the attention of the policymakers of the KSA as it may disturb the set targets of the vision 2030. It would be a rational policy suggestion would be that the policymakers are to upgrade the industrial structure in order to escape the negative consequences of the aging population. Structural transformation in the industrial sector favoring the aging population would help the KSA economy to sustain the long run growth performance. On the other hand, age dependency is found to be impacting the growth process of KSA both positively and significantly. The coefficient of population dependency is positive as well as significant in the

estimation. It means that population dependency is playing a significant role in promoting the growth performance of KSA.

The results confirmed the positive and significant role of human capital in promoting the growth performance of KSA. The coefficient of human capital is positive and significant. Our results are aligned with the results of Dewan and Hussein (2001) and Barro (2003). Human capital is the main driver of growth and hence the authorities of Saudi Government must investment significantly in the education sector. An improved education sector would increase human capital due to which the growth performance would be improved enormously. The results further show that domestic investment has improved the growth performance of KSA, which is consistent with the theoretical and empirical literature. For instance, our results regarding the positive influence of domestic investment on economic growth are consistent with the findings of Barro (2003) who also endorsed a positive relationship between investment and growth.

Our results also showed that the inflation rate has deteriorated the economic performance of KSA. Inflation is harmful for the economy as it shakes the confidence of investors as well as consumers. Tahir and Azid (2015) also provided significant evidence about the adverse consequences of inflation and commented that it creates uncertainty in the economy due to which the confidence of stakeholders inversely impacted. Hence, their significant role in uplifting the growth process weakens. Finally, the impact of trade liberalization on the growth of KSA is positive and not significant. However, trade liberalization is important for the growth process (Dollar, 1992, Edwards, 1998). It means that the Saudi authorities need to take some aggressive steps towards liberalization of the economy. Increased liberalization would add to the growth process of KSA significantly.

Table 4. Long run Results

Variables	Coefficients	Standard Error
$\ln popag_t$	-7.569***	1.329
$\ln popdpr_t$	7.0001***	1.333
$\ln inv_t$	0.214*	0.122
$\ln edu_t$	5.487***	1.087
$\ln open_t$	0.029	0.110
inf_t	-0.008*	0.004
Constant	-8.297351	2.329

*Note: The asterisk (***, *) indicates significance level at 1 and 10 percent level.*

4.5 Short Run Results

Table 5 includes the short run findings. The short run results showed that in the short run only investment and trade openness matter for achieving higher economic growth. Similarly, inflation rate is also detrimental for economic performance in the short run, the same as like the long run. Moreover, in short run, education is insignificant which means that education only matters in long run. Furthermore, in the short run, both population ageing and dependency ratios are also insignificant. Finally, the coefficient of ECT is (-0.09) which shows that adjustment from the short run towards the long run is 9 % per year.

Table 5. Short Run Results

Variables	Coefficients	Standard Error
$\Delta \ln popag_t$	-5.896	6.601
$\Delta \ln popdpr_t$	5.126	10.571
$\Delta \ln inv_t$	0.281*	0.154
$\Delta \ln edu_t$	1.179	8.004
$\Delta \ln open_t$	0.287***	0.053
Δinf_t	-0.020***	0.002
ECT (-1)	-0.098***	0.007

*Note: The asterisk (***, **) indicates significance level at 1 and 5 percent level.*

4.6 Diagnostic Testing

Diagnostics are shown in Table 6. The results show that no econometric issue is detected in the estimated model. The results confirmed that “serial correlation” and “heteroscedasticity” are absent. Moreover, the functional form is correct as confirmed by the “Ramsey test”. Finally, the distribution is normal as evident from the “Jarque-Bera test”.

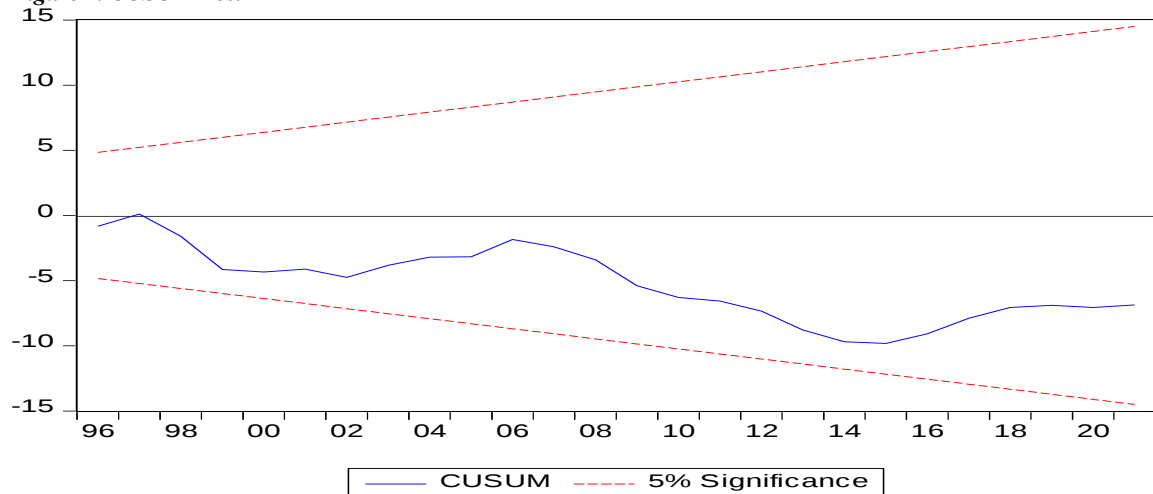
Table 6. Diagnostics

Tests	“Hypothesis”	“Test-Value + Prob.”	“Decision”
“LM-Test”	“Ho: No serial correlation”	2.522 (0.125)	“No serial correlation”
“White-Test”	“Ho: No heteroscedasticity”	1.289 (0.323)	“No heteroscedasticity”
“Jarque-Bera Test”	“Ho: Data is normal”	3.268 (0.195)	“Normal distribution”
“Ramsey-Test”	“Ho: Correct functional form”	1.753 (0.218)	“Correct functional form”

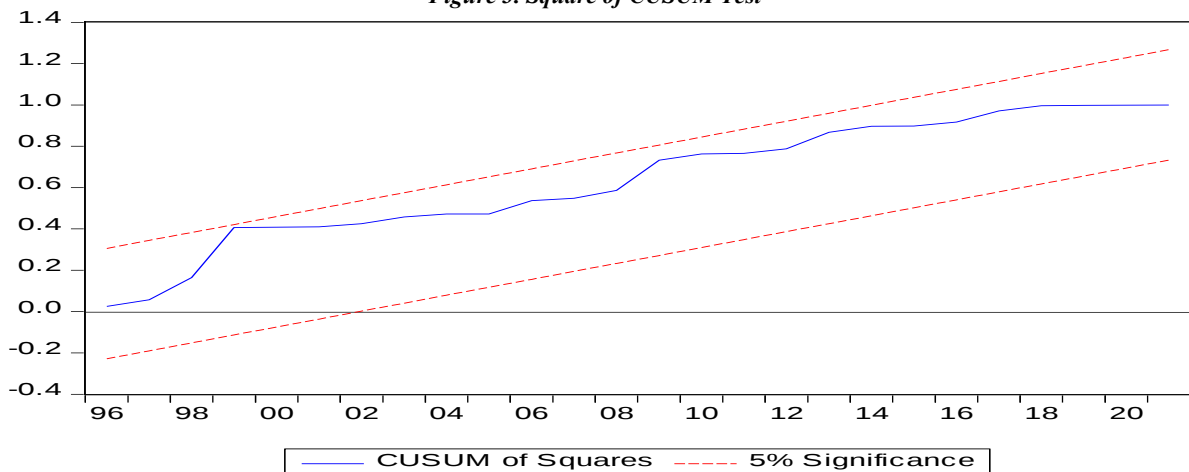
4.7 The Stability of Residuals

In this section, the study carried out the well know “CUSUM test” and the “Square of CUSUM test” for assessing the stability of error term. Figure 2 and Figure 3 provided below display the results. Both the mentioned figures have reflected the stability of the error term as the estimated lines are inside the critical limits. The stability of error term basically reflects the validity and reliability of results. Consequently, our findings could be used with confidence by the policymakers of KSA regarding improving economic growth amid the problem of population aging.

“Figure 2. CUSUM Test”



“Figure 3. Square of CUSUM Test”



5.0 Causality Findings

Causality findings are demonstrated in Table 7. The causality findings revealed several causal relationships both unilateral as well as bilateral. A two-way causal relationship is found between population aging and economic growth, education and economic growth and trade openness and investment rate. On the other several, we found that population dependency is linked with growth and inflation rate while economic growth is associated with investment rate in unilaterally manner.

Similarly, trade openness is causing a population dependency ratio while population aging is causing an inflation rate. Finally, the findings showed that trade openness is connected unilaterally with population aging while education is linked with inflation rate in a unilateral manner.

Table 7. Causality

"Hypothesis"	Test-Value	Prob. Value
$lnpopdpr_t$ to lny	19.3159***	9.E-05
lny to $lnpopdpr_t$	1.62235	0.2107
$lnpopag_t$ to lny	5.10613**	0.0298
lny to $lnpopag_t$	2.71594*	0.1078
$lnedu_t$ to lny	53.7934***	1.E-08
lny to $lnedu_t$	8.12724***	0.0071
$lninv_t$ to lny	1.67435	0.2037
lny to $lninv_t$	3.14362*	0.0845
inf_t to lny	0.08815	0.7682
lny to inf_t	1.82194	0.1853
$lnopen_t$ to lny	1.66603	0.2048
lny to $lnopen_t$	0.15033	0.7004
$lnpopag_t$ to $lnpopdpr_t$	0.98624	0.3271
$lnpopdpr_t$ to $lnpopag_t$	1.83336	0.1839
$lnedu_t$ to $lnpopdpr_t$	0.09377	0.7611
$lnpopdpr_t$ to $lnedu_t$	0.14865	0.7020
$lninv_t$ to $lnpopdpr_t$	0.12118	0.7297
$lnpopdpr_t$ to $lninv_t$	1.46839	0.2333
inf_t to $lnpopdpr_t$	2.46240	0.1251
$lnpopdpr_t$ to inf_t	3.62603*	0.0647
$lnopen_t$ to $lnpopdpr_t$	16.4514***	0.0002
$lnpopdpr_t$ to $lnopen_t$	0.11422	0.7373
$lnedu_t$ to $lnpopag_t$	1.06848	0.3080
$lnpopag_t$ to $lnedu_t$	0.23019	0.6342
$lninv_t$ to $lnpopag_t$	0.11037	0.7416
$lnpopag_t$ to $lninv_t$	2.18234	0.1481
inf_t to $lnpopag_t$	1.99431	0.1662
$lnpopag_t$ to inf_t	4.68498**	0.0370
$lnopen_t$ to $lnpopag_t$	19.6878***	8.E-05
$lnpopag_t$ to $lnopen_t$	0.32713	0.5708
$lninv_t$ to $lnedu_t$	0.37146	0.5459
$lnedu_t$ to $lninv_t$	0.68160	0.4143
inf_t to $lnedu_t$	1.02976	0.3168
$lnedu_t$ to inf_t	3.04951*	0.0891
$lnopen_t$ to $lnedu_t$	1.26567	0.2678
$lnedu_t$ to $lnopen_t$	7.5E-05	0.9931
inf_t to $lninv_t$	2.60680	0.1149
$lninv_t$ to inf_t	0.02779	0.8685
$lnopen_t$ to $lninv_t$	8.01884***	0.0074
$lninv_t$ to $lnopen_t$	3.55528*	0.0672
$lnopen_t$ to inf_t	0.79725	0.3777
inf_t to $lnopen_t$	1.14695	0.2911

6.0 Conclusions and Implications

6.1 Concluding Remarks

This study was intended to assess the role of population aging in the process of economic growth which has received relatively less attention in the context of KSA. The analysis carried out is based on the observations of KSA sourced from credible sources for the period 1981-2021. For the short run and long run impacts, the study employed the well-known ARDL modeling approach.

Our results have confirmed that population aging is a potential threat for the growth process of KSA. It is a fact that population aging harms the growth process as the efficiency of aged population is far less as compared to the younger population. On the other hand, our results underscore that dependency ratio is impacting the growth process positively and significantly. Furthermore, our results also demonstrated that human capital and investment are the main driving forces behind the growth of KSA in the long run. The inflation rate has negatively while trade openness has insignificantly impacted the growth performance. The short run analysis indicated the growth of KSA is dependent on trade openness and domestic investment. Finally, the causality analysis displayed several one-way and two-way causal relationships among the variables including the bidirectionality between population aging and economic growth.

6.2 Implications of Research

Following are the implications of our research study.

- 1) The results showed that population aging is responsible for the poor growth performance of KSA. This could be because the aged population is contributing relatively less to the growth process as compared to the younger population. Therefore, the older population need to be encouraged and motivated to enhance their contribution to the growth performance. Moreover, some necessary structural changes are required in the industrial sector to turn it favorable for the aged population.
- 2) Secondly, it is suggested the authorities of KSA should increase their investment both in physical capital and in human capital as both these factors have added to the growth performance positively. Increased human capital and the availability of physical capital would help the economy to achieve long run sustainable growth.
- 3) The inflation rate needs to be monitored as it is harmful for growth performance in the light of the acquired results. The statistics presented indicated that KSA has done well over the years in keeping the inflation rate at a reasonable limit.
- 4) The policy of trade liberalization needs to be executed in full speed in order to make it work for improvement in economic growth.

Appendix Section

Table 1 A. Variables and Sources

Variables	Definition	Source
y_t	“Economic growth (The growth rate of GDP per capita”	“WDI”
$popag_t$	“(Population ages 65 and above (% of total population)”	“WDI”
$popdpr_t$	“(Age dependency ratio, old (% of working-age population)”	“WDI”
inv_t	“Gross fixed capital formation as % of GDP”	“WDI”
edu_t	“Human Capital Index”	“PWT”
$open_t$	“Trade as % of GDP”	“WDI”
inf_t	“The growth rate of consumer price index”	“WDI”

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Industrial Production and Carbon Emissions: A Comparative Analysis of Selected Arab and European Countries (1990–2023) ¹

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Abstract: The study investigated the impact of industrial production on carbon emissions in selected European countries versus selected Arab countries. Using the econometrics methodology by applying the Granger Causality Test, (OLS) Model, Fixed Variable Panel data VS Random Variable Panel data models. The results showed that industrial production causes carbon emissions and vice versa in the EU countries, as for the case of Arab countries industrial production does not cause carbon emissions, this may reflect the differences between the volume of industrial production in each case, this result is consistent with (Abokyi et al., 2019), in addition there is an impact of industrial production on carbon emissions in both groups of countries, this means that every rise in industrial production leads to a corresponding rise in carbon emissions, which aligns well with the current reality and is supported by (Xiaoqing & Jianlan, 2011). The study recommends targeting sectors like chemicals, cement, and iron and steel petrochemicals, which account for over 70% of total emissions, aligning with the findings of (Brown et al., 2012). Alternatively, it is crucial to measure the emissions generated by industrial operations to comprehend the worldwide carbon balance and create an appropriate climate strategy, as stated by (Liu, 2016). The study also recommends stimulate an industrial investment environment compatible with environmental protection and carbon reduction considerations in Arab countries highlighting the importance of using new and renewable energy and clean technology in manufacturing from all countries of the world so that it can achieve sustainable development.

Keywords: Industry, Industrial production, Carbon Emissions, Arab Countries, European Union Countries.

الإنتاج الصناعي وانبعاثات الكربون: دراسة مقارنة لعدة دول عربية ودول أوروبية (1990-2023) ¹

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المستخلص: هدفت الدراسة إلى استكشاف أثر الإنتاج الصناعي على انبعاثات الكربون في عدة دول أوروبية مقابل عدة دول عربية باستخدام منهجية الاقتصاد القياسي حيث تم تطبيق اختبار جرانجر للسببية، نماذج انحدار خطي متعدد (OLS)، نماذج تحليل لوحة المتغيرات الثابتة، ونماذج (تحليل لوحة المتغيرات العشوائية). أظهرت النتائج أن الإنتاج الصناعي يسبب انبعاثات كربونية والعكس صحيح في حال الدول الأوروبية، أما في حال الدول العربية فإن الإنتاج الصناعي لا يسبب انبعاثات كربونية، وربما يعود ذلك لاختلاف حجم الإنتاج الصناعي في كل حالة، هذه النتيجة تتوافق مع نتائج دراسة (Abokyi et al., 2019). كما أكدت النتائج أن هناك تأثير للإنتاج الصناعي على الانبعاثات الكربونية في كلا المجموعتين من الدول، إلا أن التأثير أكثر وضوحاً في حالة الدول الأوروبية وهذا يعني أن كل ارتفاع في الإنتاج الصناعي يؤدي إلى ارتفاع مماثل في انبعاثات الكربون، ولكن نسبة الارتفاع في حال الدول الأوروبية أعلى منها في حالة الدول العربية، وهو ما يتوافق بشكل جيد مع الواقع الحالي ويدعمه نتائج دراسة (Xiaoqing & Jianlan, 2011). وأوصت الدراسة بضرورة تركيز الجهود نحو تخفيض انبعاثات الكربون من القطاع الصناعي عامة، واستهداف صناعات المواد الكيماوية، الاسمنت، البتروكيماويات والحديد والصلب حيث تمثل وحدها أكثر من 70% من إجمالي انبعاثات الكربون من القطاع الصناعي، ويتوافق ذلك مع دراسة (Brown et al., 2012). وأنه من الضروري قياس الانبعاثات الناتجة عن العمليات الصناعية لفهم توازن الكربون في جميع أنحاء العالم ووضع استراتيجية مناخية مناسبة أكثر عدالة مع وضع سياسات صناعية في الدول العربية تحفز بيئة استثمار صناعي متوافقة مع اعتبارات حماية البيئة وخفض الكربون. وهذا يؤكد أهمية استخدام الطاقة الجديدة والمتجددة والتكنولوجيا النظيفة في التصنيع في جميع دول العالم.

الكلمات المفتاحية: الصناعة، الانتاج الصناعي، انبعاثات الكربون، الدول العربية، دول الاتحاد الأوروبي.

¹ The selected arab countries are: Egypt, Saudi Arabia, Syria, UAE, and Tunisia, the selected European countries are: Germany, France, Sweden, Spain, and the UK.

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1. INTRODUCTION

The 2007 IPCC Fourth Assessment Report states that burning fossil fuels is the primary source of greenhouse gases, accounting for 95.3% of the total CO₂ emissions. Many domestic academics examine the connection between CO₂ emissions energy consumption and economic growth from a qualitative and quantitative research standpoint. However, the connection between industrial restructuring and a low-carbon economy is less well-studied, and most research focuses on qualitative analysis.

In this study, the impact of industrial production on the Co₂ emissions, in selected Arab countries Vs selected European countries are examined. The Arab countries were compared with the European Union countries, these countries were chosen for study as they are classified as among the most industrialized countries in both groups to challenge the idea of equal obligations in climate change negotiations based on the damage caused by carbon emissions, particularly from industrial production.

The US EPA (2016) states that the consumption of fossil fuels is the main cause of CO₂ emissions worldwide, and empirical evidence supports this claim (Kwakwa and Alhassan, 2018); Nnaji et al., 2013).

This study aims to test the hypothesis:

H0: Industrial production is the main cause of carbon emissions in Arab countries compared to European Union countries during the period 1990-2023.

H1: Industrial production is not the main responsible for carbon emissions, applying to the Arab countries compared to the state of the European Union countries during the period 1990-2023.

H2: The volume of industrial production in Arab countries is much less than the volume of industrial production in European countries.

H3: The volume of carbon emissions in Arab countries is much less than the European countries.

The study adopts the methodology of econometrics by applying the Granger Causality Test, and then the (OLS) Model, fixed panel Vs random panel data also applied.

Often used to test the cointegration relationship between two variables, the Engle-Granger test consists of two steps: cointegration regression is the first step, and Granger causality tests are used to confirm the relationship between the CO₂ and the Indus variables in the chosen countries.

The World Bank Data Indicators WDI (2024) version of the annual time series data, which covered the years 1990–2023, was used in the study. Since information on CO₂ emissions in the chosen Arab and EU nations was available, this time frame was used. Value added (as a percentage of GDP), industry (including construction), GDP (constant 2015 US\$) as a control independent variable, and CO₂ emissions (kg per 2021 PPP \$ of GDP) as the dependent variable were among the variables of interest for which data was gathered.

2. LITERATURE REVIEW

From the energy consumption perspective (Wise et al., 2007) present an overview and scenario findings from the long-term energy consumption model in the US industrial sector, which included a module in the ObJECTS-MiniCAM integrated assessment model. With an emphasis on energy technologies and fuel choices spanning a century, this new industrial model enables the assessment of the industrial sector's response to climate policy within a framework of global modeling. The study clarified that one of the significant issues was defining an aggregate level that could reflect the dynamics of industrial energy demand reactions to pricing and regulations while still being manageable over an extended period.

(Alberola et al., 2008) conducted a critical analysis of the effects of industrial output on spot pricing for emissions permits during Phase I for industries covered by the EU Emissions Trading Scheme (EU ETS) from the perspective of industrial production (2005-2007). Initially, sector production indices are used as a proxy to measure economic activity in the industries that are subject to the EU ETS. The ratio of allowance allocation to baseline CO₂ emissions is used to calculate the amount that an installation is restricted by the EU ETS. According to the study, changes in carbon pricing are a result of industrial production in the three industries that are subject to the EU ETS: combustion, paper, and iron. They also show that errors in energy price predictions and extreme weather events also affect carbon prices.

Although the goal of (Xiaoqing & Jianlan, 2011) study was to quantify the relationship between CO₂ emissions and industrial structure adjustment, the study found that there is a long-term stable equilibrium relationship between the two in Shandong Province. Granger causality tests also demonstrate that the industrial structure is the cause of the change in emissions, but the latter is not the cause of the former. Three key findings are obtained by constructing the decomposition model of CO₂ emissions, which measures the contributions of industrial structure, technical efficiency, and economic growth to the growth of CO₂ emissions: (1) The overall economy's shift is the primary driver of emissions; (2) the industrial structure's shift contributes differently to emissions at different phases, from 1994 to 1999 and from 2006 to 2009.

(Brown et al., 2012), found that an ongoing, dedicated effort is needed to reduce industrial emissions and the alternatives for lowering industrial CO₂ are also described in this briefing paper. Focusing on the industries that contribute the most share (>70%) of emissions, including chemicals, cement, and iron and steel petrochemicals. The article provides a summary of industrial mitigation, technologies, including those that relate to specific processes as well as spread over the entire sector. The potential for these to reduce technology, their affordability and adoption challenges, as well as the policies to remove these obstacles are covered. The study concluded that to fully grasp the scope of energy efficiency and emissions abatement options, a concentrated effort to enhance emissions measurements and benchmarking is still required. The implementation of cross-cutting energy efficiency improvements should be hampered by certain obstacles, which should be addressed. These barriers are frequently "social" in nature, such as managerial and organizational structures or ignorance, as opposed to financial. Increases in energy efficiency can save a lot of CO₂ and are frequently inexpensive or even free. It is important to use suitable mechanisms, like a carbon price, subsidies, or regulations, to encourage the use of biomass and waste instead of fuels and raw materials.

In his 2015 study, "National carbon emissions from the industry process: Production of glass, soda ash, ammonia, calcium carbide, and alumina," Zhu Liu attempted to determine the relationship between industrial production and carbon emissions in China, one of the world's most industrialized nations. He did this by estimating the carbon emissions from the manufacturing of five major industrial products and calculating the emissions from five different types of major industry production processes using a bottom-up data source approach. He discovered that quantifying the emissions from industrial processes is essential for comprehending the global carbon budget and creating an appropriate climate policy.

However, in their attempt to examine the same relationship over an extended period in Turkey, (Gokmenoglu et al., 2015) used the Granger causality test and discovered a unidirectional association between financial development and carbon emissions.

According to (Andrew, 2018) quantifying global process emissions from cement production is difficult due to data availability issues and the need for strong assumptions for analysis. It is no longer feasible to use cement production data with constant emission factors since countries all over the world have been producing cement with decreased clinker ratios during the past three decades. Compared to other attempts, the new worldwide cement emissions database given here relies less on conjecture and more on official and trustworthy data sources. The database is meant to be utilized in the global carbon budget and updated yearly with new data and improved methodology. Data will increasingly replace assumptions in the creation of datasets as more nations estimate their emissions and provide detailed

reports to the UNFCCC. Since China and India are the two biggest manufacturers of cement worldwide and official time-series estimates are insufficient, there is still work to be done to improve estimates of cement emissions from both countries.

Focussing on how fossil fuels affect CO₂ emissions is unusual for developing countries like Ghana (Abokyi et al., 2019). The ARDL approach was applied in this investigation. Analyzing the feasibility of applying the Bayer-Hanck joint cointegration method and structural breakdowns The EKC hypothesis highlights the importance of fossil fuel use and economic growth in Ghana's dynamic link between industrial deFeroz Kazivelopment and carbon dioxide emissions (CO₂). Cointegration of the elements is found, and the long- and short-term characteristics both showed indications of industrial growth and a U-shaped link between CO₂ emissions, which was further confirmed. according to Lind and Mehlum's U-test. There is a one-way causal relationship in the short term between CO₂ emissions and the usage of fossil fuels. The study encourages the efficient application of policies. A one-way causal relationship between the usage of fossil fuels and CO₂ emissions was demonstrated via the short-run causality. To achieve policy objectives, the paper advocates for low-carbon emission and efficient technologies.

(Sibanda & Ndlela, 2020) tried also to investigate the relationship between agriculture/ industrial output and carbon emission in South Africa using annual frequency data for the 1960-2017 data set, applied the Autoregressive Distributed Lag (ARDL) technique, they found that industrial output had no effect on carbon emission, but agriculture output negatively influenced by carbon emission and industrial output, then adversely affecting food security.

The focus of (Islam et al., 2017) is on environmental awareness and its connection to economic development. Researchers have long maintained that both should be reduced since sustainable growth and environmental degradation are interdependent. This study looks at how Bangladesh's industrial production index growth, total energy consumption, and economic development relate to environmental degradation (using carbon emissions as a proxy for degradation) between 1998 and 2013. This study uses the Vector Autoregression (VAR) Model and variance decomposition of VAR to investigate the relationship between these factors and carbon emissions. The VAR model's findings show a strong correlation between industrial production, GDP per capita, and carbon emissions. Carbon emissions regularly affect industrial output, according to additional study employing variance decomposition.

According to (Yoro & Daramola, 2020), researchers have worked extremely hard to decrease the amount of anthropogenic CO₂ that is released into the atmosphere. The literature reviewed in this study demonstrates that various methods, including adsorption, absorption, and membrane separation, have been proposed and tested in the literature for CO₂ capture. CO₂ capture is a costly technology in many nations due to the high energy and material requirements of the current methods. In order to lower the high energy and material needs in the previously mentioned CO₂ capture systems, this study proposes that the application of process integration techniques through heat and mass exchanger network synthesis can be expanded. Furthermore, the study's research findings demonstrate that the primary human activities responsible for greenhouse gas emissions and global warming include transportation, cement manufacture, and electricity generating. With the addition of CO₂ collection mechanisms to the current power plants, this study proves that burning fossil fuels (such as coal) to generate electricity is still possible.

According to (Rahman et al., 2022), industrial processes and product use (IPPU) have been steadily increasing in the Kingdom of Saudi Arabia. Emissions from the IPPU have been trending upward. This study looked into cross-sectional and time-series analyses of the IPPU industry. The Kingdom's top source categories are cement, iron and steel, and petrochemicals. The production of titanium dioxide, zinc, and aluminium has expanded in recent years. In 2020, emissions from IPPU (excluding energy use) reached 78 million tons of CO₂ equivalent (CO₂eq), with the cement industry being the largest contributor (35.5%), followed by the petrochemical (32.3%) and iron and steel industries (16.8%). A scenario-based projection estimated that emissions could range between 199 and 426 million tons of CO₂eq by 2050. The Kingdom's efforts primarily focus on climate change adaptation and economic

divergence while achieving mitigation co-benefits. Key mitigation strategies for this sector include (i) energy efficiency, (ii) emissions efficiency, (iii) material efficiency, (iv) product recycling and material reuse, (v) extended product lifespan, and (vi) demand management.

(Zhang et al., 2022) examined the CO₂ emissions inventory and its uncertainty analysis of China's industrial parks. Industrial parks are essential to reaching carbon neutrality and the carbon peak in industrial sectors. The first stage in reaching the carbon peak of industrial parks is creating the inventory of CO₂ emissions. This study created a thorough inventory of CO₂ emissions for industrial parks that included three sections: waste disposal, industrial processes, and energy usage. The study created an uncertainty analysis framework and took scope 1, 2, and 3 emissions into account. By breaking down the emissions into scopes 1, 2, and 3, scope 2 can be found to be the biggest source of emissions. The study also included activity levels, emissions factors, and unspecific factors in its inventory uncertainty analyses. These findings could, in general, encourage the development of greenhouse gas accounting guidelines for industrial parks in China.

(Kurnia et al., 2020) explored four key aspects of firm value: the impact of carbon emission disclosure on firm value, the influence of good corporate governance on firm value, the mediating role of financial performance between carbon emission disclosure and firm value, and the mediating role of financial performance between good corporate governance and firm value. The study analyzed a sample of 43 mining, agricultural, and manufacturing companies listed on the Indonesian Stock Exchange from 2015 to 2017. Carbon emission disclosure was assessed using the Environmental Aspect indicator from the Global Reporting Initiative Series, while corporate governance was evaluated based on factors such as investor disclosure, audit committees, boards of directors, outside directors, shareholder rights, and internal auditors. Financial performance was measured using return on investment as a key indicator.

In an article published before the UN Global Climate Summit in Paris, (Yessekina, 2015) explores current trends in global warming, greenhouse gas pollution, and debates regarding the roles of industrialized and poor nations. The article talks about decarbonization as a national program that involves advanced tools for reducing CO₂ levels, improving energy efficiency, and setting up emissions trading systems. The author emphasizes that because Kazakhstan and Turkmenistan have the greatest potential to emit greenhouse gases (GHGs) in the region, they should be included in the UNFCCC and participate in the global effort to build national decarbonization programs. These policies enable these nations to participate in the global carbon trading market, access foreign financial resources, and substantially lower CO₂ emissions in the area.

(Bezić et al., 2022) Explored the factors causing CO₂ emissions in the EU and the potential for reducing them in the fourth industrial revolution. The study focuses on the 27 EU countries and examines the Panel Generalized Method of Moments (GMM) two-step dynamic estimator from 2012 to 2019. The study found that the EU is focused on sustainable development through its strategies and economic policies. The results also show that creativity economic components that influence a country's growth and prosperity, are all negatively correlated with CO₂ emissions and, therefore, make a substantial impact on the decrease in carbon dioxide emissions. based on the empirical findings, it can be inferred that The EU must increase innovation activity and technological advancements to achieve sustainable development goals.

By evaluating their Circular Carbon Economy Index (CCEI), we examine Saudi Arabia (KSA), atar,the United Arab Emirates (UAE), Kuwait, Algeria, and Iraq on the effects of implementing carbon capture and storage technology in the Kingdom (Baidas, 2024), Saudi Arabia, Qatar, the United Arab Emirates, and Kuwait all scored higher on the CCEI than Algeria and Iraq, according to the study. This indicates that these countries have implemented CCE-transition policies more thoroughly and have increased funding for modernization projects that aim to reduce emissions, change their industrial composition, develop top-notch human resources, and raise the caliber of their governmental bodies.

Hence, all previous studies and literature in the field of studying the relationship between industrial production and carbon dioxide emissions did not agree on the direction of the relationship between the two variables absolutely, and none of them dealt with the study of the causal relationship between the two variables in the group of European Union countries compared to the group of Arab countries. In examining the direction and magnitude of the relationship between industrial production and carbon emissions in two sizable groups of nations—one serving as a model for developed nations and the other as a model for developing nations—the current study should be a useful scientific addition. A variety of research techniques from earlier studies are employed in this one.

3. RESEARCH METHODS AND DATA SOURCES

3.1. DATA

Table (1) below lists the variables that were selected to investigate the relationship between industrial production and carbon emissions in the selected Arab countries and the selected European Union countries between 1990 and 2023. All of the variables that make up the econometric model are defined in Table (1). Every annual statistic used in the model, which covers the years 1990–2023, was taken from World Bank tables. The data analysis was carried out with E-Views 12.

Table (1): The model's economic variables

Name	Code	Data Source	Definition
Industry (including construction), value added (% of GDP)	Indus Arab Indus Eu	World Bank Database	ISIC divisions 05–43 are associated with industry (including construction) and manufacturing (ISIC divisions 10–33). It encompasses value-added in construction, mining, manufacturing (sometimes shown as a separate subdivision), power, gas, and water. A sector's net output after subtracting intermediate inputs and totalling all outputs is known as value added.
CO2 emissions (kg per 2021 PPP \$ of GDP)	Co2Arab Co2Eu	World Bank Database	Emissions of carbon dioxide are produced when fossil fuels are burned and cement is made. Among these are carbon dioxide emissions from gas flaring and the ingestion of solid, liquid, and gas fuels.
GDP (constant 2015 US\$)	GDPArab GDPEU	World Bank Database	Gross Domestic Product (GDP) at buyer's prices represents the total gross value added by all domestic producers to the economy, including product taxes and excluding subsidies that influence product value. The data is presented in US dollars, adjusted to constant 2015 prices.

(Source: World Bank national accounts data, and OECD National Accounts data files, <https://tradingeconomics.com/united-states/co2-emissions-kg-per-ppp-dollar-of-gdp-wb-data.html>)

3.2. METHODOLOGY

The study intends to ascertain the relationship between CO2 emissions (kg per 2021 PPP \$ of GDP) and industry value added (% of GDP), including construction, in the Arab countries group vs the European Union countries group from 1990 to 2023. The direct and unambiguous causal relationship between industrial production and carbon emissions is explained by the Granger Causality Test. The relationship between industrial production and carbon emissions was further investigated using the Ordinary Least Square (OLS) model and the Panel data fixed vs. random model. the main model will take the following formula:

$$Y_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2it} + \varepsilon_{it} \quad (1)$$

Where Y_{it} is the dependent variable, refers to the CO2 emissions (kg per 2021 PPP \$ of GDP)

α is the intercept,

β_1 represents the partial coefficients for the independent variable X_{1it} (which refers to Industry (including construction) value added (% of GDP))

β_2 represents the partial coefficients for the independent variable x_{2it} (which refers to GDP (constant 2015 US\$) as a control independent variable)

In the study, this model will be applied twice. It will be used to examine the effects of industrial value added on Co2 emissions in these selected Arab countries. Then, it will be used to examine the same relationship in the selected European Union countries group.

4. RESULT ANALYSIS AND DISCUSSION

4.1. DESCRIPTIVE AND TESTS FOR MODEL VARIABLES:

Table(2): Descriptive Statistics for the selected Arab countries

	CO2	GDP	Indus
Mean	0.300596	25.45147	3.566417
Median	0.281696	25.87089	3.529392
Max	0.723988	27.38514	4.196139
Min	0.125933	23.18477	2.740281
Std. Dev	0.125933	1.299949	0.339997
Jarque- Bera	42.10700	17.51101	4.494070
Prob	0.000000	0.000158	0.105712
Sum	51.101134	4326.750	606.2908
Sum Sq. Dev	2.553747	285.5876	19.53601
Observations	170	170	170

Source: Calculated by the researcher using E-views 12, and World Bank data

Quantitative insights into the chosen data series are offered by descriptive statistics. Standard deviation and central measurements are shown in Table (3) below and Table (2) above. According to the findings, the mean of every variable chosen during the study period was positive. However, when compared to the other variables in the model, a high standard deviation indicates the highest value (GDP) in Arab countries and an identical outcome for the chosen European countries.

Table (3): Descriptive Statistics for the selected European countries

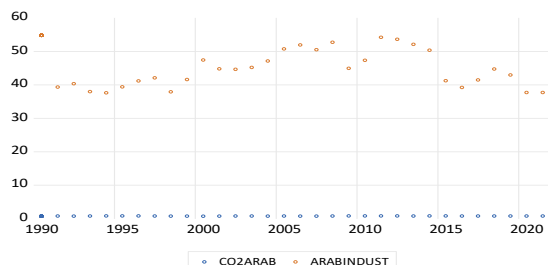
	CO2	GDP	Indus
Mean	0.146994	3.140360	28.02127
Median	0.143069	3.165157	28.32791
Max	0.283526	3.512266	28.92124
Min	0.053992	2.797015	26.36917
Std. Dev	0.052231	0.173807	0.753421
Jarque- Bera	5.517755	9.099720	21.35240
Prob	0.063363	0.010569	0.000023
Sum	24.98906	533.8612	4763.615
Sum Sq. Dev	0.461037	5.105282	95.93175
Observations	170	170	170

Source: Calculated by the researcher using E-views 12, and World Bank data

In general, there are three steps to be followed according to the methodology of studying time series: The unit root test to determine the degree of integration, the co-integration test between this series, and the causality test. In this study, these three standard steps were followed according to Enders (1995) for the following reasons: 1st, to ensure that all variables under study are stationary whether at the levels or at the first differences (unit root test), 2nd, to identify the possibility of complementarity relationships between variables in the long run (cointegration tests), 3rd, to determine the direction of causation, further

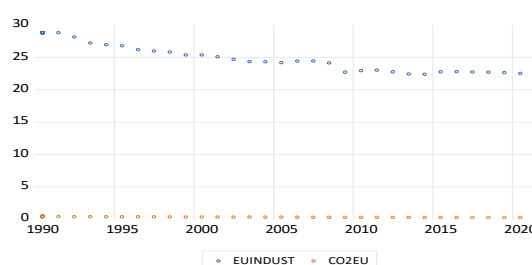
Autoregressive distributed lags (ARDL) model will be applied, because this model uses a general-to-specific modelling framework with enough lags to represent the data generation process.

Figure (1): Trends of CO2 In Arab Countries and Arab Industrial Output



Source: World Bank Data Website

Figure (2): Trends of CO2 In EU Countries and EU Industrial Output



Source: World Bank Data Website

4.2. UNIT ROOT TEST:

The stationarity of the time series and the order of data integration are assessed using a unit root test. The null hypothesis states that $D(\text{ARABCO}_2)$ has a unit root. Based on the unit root test results at the first difference, as shown in Table (3), the null hypothesis can be rejected, indicating that the variables do not have a unit root.

Table (4): Unit Root Test Results Augmented Ducky- Fuller

Variables	Level		1st difference
	Test	Prob	Prob
EUINDUST (For Eu industry)	Fisher ADF	0.000044	0.0005
ARABINDUST(For Arab country's industry)	Fisher ADF	0.000000	0.0000
EUCO2 (For Eu co2 emissions)	Fisher ADF	0.000031	0.0004
ARABCO2 (For Arab countries co2 emissions)	Fisher ADF	0.000015	0.0002

Source: Calculated by the author, using WB data, and applied with E-views

4.3. JOHANSEN COINTEGRATION TEST

4.3.1. FOR ARAB COUNTRIES:

Table(5):Unrestricted Cointegration Rank Test (Trace)

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	1.000000	1062.576	12.32090	0.0000
At most 1	0.066374	2.060374	4.129906	0.1782

Source: Calculated by the author, using WB data, and applied with E-views

The study accepts alternative hypothesis H1, which states that industrial production in Arab countries was not the primary cause of carbon emissions, and vice versa for European countries. This is because the previous results of the ADF unit root test, which are shown in Table 3, show that the null hypothesis of unit root is rejected for all variables, i.e. integrated of order 0 (I(0)).

4.3.2. FOR EU COUNTRIES:

Table(6): Unrestricted Cointegration Rank Test (Trace)

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	1.000000	1091.909	20.26184	0.0000
At most 1 *	0.297638	10.59918	9.164546	0.0265

Source: Calculated by the author, using WB data, and applied with E-views

The previous results indicate that the trace statistic is greater than the critical Value (0.05) at the first deference, so we can reject H0 (Where there is just one cointegration between variables), and accept the alternative hypothesis H1, which means that there is more than one cointegration between variables for the European countries group.

4.4. GRANGER CAUSALITY TEST:

The Granger causality test is used to assess whether one time series can help forecast another by examining causal relationships between two variables over time. This method provides a probabilistic approach to causality by analyzing observed data for correlation patterns. A key advantage of time series vector autoregression (VAR) is its ability to test causality in a specific sense. Originally introduced by Granger (1969), this test is commonly referred to as the Granger causality test (Feroz Kazi, 2020). In this study, the Granger causality test will be applied to examine the relationship between CO₂ emissions and the value added by the industry (including construction) as a percentage of GDP in Arab and EU countries.

Table (7): Granger test results

Null Hypothesis:	Obs	F-Statistic
CO2ARAB does not Granger Cause ARABINDUST	30	0.0226
ARABINDUST does not Granger Cause CO2ARAB	0.9373	0.4050
Null Hypothesis:	Obs	F-Statistic
CO2EU does not Granger Cause EUINDUST	30	1.8540
EUINDUST does not Granger Cause CO2EU	1.2054	0.3164

Source: Calculated by the author, using WB data, and applied with E-views12

The results above show that :

CO2EU  EUINDUS

As F Statistic is greater than F Probability, then we accept H0 and refuse H1, so there is a causal relationship between variables. This means that there is a positive relationship between industry and Co2 emission in European countries, but also each of the two variables causes the other one.

ARABINDUST  CO2ARAB

But for Arab countries, the result shows that ARABINDUST does not Granger Cause CO2ARAB, this is a logical result as the size of the industrial sector and production in the Arab countries is still below the level that raises carbon emissions, and on the contrary in the case of European countries, where the volume of industrial production increases and carbon emissions rise with it, and the relationship here is mutual. This result is consistent with Ghana Eric Abokyi & others(2019). This result supports the necessity of reconsidering industrial development plans in Arab countries and strategies to support industrial production.

4.5. Ordinary Least Squares (OLS) MODEL:

In its simplest form, OLS regression is used to assume a linear relationship between the x predictor and the y result variable in many scientific domains, including economics. It solves the $y = a + bx + e$ model, where e is the residual error, or the difference between the predicted and actual score for any given value of x , b is a regression coefficient that quantifies how much y varies for every unit change in x , and a is an intercept or value of y at $x = 0$. Since it establishes the degree, direction, and intensity of the relationship between y and x , the regression coefficient b is the most significant (Kleinbaum et al., 1988).

So, in this study, the OLS model was applied as mentioned in the methodology above, and in Table (7) The results show that industrial production in Arab countries affects carbon emissions, as the coefficient has a positive sign and a value of 0.19. Table (8) also shows that for the European countries, industrial production also affects Co2 emissions as the coefficient has a positive sign and a value of 0.21. Hence, the previous results support the scientific fact that industrial production increases carbon emissions, but noting that this effect in European countries is stronger than its counterpart in Arab countries, this is due to the huge volume of industrial production in European countries. This result is consistent with (Xiaoqing & Jianlan, 2011).

Table(8): OLS model for Arab countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	1.748	0.172	10.11	0.0000
INUS	0.196	0.040	4.882	0.0000
GDP	-0.084	0.010	-8.010	0.0000
R^2	0.301			
Adjusted R^2	0.293			
Log Likelihood	146.16			
F- Statistic	36.096	Durbin - Watson	0.054	
Prob(F-Statistic)	0.000000			

Table(9): OLS model for Arab countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	-1.311	0.126	-10.327	.0000
INUS	0.215	0.016	13.313	.0000
GDP	0.027	0.003	7.442	.0000
R^2	0.540			
Adjusted R^2	0.535			
Log Likelihood	327.299			
F- Statistic	98.357	Durbin - Watson	0.059	
Prob(F-Statistic)	0.000000			

Source: Calculated by the author, using WB data, and applied with E-views

4.6. Panel data model:

Data that shows how entities (i) behave across time (t) is called panel data, sometimes referred to as longitudinal or cross-sectional time-series data. (X_{it} , Y_{it}), where $t=1, \dots, T$; $i=1, \dots, n$. Panel data addresses the bias caused by omitted variables due to the diversity of the data. This is achieved by taking into consideration variables that are associated with the predictors but are not observable, accessible, or quantifiable. There are two types: entity fixed effects are variables that don't change over time but vary from one entity to another (cultural factors, differences in business practices between businesses, etc.).

Time-fixed effects are variables that vary over time but do not vary between entities (such as international agreements, federal rules, and national policies).

So, in this study the time fixed and the random models were applied as The entity fixed effects regression model is $Y_{it} = \alpha_i + \beta X_{it} + u_i + e_{it}$, where;

Y_{it} outcome variable (for entity i at time t).

α_i is the unknown intercept for each entity (n entity-specific intercepts).

X_{it} is a vector of predictors (for entity i at time t).

ui within-entity error term ;

eit overall error term.

While the entity and time-fixed effects regression model is $Y_{it} = \alpha_i + \beta X_{it} + \delta t + ui + eit$,
where;

Y_{it} outcome variable (for entity i at time t).

α_i is the unknown intercept for each entity (n entity-specific intercepts).

X_{it} is a vector of predictors (for entity i at time t).

δt is the unknown coefficient for the time regressors (t) ui within-entity error term ;

eit overall error term.

Table(10):
Fixed effects regression results for Arab countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	0.466	0.247	1.888	0.060
INUS	0.039	0.023	1.691	0.092
GDP	-0.012	0.009	-1.226	0.221
R^2	0.872			
Adjusted R^2	0.868			
Log Likelihood	290.928			
F- Statistic	186.480	Durbin-Watson	0.154	
Prob(F-Statistic)	0.000000			

Table (11):
Fixed effects regression results for EU countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	3.811	0.389	9.792	0.000
INUS	0.115	0.018	6.113	0.000
GDP	-0.143	0.012	-11.844	0.000
R^2	0.896			
Adjusted R^2	0.892			
Log Likelihood	453.681			
F- Statistic		Durbin-Watson	0.162	
Prob(F-Statistic)	0.000000			

Source: Calculated by the author, using WB data, and applied with E-views

The above Fixed effects regression results show that Industrial production in both groups, whether Arab or European countries, affects carbon emissions, although the effect is stronger in the case of European countries.

Table (12):
Random effects regression results for Arab countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	0.512	0.247	2.274	0.040
INUS	0.039	0.023	1.685	0.093
GDP	-0.013	0.009	-1.432	0.153
Weighted Statistics				
R^2	0.023			
Adjusted R^2	0.001			
F- Statistic	1.994	Durbin-Watson	0.150	
Prob(F-Statistic)	0.139			
Unweighted Statistics				
R-squared	0.084	Durbin-Watson	0.021	

Table (13):
Random effects regression results for EU countries

Variable	Coefficient	Std. Error	T - Statistics	Prob.
c	1.873	0.314	5.957	0.000
INUS	0.189	0.016	11.439	0.000
GDP	-0.082	0.009	-8.465	0.000
Weighted Statistics				
R^2	0.756			
Adjusted R^2	0.753			
F- Statistic	259.070	Durbin-Watson	0.126	
Prob(F-Statistic)	0.000			
Unweighted Statistics				
R-squared	-1.948	Durbin-Watson	0.006	

Source: Calculated by the author, using WB data, and applied with E-views

The above random effects regression results also show that Industrial production in both groups, whether Arab or European countries, affects carbon emissions, although the effect is stronger in the case of European countries.

The study then applied the Husman Test to test the hypothesis:

H0: Random test is preferred to fixed effect.

H1: fixed test is preferred to Random effect.

Table (14):
Husman test results for Arab countries

Variable	Fixed	Random	Var(Diff.)	Prob.
INUS	0.039	0.039	0.000	0.893
GDP	0.012	-0.013	0.000	0.336
R^2	0.872			
Adjusted R^2	0.868			
F-Statistic	186.48	Durbin-Watson	0.154	
Prob(F-Statistic)	0.0000			

Table (15):
Husman test results for EU countries

Variable	Fixed	Random	Var(Diff.)	Prob.
INUS	0.115	0.189	0.000	0.000
GDP	-0.143	0.082	0.000	0.000
R^2	0.896			
Adjusted R^2	0.892			
F-Statistic	234.539	Durbin-Watson	0.162	
Prob(F-Statistic)	0.0000			

Source: Calculated by the author, using WB data, and applied with E-views

We accept H0, so the random effects results are more accurate and reliable. This means that the results all go in the same direction and support the effect of industrial production on carbon emissions in both groups of countries. They also confirm that this effect is stronger and clearer in European countries compared to Arab countries.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS:

The study found a positive causal relationship between industrial output and Co2 emission in the selected European countries, but each of the two variables also causes the other one. For the selected Arab countries, the result shows that ARABINDUST does not Granger Cause CO2ARAB, this is a logical result as the size of the industrial sector and production in the Arab countries is still below the level that raises carbon emissions, and on the contrary in the case of European countries, where the volume of industrial production increases and carbon emissions rise with it, and the relationship here is mutual, so the volume of industrial production in Arab countries cannot be compared to its counterpart in European countries. This result is consistent with (Abokyi et al., 2019), and (Sibanda & Ndlela, 2020).

The results also confirmed the presence of a clear impact of industrial production on carbon emissions, whether in the selected Arab countries or European countries, emphasizing that the effects in the case of European countries are more clear from a statistical standpoint, and from a practical standpoint also given the large volume of industrial production in them compared to Arab countries. This result is consistent with (Xiaoqing & Jianlan, 2011).

The study recommends that dedicated effort is needed to reduce industrial emissions. focusing on the industries that contribute the most share (>70%) of emissions, including chemicals, cement, and iron and steel petrochemicals, this is consistent with (Brown et al., 2012). On the other hand, quantifying the emissions from industrial processes is critical for understanding the global carbon budget and developing a suitable climate policy, and this is consistent with (Cui et al., 2019) Industry must remain competitive not only inside Europe but also globally to continue to ensure prosperity and economic success. This calls for the kind of business environment that encourages innovation and reducing CO2 that a contemporary industrial policy may establish. Fair competition is crucial in global marketplaces as well. The Arab countries could develop their industrial sectors without significantly increasing carbon emissions this is through the use of new, renewable, and low-carbon energy methods and supporting green economy strategies in developing the industrial sector.

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Pilgrimage Tourism, Economic growth & Energy consumption: Their Impact on Carbon Emission in Saudi Arabia

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Abstract: Saudi Arabia's Vision 2030 focuses on economic diversification and includes initiatives to enhance the pilgrimage experience for religious tourists while reducing CO2 emissions. Given the environmental challenges posed by tourism—particularly pilgrimage tourism—there is limited research on its impact on environmental change. This study addresses that gap by analysing the relationships between CO2 emissions, energy consumption, economic growth, and pilgrimage tourism in Saudi Arabia, using annual time series data from 1996 to 2022. Employing the Vector Error Correction Model (VECM) and the Granger causality test, the results confirm significant long-term associations among these variables. The Johansen cointegration test shows a positive link between energy consumption and GDP growth, although an increase in pilgrim arrivals negatively affects carbon emissions. Specifically, as CO2 levels increase, pilgrimage tourism growth declines by 0.07%, indicating a negative cointegration effect. The VECM results suggest that economic growth and increased energy consumption awareness reduce carbon emissions, highlighting the potential of a circular carbon economy (CCE) consistent with the Paris Agreement and Sustainable Development Goals (SDGs). However, pilgrimage tourism still contributes significantly to carbon emissions. These findings offer crucial policy implications for managing environmental concerns within the Vision 2030 framework.

Key words: Saudi Arabia, Pilgrimage Tourism, CO2, Energy Consumption.

JEL CODES: Q43; Q55; Z3

السياحة الدينية، النمو الاقتصادي واستهلاك الطاقة: تأثيرها على انبعاث الكربون في المملكة العربية السعودية

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المستخلص: تركّز رؤية المملكة العربية السعودية 2030 على التنوع الاقتصادي وتتضمن مبادرات لتعزيز تجربة الحج للسياح الدينيين مع تقليل انبعاثات ثاني أكسيد الكربون. ونظراً للتحديات البيئية التي تفرضها السياحة - وخاصة سياحة الحج - فإن الأبحاث حول تأثيرها على التغير البيئي محدودة. تتناول هذه الدراسة هذه الفجوة من خلال تحليل العلاقات بين انبعاثات ثاني أكسيد الكربون، واستهلاك الطاقة، والنمو الاقتصادي، وسياحة الحج في المملكة العربية السعودية، باستخدام بيانات السلاسل الزمنية السنوية من 1996 إلى 2022. استخدم نموذج تصحيح الخطأ المتجه (VECM) واختبار السببية جرانجر تؤكد النتائج وجود ارتباطات كبيرة طويلة المدى بين هذه المتغيرات. ويظهر اختبار يوهانسن للتكامل المشترك وجود صلة إيجابية بين استهلاك الطاقة ونمو الناتج المحلي الإجمالي، على الرغم من أن الزيادة في أعداد الحجاج الوافدين تؤثر سلباً على انبعاثات الكربون. وعلى وجه التحديد، مع زيادة مستويات ثاني أكسيد الكربون، ينخفض نمو سياحة الحج بنسبة 0.07%، مما يشير إلى تأثير سلبي للتكامل المشترك. تشير نتائج VECM إلى أن النمو الاقتصادي وزيادة الوعي باستهلاك الطاقة يقللان من انبعاثات الكربون، مما يسلط الضوء على إمكانات اقتصاد الكربون الدائري (CCE) بما يتوافق مع اتفاق باريس وأهداف التنمية المستدامة (SDGs). ومع ذلك، لا تزال سياحة الحج تساهم بشكل كبير في انبعاثات الكربون. تقدم هذه النتائج آثاراً سياسية حاسمة لإدارة المخاوف البيئية ضمن إطار رؤية 2030.

الكلمات الرئيسية: المملكة العربية السعودية، سياحة الحج، ثاني أكسيد الكربون، استهلاك الطاقة.

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1. Introduction:

Travel for pleasure, recreation, exploration, religious, family, or business purposes that lasts only a short while is referred to as tourism. Nowadays, tourism is one of the main sources of income for both developed and developing nations, and it is crucial to the growth of the global economy (Costa 2017). The growth of tourism is influenced by a variety of reasons, one of which is religious motivation. Religious tourism pertains to types of tourism that have religious connotations and has been a perpetual phenomenon throughout the history of religions (Rinschede, 1992). The market for religious travel has grown into a billion-dollar industry worldwide (Hashim et al., 2007) and the majority being Muslims, Christians and Hindus (Olsen& Timothy, 2006). Religious tourism has massively increased in recent decades. It is also called pilgrimage tourism or belief tourism. The Asia-Pacific area is regarded as the world's religious core, with the biggest number of pilgrims and visitors attending religious events on both international and domestic tours (World Tourism Organization,2011). There are an estimated 600 million national and international religious and spiritual travels worldwide, with Europe accounting for 40% and Asia accounting for more than half. According to UNESCO, 60% of the world's population practices a religion, and these believers provide the demographic backbone of religious tourism (World Tourism Organization,2011). Religiously significant cities play an important role in promoting belief tourism. The Vatican for Christians, Varanasi for Hindus, and Mecca for Muslims are recognised as religious centres. The pilgrims' increased expenditure on transportation, lodging, meals, and mementos helps local companies and creates jobs. However, notwithstanding these positive effects, tourism is considered as a substantial contributor to the environmental problem, mainly to climate adjustment.

The convergence of environmental change and religious tourism is gaining importance in the global context, as both factors influence and are influenced by each other. Major religious events frequently create considerable environmental issues, such as waste generation, carbon emissions from transportation, and resource depletion. As the number of pilgrims increases, particularly in developing countries, the accumulated environmental impact of religious tourism becomes an urgent matter that necessitates efficient management techniques. The Paris Agreement and the United Nations Sustainable Development Goals (SDGs) represent a global commitment to sustainability, and they influence how religious tourism is approached. Countries are encouraged to adopt policies that promote sustainable tourism practices, especially those involving religious travel.

The biggest religious tourist event in the world happens every year during the Hajj pilgrimage in Mecca, Saudi Arabia. Hajj is an obligatory religious requirement for Muslims that must be performed at least once in their lives by all adult Muslims who are physically and financially capable of making the journey and sustaining their families while away from home. Therefore, millions of Muslims from around 183 different countries and cultures perform the Hajj every year (Parker & Gaine, 2019).Saudi Arabia is a country rich in religious significance and has a long history, having been the birthplace of Islam. As such, its tourism attraction is closely linked to its religious significance. Prior to the discovery of oil, Saudi Arabia's economy dependent on agriculture and tourism earnings from Muslim pilgrimages to the holy city of Mecca. Despite the fact that oil is the backbone of Saudi Arabia's economy, pilgrimage tourism provides a considerable source of financial stability; yet, it has a negative influence on the environment. The Hajj generates significant solid and liquid waste, consumes vast amounts of scarce fresh water, and emits high levels of greenhouse gases. Given the duration of the pilgrimage—roughly three weeks—and the fact that pilgrims continue to carry out their essential daily tasks while in the holy cities, it is inevitable that Saudi Arabia was impacted by these events. Ozturk et al.(2022) discovered pilgrimage tourism will inevitably have an environmental cost. Khwaja et al. (2014) discovered that air pollution levels during the Hajj surpassed World Health Organisation (WHO) norms. Butenhoff et al. (2015) observed that the Hajj event causes air pollution in Mecca to rise above that of other cities in Saudi Arabia. Notwithstanding the environmental repercussions the issue gets little attention in Saudi Arabia. Thus, this study explores the relationship between pilgrimage tourism, energy consumption and economic growth on carbon emission in Saudi Arabia data period from 1996 to 2022. Saudi Arabia introduced the notion of the circular carbon economy (CCE) as a framework for reducing emissions to a level in tandem with the objectives of the Paris Agreement during its Presidency of the Group of Twenty (G20) in

2020 (Shehri et al., 2022). The Paris Agreement and the Sustainable Development Goals (SDGs) are strongly associated. According to United Nations (UN) Goal 13 of the SDGs seeks for immediate action to mitigate climate change, which addresses the Paris Agreement's ambition to limit global temperature rise to well below 2 degrees Celsius.

The environment in Saudi Arabia is said to be significantly impacted by pilgrimage tourism. It has been shown that pilgrimage tourism boosts economic growth and income, but its negative environmental effects need to be examined and addressed by every appropriate stakeholder. Thus, this study investigates the role of energy consumption, Pilgrimage tourism and economic growth in carbon emission in Saudi Arabia for the period of 1996-2022. In addition, to find out the effects that Muslims' pilgrimages have on the environment when they are engaged in religious devotion. As a result, the main hypothesis is that Saudi Arabia's atmospheric pollution is impacted by pilgrimage tourism. Finally, it presents a numbers of policy recommendations. The study uses vector error correction model (VECM), which is used to examine the short-and long run impacts of energy consumption, economic growth and pilgrimage tourism on carbon emission in Saudi Arabia. This paper adopted time series VECM approach to conduct stationary test, cointegration test, stability test, and Granger causality test. And also used cholesky variance decomposition technique to trace back shocks into the future. To the best of the researcher knowledge, this is the first paper in the literature to investigate the relationship between religious tourism, energy consumption and economic growth in carbon emission using vector error correction model in the context of Saudi Arabia, and this is the paper's main novelty. Given that this study contributes to the body of knowledge on the Saudi Arabia's Vision 2030, which aim to achieve net zero emission by 2060 through Circular Carbon Economy, it also adds a significant value to policy and practice.

The rest of this paper is organised as follows: section 2 reviews the literature on this subject, while section 3 shows the model specification and methodology. Section 4 presents empirical results. Lastly, section 5 describes the conclusion and policy implications.

2. Literature Review:

The surge in worldwide demand for energy has led to a greater reliance on fossil fuels. Consequently, the world environment has deteriorated due to a commensurate rise in carbon emissions. Tourism, as an economic activity, cannot only generate economic prosperity and encourage development, but it also consumes significant amounts of energy and natural resources and emits an enormous quantity of carbon dioxide. The relationship of tourism, energy consumption, economic growth, and carbon emissions is currently a hot topic in academia. In this section, the literature review analysed the tourism-economic growth-energy consumption-carbon emission linkages without distinguishing between religious tourism and general tourist.

Several studies have examined the relationship between tourism and economic growth, and the results show that these relationships are subtle. The tourism-led growth hypothesis is supported by a number of studies that show how the development of tourism can spur economic growth (Samimi & Sadeghi, 2011; Gwenhure & Odhiambo, 2017; Naseem, 2021; Alcalá-Ordóñez et al., 2023). Some study observed bidirectional causality, where tourism and economic growth strengthen one another (Samimi & Sadeghi, 2011; Corrie et al., 2013; Assadzadeh and Nasab., 2012; Caglayan, Ebru et al., 2012; Aslan, 2016; Bilen et al., 2017; Pulido-Fernandez and Garcia, 2020; C. Wijessekara et al., 2022). Nevertheless, the direction of causality can vary, with economically stronger and more democratic countries frequently showing bidirectional correlations between tourism and growth (N. Antonakakis et al., 2019). In Mexico unidirectional causality between tourism development and economic growth was discovered (Barida et al., 2008). Additionally, studies such as Akinboade and Braimoh (2009), Schubert et al. (2010), Brida et al. (2015), Kum et al. (2015) and Tang and Tan (2015), Akadiri et al. (2019), Badulescu et al. (2020) have found a unidirectional causal association between growing tourism and economic growth.

Numerous studies have suggested that tourism stimulates economic growth, especially for emerging nations and small island economies such as Mauritius (R. Durbarry, 2004). While tourism is frequently viewed as a potential driver of economic development, particularly in developing

nations (Fadi Fawaz et al., 2014; R. Durbarry, 2004; Enilov & Wang, 2021), the nature of this relationship varies depending on economic, political, and tourism-specific factors (N Antonakakis et al., 2019). Tourism contributes more to economic growth in regions such as Africa, Asia, and Latin America, as well as countries where tourism accounts for a larger part of GDP (Stanislav Ivanov & Webster, 2011). Tourism's role in the expansion of the economy changes with time (Santamaria and Filis, 2019). These findings illustrate the multifaceted and context-dependent aspects of tourist activity's impact on economic development.

Recent research looks at the relationship between tourism and economic growth in a variety of circumstances. Tourism market diversification has been shown to boost economic growth, particularly in low- and lower-middle-income nations (Peng et al., 2023). In Greece, a long-term association between tourism and economic growth was discovered, implying that international tourism has a favourable impact on economic growth (Mavrommati et al., 2024). However, the tourism-economic growth link can be nonlinear and time-varying, as seen in the Schengen region, where it was positive between 1995 and 2003 but negative during economic crises (Dogan & Zhang, 2023). Although tourism can help with regional economic development through the creation of jobs, research in Jambi, Indonesia, discovered that tourist visits, unemployment, and poverty all had an impact on economic growth, but not significantly (Amry et al., 2023). These findings emphasize the complexity and context-dependence of tourism's impact on economic growth.

Tourism's tendency to boost carbon emissions is a complicated and contentious issue. Some research indicates a positive association between tourism development and carbon emissions (Ahmed Amzath & Laijun Zhao, 2014; C. León et al., 2014), while others suggest environmentally friendly innovations may minimise this effect (Erdoğan et al., 2022). The link varies by country, with wealthy nations having a greater impact than less developed ones (León et al., 2014). The tourism-emission linkage lacks accord, with conflicting findings reported across geographies, income levels, and the sector's economic importance (Sun et al., 2022). To solve this issue, a few scholars propose raising sustainable tourist practices such as guest homes and minimising domestic transfers (Ahmed Amzath and Laijun Zhao, 2014). Erdoğan et al. (2022) emphasise the need of eco-friendly transportation systems in reducing emissions. These findings highlight the need for a critical reconsideration of tourism-carbon interrelationships, as well as improved research techniques, to inform successful policymaking (Sun et al., 2022).

The most recent research on tourism and carbon emissions demonstrates the industry's complex relationship with climate change. Tourism contributes significantly to worldwide GDP while also accounting for around 8% of global greenhouse gas emissions (Liu et al., 2023). An inverted N-shaped relationship between tourism and CO₂ emissions has been identified, indicating the sector's potential for sustainability as it evolves (Purwono et al., 2024). However, without mitigation actions, tourism might exhaust 40% of the world's remaining carbon budget, limiting warming to 1.5°C (Gössling et al., 2023). Corporate, political, and technical constraints impede the industry's ability to execute efficient decarbonization initiatives. In Europe, where tourism is a key economic contributor, both climate and carbon risks are substantial issues, with climate risk dominating research (Steiger et al., 2023). Addressing these difficulties requires comprehensive strategies that include renewable energy adoption, sustainable practices, and policy initiatives.

The intricate connections between tourism, economic growth, consumption of energy, and carbon emissions in various economies have been the subject of recent studies. Using the panel VAR approach, Tiwari et al. (2013) examined the relationship between energy use, tourism, and climate change in 25 OECD nations between 1995 and 2005. The findings of the analysis demonstrated that there was a positive correlation between tourism and energy use, as well as a one standard deviation shock to climate change and emissions. Tang and Abosedra (2014) examined the relationship between political instability, tourism, economic growth, and energy consumption. Their study used the GMM estimator to evaluate data from 24 MENA countries for the years 2001 to 2009, and the findings suggest that energy consumption and tourism play a role in the economic expansion of MENA nations. Danish et al. (2019) claim that rising CO₂ emissions across all income levels are caused by rising energy usage. According to Eyuboglu and Uzar (2019), tourism, energy use, and growth all hamper environmental quality by increasing emission concentrations in Turkey. Tourism

and energy usage in Singapore were found to increase CO₂ emissions, but economic growth had a negative influence (Raihan et al., 2022; Raihan & Tuspekova, 2022). Comparable results were observed in India, where energy use and tourism increased CO₂ emissions (Jayasinghe & Selvanathan, 2021). A parallel study of developed and developing nations found that tourism has a positive impact on economic growth in both contexts, validating the tourism-led growth hypothesis. However, the impact of tourism on CO₂ emissions decreases faster in developed economies, consistent with the environmental Kuznets curve hypothesis (Paramati et al., 2016). Azam et al. (2018) examined how tourism affects environmental quality in Malaysia, Singapore, and Thailand. Their findings revealed that, whereas tourism has a favourable impact in Malaysia, it has an opposite effect in Thailand and Singapore. Pablo-Romero et al. (2019) evaluated the effects of tourism on the environment in 12 Spanish Mediterranean provinces between 1999 and 2014. Empirical studies revealed that tourism development leads to increased electricity consumption, and consequently temperature fluctuations. Kocak et al. (2019) evaluated the link between tourism and CO₂ emissions and found a long-term causal association between the two.

Basarir and Cakir (2015) performed panel data analysis in order to determine the direction of relationship between CO₂ emissions, financial development, energy consumption, and tourism in Turkey and four EU countries. Their finding suggested that there is unidirectional causal relationship between the tourist arrivals and financial development. And also, there is a bi-directional causality relationship between CO₂ emission, financial development, and energy and tourist arrival.

Dogan and Aslan (2017) investigated the link between CO₂ emissions, real GDP, energy consumption, and tourism in European Union nations from 1995 to 2011, employing FMOLS and DOLS methodologies as well as the panel Granger causality test. Their findings suggested that there is unidirectional causality from tourist to carbon emissions, as well as bidirectional causality between CO₂ emissions and energy consumption, and real GDP and CO₂ emissions.

Tourism growth has been shown to have a considerable positive impact on carbon dioxide emissions in both the short and long term (B. Shakouri et al., 2017; K. Zaman et al., 2017; N. Nwaeze et al., 2023; Kemal Eyuboglu and Umut Uzar, 2019; Selvanathan, E.A. et.al, 2020). Economic growth and energy use both contribute to higher CO₂ emissions (N. Nwaeze et al., 2023; Kemal Eyuboglu & Umut Uzar, 2019). Surprisingly, environmental quality has been discovered to influence tourists' location preferences (Kemal Eyuboglu & Umut Uzar, 2019). Above recent studies findings illustrate the intricate connection between tourism, economic variables, and environmental repercussions, emphasising the importance of sustainable tourism practices and regulations that reduce CO₂ emissions while promoting economic growth.

More recent studies have looked at the intricate connections between tourism, economic growth, energy use, and carbon emissions. Khan et al. (2023) discovered an inverse relationship between CO₂ emissions and tourism in Kuwait, with economic growth and increased energy use lowering emissions. In a comparable manner Jebli and Hadhri (2018) found that energy use and tourism help to reduce transport emissions in popular tourist sites. Wasti and Zaidi (2020) found that CO₂ emissions and energy consumption boost economic growth in Kuwait. According to Khan et al. (2020), tourism boosts CO₂ emissions, energy consumption, and capital expenditure in Pakistan. The studies predominantly agree that there are causal correlations between these variables, albeit in varying directions (Khan et al., 2023; Jebli & Hadhri, 2018; Wasti & Zaidi, 2020). These findings highlight the importance of integrated strategies that promote sustainable tourism development while minimising environmental impacts (Khan et al., 2020).

Recent research has looked into the complex links between tourism, economic growth, energy use, and carbon emissions in several Asian economies. Tourism development has been linked to significantly higher CO₂ emissions in Singapore and other Asian countries (Asif Raihan et al., 2022; Misbah Nosheen et al., 2021). However, economic growth has had conflicting consequences, with some research finding that emissions may decrease as economies improve (Asif Raihan et al., 2022; Misbah Nosheen et al., 2021). Energy use, notably from fossil fuels, has continuously been associated to higher CO₂ emissions (Asif Raihan et al., 2022; Guo et al., 2023). To address these environmental concerns, academics have underlined the necessity of promoting sustainable tourism

practices, expanding renewable energy use, and creating green financing markets (Asif Raihan et al., 2022; Guo et al., 2023). The rising corpus of work on this topic emphasizes the importance of a thorough understanding of tourism's economic, social, and environmental implications (J. Brida et al., 2023).

Recent research has looked at the intricate links between religious tourism, economic growth, energy usage, and carbon emissions. In Saudi Arabia, pilgrimage tourism was discovered to have a positive influence on CO₂ emissions, with a bidirectional causal relationship between tourism and GDP (Ozturk et al., 2021; Tabash et al., 2023). Similarly, in India, tourism and energy consumption both contributed favorably to CO₂ emissions, with long-term causation linking both factors to emissions (Jayasinghe & Selvanathan, 2021). In China, there were bidirectional short-term causalities between GDP and tourism, as well as unidirectional long-term causalities from energy consumption to other variables (Zhang & Zhang, 2020). These findings emphasize the environmental costs of religious and general tourism, indicating the necessity for sustainable tourism practices and revised pollution-reduction measures. The studies also underline the need of taking tourism into account when investigating the relationship between economic growth, energy consumption, and environmental deterioration (Ozturk et al., 2021; Tabash et al., 2023; Jayasinghe and Selvanathan, 2021; Zhang & Zhang, 2020).

In Saudi Arabia context very few recent research has looked into the complex relationships between tourism, economic growth, energy use, and carbon emissions. Tourism, particularly religious pilgrimage, has been shown to boost economic growth while also contributing to higher CO₂ emissions (Ozturk et al., 2021; Jamel, 2020). While economic growth generally has a negative influence on emissions, energy consumption and oil prices show favourable effects (Ozturk et al., 2021). The country's Green Vision seeks to achieve sustainability in a variety of areas, with research revealing links between energy consumption, economic growth, tourism, and carbon emissions (Faisal et al., 2024). According to the Environmental Kuznets Curve, international tourism has a U-shaped connection with carbon emissions (Li et al., 2024). However, it has been demonstrated that using renewable energy reduces environmental damage (Li et al., 2024). These results emphasise the obstacles and prospects that Saudi Arabia faces in maintaining economic growth, tourism development, and environmental sustainability. Several studies have revealed that economic growth and energy consumption are major drivers of rising CO₂ emissions in the country (Amjad Ali et al., 2023; Mahmood et al., 2019; Alkhathlan. K, 2012). An inverted U-shaped relationship between economic growth and CO₂ emissions has been established, with Saudi Arabia currently at the first stage of expansion contributing to environmental degradation (Alkhateeb et al., 2020). To solve these issues, researchers suggest switching to renewable energy and cleaner technology in order to separate economic growth from environmental degradation (Amjad Ali et al., 2023; Haider Mahmood et al., 2019). These findings highlight the importance of implementing balanced policies that support long-term economic development while also protecting the environment.

When the empirical literature on the relationship between tourism, energy consumption, economic growth, and carbon emissions is examined, it is determined that there is no distinction between religious tourism and has a scarcity of research in this field.

3. Methodology

3.1 Data subsection

This model draws information from the World Development Indicators (WDI), the British Petroleum (BP) Statistics and the Hajj Statistics obtained from Saudi Arabia General Authority for Statistics. Statistics on energy consumption and carbon dioxide emissions are from BP, while statistics on economic growth (in terms of GDP in current US dollars) from World Development Indicators and the number of pilgrims coming from abroad to Saudi Arabia from Saudi Arabia General Authority for Statistics. This paper investigates the connection between Carbon emissions, energy consumption, economic growth, and pilgrimage tourism in Saudi Arabia from 1996-2022.

3.2 Model specification

Carbon emissions, energy consumption, economic growth, and pilgrimage tourism are just some of the study variables analyzed using econometric models used by Ozturk et al (2021) before. The model can be formulated as follows:

$$\text{Carbon emissions} = f(\text{energy consumption; economic growth; Hajj pilgrims}) \quad (1)$$

Many research (Naseem.S.,2021, A. M. Khan et al., 2021; Murshed et al., 2022; U. Khan et al., 2022) have recommended normalising data sets before using them in an econometric model. All the study's variables could benefit from a logarithmic transformation to maintain measurement consistency and prevent issues with distributional features. This could also lead to stationarity in the variable series. This is particularly true for variables with varying measurement units, such as total energy consumption and carbon dioxide emissions, which are expressed as indices. Consequently, each variable is converted into a logarithmic function and employed in a real term:

$$LY_t = \log(Y_t) \quad (2)$$

This can also be characterized in a log-linear econometric format:

$$\ln ct = \beta_0 + \beta_1 \ln ent + \beta_2 \ln gt + \beta_3 \ln npt + \epsilon_t \quad (3)$$

Where β_0 is the constant term, β_1 is the coefficient of the variable (energy consumption), β_2 is the coefficient of variables (economic growth), β_3 is the coefficient of variables (number of foreign pilgrims' arrival), t is the time trend, and ϵ_t is the random error term assumed to be normal, identical, and independently distributed.

3.3 Methodology

Unit Root test

Augmented Dickey Fuller (ADF) and Phillip Perron (PP) unit root tests are adopted to investigate the stationary importance for long-term connection of time series data. Both these tests will be carried out.

The following regression estimates the general form of the A.D.F. test

$$\Delta Y_t = a + \beta Y_{t-1} + \sum \beta_i \ln i = 0 \Delta Y_i + \epsilon_t \quad (4)$$

The following regression estimates the general form of the P.P. test

$$\Delta y_t = \alpha + \beta \Delta y_t \quad (5)$$

The basic difference between the ADF and PP tests is that PP is a non-parametric test, meaning that it does not need to specify the form of the serial correlation of Δy_t under the null hypothesis (Shrestha & Bhatta, 2018).

Cointegration test

The Johansen co-integration test is validated by similar integration order, but the optimal lag is determined before estimating co-integrating among variables, as the first step. In this paper, the Johansen test is used to investigate the existence of cointegration between CO2 emission, Energy consumption, GDP, and number of foreign pilgrims' arrival. The null hypothesis of the Johansen test of cointegration is that "CO2 emissions, energy consumptions, GDP, and number of foreign pilgrims' arrival are not cointegrated". If the critical value is greater than the trace and max statistic, we can reject the null hypothesis. This implies that "CO2 emission, Energy consumption, GDP, and number of foreign pilgrims' arrival are co-integrated".

Vector Error Correction Model

VECM is an effective method for analysing dynamic economic relationships when the variables are cointegrated. In comparison to other models, it is particularly useful for investigating the long-term relationship and short-term dynamics of multiple variables employed in this study. It identifies the long-term equilibrium while preserving information about short-term modifications.

The cointegrating equation and long run Model can be expressed as:

$$ECT_{t-1} = Y_{t-1} - n_j X_{t-1} - \epsilon_m R_{t-1} \quad (6)$$

VECM can be expressed as:

$$\Delta \ln c_t = \alpha + \sum_{i=1}^{k-1} \beta_i \Delta \ln c_{t-i} + \sum_{j=1}^{k-1} \phi_j \Delta \ln e_{t-j} + \sum_{m=1}^{k-1} \phi_m \Delta \ln g_{t-m} + \sum_{n=1}^{k-1} \phi_n \Delta \ln n_{t-n} + \lambda_1 ECT_{t-1} + \mu_1 t \quad (7)$$

Where;

$\ln c$ = log value of carbon dioxide emission

$\ln e$ = log value energy consumption

$\ln g$ = log value of Economic Growth measured in terms of GDP (current US\$)

$\ln n$ = log value of number of foreign pilgrims' arrival

$k-1$ = the optimal lag length is reduced by 1

β_i ; ϕ_j ; ϕ_m , n = short-run dynamic coefficients of the model's adjustment long-run equilibrium

λ_1 = speed of adjustment parameter with a negative sign

ECT_{t-1} = the error correction term is the lagged value of the residuals obtained from the cointegration regression of the dependent variable on the regressors. Contains long-run information derived from the long-run cointegrating relationship.

$\mu_1 t$ = residuals in the equations

Causality Test:

Finally, the causality relationship between variables will be determined by Granger causality analysis. The Granger causality test is used to establish the existence of the relationship between variables and to determine the direction of this relationship, if any. The equations for this test are shown as below (Engle & Granger, 1987; Granger, 1988):

$$y_t = \sum_{i=1}^k a_i y_{t-i} + \sum_{i=1}^k \beta_i x_{t-i} + \mu_1 t \quad (8)$$

$$x_t = \sum_{i=1}^k \theta_i x_{t-i} + \sum_{i=1}^k \gamma_i y_{t-i} + \mu_2 t \quad (9)$$

4. Empirical Result

4.1 Unit Root Test:

The ADF and PP unit root test are used, and the results are shown in Table 1. According to the results, all the series contain unit roots at the level and become stationary when the first differences are taken. Hence, it paved the way to use the Johansen cointegration test for further analysis.

Table 1: Unit Root Test by augmented Dickey Fuller & Philips Perron

		ADF		PP	
		t-Statistics	Prob.	Adj.t-stat	Prob.
LNC	I (0)	-1.090	0.1438	-1.030	0.9399
	I (1)	-2.190	0.0200	-3.024	0.0327
LNE	I (0)	-0.081	0.9933	-0.498	0.9835
	I (1)	-3.522	0.0371	-3.579	0.0317

		ADF		PP	
LNNP	I (0)	-2.105	0.5431	-2.159	0.5131
	I (1)	-4.774	0.0005	-4.773	0.0005
LNG	I (0)	-1.742	0.7321	-1.837	0.6867
	I (1)	-4.241	0.0039	-4.171	0.0000

Source: Authors' Calculations

4.2 Lag order selection

The application of the Johansen co-integration test is validated by the presence of a similar order of integration, as reported by the ADF and PP unit root tests. However, the optimal lag is determined before estimating the co-integrating among the variables. The choice of an optimal lag is the first step in the Johansen cointegration test. Hence, in this section, the vector autoregression (VAR) specification is used to establish the appropriate lag length for the cointegration test in this section. The results of the VAR lag selection are presented in Table 2. From the table, it is clear that lag 2 has the minimum Akaike information criterion (AIC). Consequently, lag 2(K = 2) is selected as the optimal lag in the equation models.

Table 2: Lag order selection

Lag order	AIC	SIC	HQIC
0	-7.33771	-7.29098	-7.13934
1	-13.6253	-13.3916	-12.6334
2	-14.0222*	-13.6016*	-12.2369

Source: Authors' Calculations

4.3 Cointegration analysis:

The result of the Johansen cointegration test are shown in Table 3. At maximum rank 3, trace and max statistics are less than 5% critical value, the model's null hypothesis of no cointegration is rejected compared to the alternative that there is a cointegration link at a lag of 2. Therefore, the study concludes that there is a long run relationship between carbon emissions, energy consumption, economic growth and foreign pilgrims' arrival in Saudi Arabia.

Table 3: Johansen cointegration test for carbon mission as a dependent variable

Maximum Rank	Eigenvalue	Trace statistics	5% critical value	Max-Eigen Statistics	5% critical value
0		55.568	39.89	23.3706	23.80
1	0.65434	32.1974	24.31	19.4764	17.89
2	0.58741	12.7210	12.53	11.0411	11.44
3	0.39460	1.6800*	3.84	1.6800	3.84
4	0.07352				

Note. AIC, SC and HQ results are based on determining the optimal lag length (lag 2).

*Denotes statistically significance for %5 critical value.

Source: Authors' Calculations

4.4 VECM estimation and analysis

The presence of cointegration relationships between Inc , $lnen$, $lnnp$ and lng suggests a long run cointegrating relation between CO emission, energy consumption, number of foreign pilgrims arrival and economic growth. Hence, the VECM can be applied. Using the maximum likelihood estimator, the cointegrating coefficient vector normalized to Inc which is the variable of interest is estimated as given in Table 4.

Table 4. Cointegration coefficient vector from VECM.

	Inc	lnen	lnnp	lng
Coefficient	1	-0.5676	0.0719	-0.161
		(0.000)	(0.000)	(0.000)

Source: Authors' Calculations.

The long-run relationship between Inc, lnen, lnnp and lng for a co-integrating vector is,

$$ECT_{t-1} = 1.00Inc_{t-1} - 0.5676lnen_{t-1} - 0.161lng_{t-1} + 0.0719lnnp_{t-1} \quad (10)$$

Coefficient signs should be reversed in the normalised cointegrating equation of Johansen model which is representing the long run. Carbon emissions(Inc) is the target variable. Lnen has a positive and significant impact on Inc in the long run. An increase in lnen will lead to increase in Inc emissions. That is, a percentage rise in energy consumption is likely to cause a 0.5676% increase in carbon emissions. lng also has a positive and significant impact on Inc in the long run, with 0.16 percentage rise in carbon emission for every percentage point of growth in GDP. However, number of foreign pilgrims' arrival has a negative and significant impact on Inc in the long run. Carbon emission is negatively correlated with number of pilgrims arrival.

Negative and statistically significant ECT coefficient for carbon emission, energy consumption, economic growth, and number of foreign pilgrims' arrival indicates there is a convergence from short dynamics towards long run equilibrium. ECT gives the speed of adjustment within which the model will restore its equilibrium following any disturbances.

$$\Delta Inc_t = -0.906ECT_{t-1} + 0.8374Inc_{t-1} - 0.519lnen_{t-1} + 0.114lnnp_{t-1} - 0.162lng_{t-1} + 0.0108 \quad (11)$$

The short-run coefficient shows that carbon emissions increase from the previous year. Carbon emissions are expected to rise by 0.8374%. As total energy consumption rises, carbon emission fall by 0.52%. Carbon emissions fall by 0.162% for every percentage point of economic growth, which is a positive sign and could be achieved through the implementation of a circular carbon economy (CCE) to reduce carbon emissions along with adhering to the Paris Agreement and Sustainable Development Goals (SDGs). However, for every percentage point of foreign pilgrims' arrival, carbon emissions go up by 0.114%.

4.5 Causality test result

Table 5 shows the result of causal relationship between the variables by using Granger causality method. The probability values in the table indicate the existence of four causality relations. Firstly, there is unidirectional causality from carbon emissions to the number of pilgrims. This result, which expresses the causality relation between carbon emissions and the number of pilgrims, is compatible with Ozturk et.al (2022) and Tiwari et.al (2013) but not with Dogan and Aslan (2017). Another result of causality proves that there is a bidirectional causality relationship between carbon emission & energy consumption. Finally, it is found that there is unidirectional causality from economic growth to number of foreign pilgrims' arrival, which is consistent with Khan et al (2023), Ozturk et.al (2022), Kim et al. (2005); Assadzadeh and Nasab (2012); Massidda and Mattana (2013); Aslan (2016) and Bilen et al. (2017).

It shows that carbon dioxide emission and economic growth led to pilgrimage tourism in one direction. However, there is bidirectional causality exist between CO2 emissions and energy consumptions.

Table 5. Granger causality test

Null Hypothesis	F-Statistics	Probability
Inc $\nRightarrow$ lnen	15.315	0.0004*
Inc $\nRightarrow$ lnnp	7.1337	0.0081*

Null Hypothesis	F-Statistics	Probability
$\ln c \neq \ln g$	1.0271	0.3854
$\ln en \neq \ln c$	3.9384	0.0460**
$\ln en \neq \ln np$	0.61541	0.5554
$\ln en \neq \ln g$	0.32285	0.7297
$\ln np \neq \ln c$	0.20198	0.8196
$\ln np \neq \ln en$	0.48967	0.6237
$\ln np \neq \ln g$	3.0788	0.0804***
$\ln g \neq \ln c$	1.3865	0.2846
$\ln g \neq \ln en$	2.389	0.1307
$\ln g \neq \ln np$	0.5962	0.5653

*, **, and*** denotes respectively 1%,5% and 10% statistically significant level.

Source: Author Calculations.

4.6 Variance decomposition analysis:

To trace back shocks into the future, the study uses the Cholesky variance decomposition technique. Evidence from Table 6 demonstrates that 3.039%, 2.53% and 0.039% of future shocks in carbon emissions are caused by economic growth, foreign pilgrims' arrival and total energy consumption. The analysis also reveals that 94% of the variation in carbon emissions could be justified by shocks within the variable itself, whereas the contributions made by energy consumption, economic growth, and pilgrimage tourism to carbon emissions were low. However, economic growth and pilgrims' arrival contribute more to carbon emissions compared to energy consumption.

Table 6: Variance decomposition of carbon emissions

Period	Lnc	Ln en	ln g	ln np
1	1	0	0	0
2	94.97%	.0364%	3.06%	1.92%
3	94.43%	.038%	3.05%	2.48%
4	94.41%	.0394%	3.038%	2.51%
5	94.40%	.0397%	3.039%	2.51%
6	94.39%	.0397%	3.039%	2.53%
7	94.39%	.0397%	3.039%	2.53%
8	94.39%	.0397%	3.039%	2.53%

Source: Author Calculations.

4.7 Stability and residual tests

The study investigates the VECM's robustness by investigating the serial correlation, heteroscedasticity, and normality tests in order to make unbiased statistical inferences. The results of the diagnostic tests for serial correlation, heteroscedasticity, and normality are shown in Table 7. The tests return, in that order, p - values of 0.2168, 0.4378, and 0.70740, all of which are greater than 5%, and show that the H0 is not accepted. This means there is no autocorrection and homoscedasticity, and the series is normally distributed. As a result, the model used for the analysis and interpretation was valid.

Table 7: Residual

	H0	Chi-squared	p-value
Lagrange-Multiplier test for residuals autocorrelation	No serial correlation	20.0754	0.2168
Breusch-Pagan test for heteroskedasticity	Residuals are homoscedastic	0.60	0.4378
Jarque-Bera Test for Normality	Residuals are not normally distributed	5.461	0.70740

5. Conclusion and policy implications:

Present paper investigates the interaction between CO₂ emission, energy consumptions, economic growth and pilgrimage tourism in Saudi Arabia by taking the annual time series data from the period of 1996 to 2022. The estimation procedures encompassed a variety of tests, including a unit root test using Augmented Dicker Fuller (ADF) and Phillip Perron (PP), a cointegration test using the Johansen cointegration test, an examination of the short and long run nexus between carbon emissions, energy consumption, economic growth, and pilgrimage tourism using vector error correction model (VECM), and the Cholesky variance decomposition technique. In addition, the study conducted several diagnostic tests.

The Johansen cointegration demonstrates a positive relationship between energy consumption and GDP growth, although an increase in number of pilgrims arrival harms carbon emissions. Pilgrimage tourism growth will drop by 0.07 percent as carbon dioxide levels rise in the atmosphere. This is known as negative cointegration. These findings are comparable to those reported by Khan et al. (2023).

Negative and statistically significant ECT coefficient for carbon emission, energy consumption, economic growth, and pilgrimage tourism indicates there is a convergence from short dynamics towards long run equilibrium. The vector error correction model indicates that there has been an increase in carbon emissions from the previous year, as supported by the short-run coefficient. It is anticipated that there will be an increase in carbon emissions of 0.84 percent. When total energy consumption increases, carbon dioxide emissions decrease by 0.52 percent. Each percentage point of economic growth reduces carbon emissions by 0.16%. These findings are indeed robust and interesting in the Saudi context, where energy consumption and economic growth are reducing CO₂ pollution in the country. This could pertain to the introduction of circular carbon economy (CCE) in lowering carbon emissions while adhering to the objectives of the Paris Agreement and Sustainable Development Goals (SDGs). However, every percentage point rise in pilgrimage tourism results in a 0.11% increase in carbon emissions. It highlights how important pilgrimage activity is in regard to air pollution, even though it only covers a section of the country. Therefore, it is detrimental to the nation's environmental quality to host a big number of pilgrims during a particular time of the year.

Granger's theory of causality says that that carbon dioxide emission and economic growth led to pilgrimage tourism in one direction. However, there is bidirectional causality exist between CO₂ emissions and energy consumptions. The impulse response function demonstrates that in the short term all variables exhibit growing tendencies but gradually begin to stabilize in the long run. Based on variance decomposition study, economic growth and pilgrimage tourism contribute more to carbon emissions than energy use.

It has been confirmed that pilgrimage tourism contributes to a country's economic growth and revenue, but its negative influence on the environment necessitates analysis and resolution by stakeholders.

The following policy recommendations for sustainable pilgrimage tourism are made based on the study findings:

1. Promote environmental awareness among pilgrims. In order to minimise emissions during the Hajj pilgrimage, it's crucial to study visitor behaviour and develop a green mindset among pilgrims. Drawing from Italy's Christian religious tourism model, which has been shown to increase spiritual awareness and environmental consciousness (Nawaz et al., 2023), similar programs can be implemented to promote sustainability among Hajj pilgrims.
2. Saudi Arabia's Vision 2030 aims to achieve net zero emissions by 2060 through a circular carbon economy approach. To achieve this, the country should establish environmentally sound regulations, ensure environmentally friendly accommodations, introduce a carbon tax system, and promote sustainable aviation fuels like kerosene derived from carbon dioxide, water, and solar energy. This will help protect natural resources and promote sustainable transportation options.
3. Develop environmentally friendly transportation solutions for pilgrims, such as electric or driverless vehicles, to reduce carbon emissions and improve traffic management during peak periods.
4. Collaborate with worldwide environmental organisations and research institutions to create and implement sustainable practices targeted to religious tourism, leveraging global expertise and cutting-edge technology.

By integrating these policies, Saudi Arabia can integrate pilgrimage tourism with its environmental goals, ensuring that economic advantages from this sector are accomplished while the natural environment remains preserved in accordance with the Saudi Green Initiative. Future studies could look at CO₂ emissions in various places of worship worldwide to provide comparative insights. This study used a relatively short annual time series dataset; consequently, future studies could use longer time series data and more advanced methodologies for a comprehensive analysis.

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Second: Working papers

Working Paper:
**The Economic Analysis of Law: How Can the Scientific Integration Between
Microeconomics and Law Lead to Prosperity and Economic Growth?**

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ورقة عمل:

كيف يمكن للتكامل العلمي بين الاقتصاد الجزئي والقانون أن يقود نحو الرخاء والنمو الاقتصادي؟

د. ياسر علي صلال المالكي

أستاذ القانون المدني المساعد في جامعة طيبة – المملكة العربية السعودية

1- The Economic Analysis of Law: Why Lawyers and Economists Should Study Each Other's Fields

The economic analysis of law represents a convergence between two major disciplines—economics and law—enabling a deeper and more integrated understanding of both. Economics, as the science of decision-making under conditions of scarcity, offers analytical tools that help predict how legal sanctions influence human behavior, particularly in situations where ideal outcomes cannot be achieved.

Why, then, should lawyers study economics, and why should economists engage with the law? For legal scholars, economics provides a lens through which laws are viewed not only as mechanisms for promoting justice but also as instruments that shape behavior through incentives—implicit prices—and serve broader policy objectives such as efficiency and distributive justice. For economists, exposure to legal reasoning offers access to the art of persuasion, a skill honed by lawyers through continuous practice. Lawyers are adept at articulating facts and framing them in morally resonant terms, a capacity often underdeveloped in economic discourse.

Moreover, both disciplines stand to gain methodologically: lawyers can adopt quantitative reasoning, model-building, and empirical analysis from economics, while economists can enrich their models by incorporating the normative and rhetorical insights of legal thought. By listening to what the law has to offer, economists can align their theories more closely with the concerns and values of real people.

2- From Incentives to Negotiation: Economic Theories in Legal Contexts

The history of law and economics encompasses a range of theories that aim to understand the relationship between legal systems and economic incentives. One of the key theories is the principal-agent model, which describes a relationship where one party, the “principal,” benefits from the careful or diligent performance of a task by another party, the “agent.” The analysis also includes alternative contractual arrangements such as sharecropping, fixed wages, and fixed rents, evaluated in terms of their efficiency and the distribution of incentives and risks. Efficient contracts are understood as those that minimize the total cost, including incentive costs, transaction costs, and risk costs.

In the context of economic games, the “Chicken Game” illustrates strategic interaction, where mutual stubbornness leads to significant losses for both parties, while the party that yields is rewarded if the other remains firm. Similarly, in the “You Quit First” game, entering the game is risky unless a player can improve their bargaining position.

The Coase Theorem is a foundational principle in law and economics, asserting that legal intervention is unnecessary when transaction costs are zero and property rights are well-defined, as

parties will naturally resort to bargaining rather than litigation. This principle implies that negotiation can correct inefficient legal rules, provided transaction costs are low and parties act rationally. Politically, it supports limited government intervention, and in diplomacy, it advocates for negotiation, reduced transaction costs, and the fostering of a positive psychological environment.

Modern game theory places the concept of “bargaining position” at the center of analysis, with parties first striving to improve their bargaining strength before entering into any negotiation or conflict.

3- Property Law and Economic Theory: A Coherent Overview

The economic analysis of property law reveals a nuanced distinction between property rules and liability rules as mechanisms of legal protection. Under a property rule, the use or consumption of property requires the explicit consent of the owner. In contrast, liability rule protection allows others to use or consume the property without the owner’s consent, provided they offer court-determined compensation. Typically, property rules are the standard legal protection, but liability rules become relevant when transaction costs are so high that voluntary bargaining between parties becomes impractical.

One of the classic illustrations of inefficient resource use under weak property regimes is the “Tragedy of the Commons.” This occurs when multiple individuals have access to a shared resource and act independently based on personal benefit, leading to overuse and depletion. For example, an individual might exploit a common resource if the personal benefit exceeds the cost divided among users ($B > C/n$), even though socially optimal usage would require $B > C$. Similarly, when it comes to investing in common infrastructure, such as irrigation, individuals will only invest if their share of the benefit exceeds the cost ($B/n > C$), while efficiency would call for investment whenever the total benefit exceeds the cost ($B > C$). Additionally, the commons can lead to “rushing costs,” where individuals harvest resources prematurely to beat others to it. Solutions to this tragedy often include privatization or the establishment of regulated commons to control access and use.

However, private property is not immune to inefficiencies. A form of “tragedy” can occur under private ownership as well. For instance, valuable assets might remain underused due to transaction costs or due to market structures like monopolies. In cases of monopolistic control, prices may be set above socially efficient levels, leading to reduced consumption. When fixed costs are involved, producers may set prices above marginal cost, again discouraging efficient levels of use and access.

An additional layer of complexity is introduced by the “Tragedy of the Anti-Commons.” This occurs when property rights are so fragmented that too many parties hold exclusion rights, and any proposed change or use requires unanimous approval. In such scenarios, coordination becomes difficult or even impossible, leading to under-use of valuable resources. The problem is exacerbated when each rights-holder seeks compensation or pricing independently, often resulting in an aggregate “price” higher than that of a single monopolist. Solutions may include reducing the number of rights-holders through mechanisms like liability rules—allowing the use of property with court-ordered compensation—or introducing third-party governance to facilitate collective decisions.

Finally, the discussion turns to the delivery of public goods and club goods, particularly whether such goods should be provided by the state. Public goods are characterized by non-excludability and non-rivalry, which makes them prone to under-provision and under-consumption if left to the market. Because individuals cannot be excluded from use and one person's use doesn't reduce availability to others, markets fail to provide these efficiently, justifying state intervention. On the other hand, club goods are excludable but non-rival, making them more suitable for private market provision.

Nevertheless, government provision of public goods has its own challenges. Through majority voting, there is a risk of misalignment between provision and actual societal needs—some goods may be overprovided if favored by the majority, while others may be underprovided if they are important to minorities. Thus, while state involvement is often necessary, it must be approached with awareness of its institutional limitations and potential inefficiencies.

4- Intellectual Property Law and Economic Theory: Legitimate Monopoly or Economic Necessity?

Intellectual property rights—such as patents and copyrights—are often viewed as legal monopolies created by legislation. Unlike traditional property rights, which regulate existing resources, intellectual property creates new, artificial rights with the purpose of incentivizing innovation and creativity. From an economic perspective, these rights are granted to encourage investment in knowledge production, but they also carry significant costs and risks.

Among the main advantages of intellectual property is that it promotes the creation of valuable inventions and artistic works by offering financial incentives to inventors and creators. It also reduces the need for defensive investments, which are aimed at protecting innovations from imitation rather than improving them.

However, these legal monopolies come with notable disadvantages. Most importantly, they often lead to under-consumption due to monopoly pricing, which restricts access to innovations for many potential users. Intellectual property also involves transaction costs, especially when licensing or transferring rights, similar to issues seen with private property in general. Moreover, there are risk-related costs: producing a successful innovation often requires luck, and the future monopoly rents are highly uncertain, making creative investment financially risky.

Additional inefficiencies arise from rushing costs, where individuals or firms invest prematurely in order to be the first to file a patent, even when the idea is not fully developed. There's also the issue of duplicative efforts, where multiple teams invest resources into developing the same idea independently, which could have been more efficient through coordination or collaboration.

Regarding the optimal duration of patents and copyrights, economic theory suggests a careful balance between costs and benefits. Ideally, the monopoly profit generated by an innovation should equal the research and development costs. Therefore, the duration of protection should not be uniform, but rather tailored to each invention, depending on its characteristics and development cost.

When it comes to the scope of protection, there is a necessary trade-off between the breadth of what is protected and the duration of protection. The broader the scope, the more important it is to limit the time period. Additionally, high transaction costs justify broader protection, as they hinder licensing and bargaining, increasing reliance on monopoly pricing to recoup investments.

A relevant question arises: Why don't we use a prize system instead of the copyright/patent regime? In theory, governments could reward innovation with direct payments. However, in practice, the transaction costs involved in evaluating innovations and assigning fair prizes are significant, and such a system remains incomplete and underdeveloped. It might become more viable in the future, but as of now, it does not provide a reliable alternative.

In the absence of practical alternatives, the current intellectual property system remains a necessary structure, albeit an imperfect one. The goal should be to strike a balance: ensuring that intellectual property protection is not so strict as to block future innovation, nor so lax that it fails to encourage the initial creative effort.

5- Tort Law from an Economic Perspective: Between Negligence and Strict Liability

Tort law governs situations in which harm or loss occurs due to unlawful conduct by another party. From an economic standpoint, the comparison between strict liability and negligence-based liability is central to understanding how costs and incentives are distributed, and how these legal doctrines influence behavior and transaction costs.

Under a strict liability regime, the injurer is required to pay compensation simply when harm and causation are established, regardless of whether fault or negligence is present. In contrast, negligence liability requires proof of harm, causation, and fault—meaning the injurer must have failed to take reasonable care to avoid the damage.

Analyzing this through the lens of transaction costs (TAC) reveals a nuanced picture. While negligence rules may result in higher litigation costs due to the effort required to determine fault,

they tend to lower the expected payment costs for injurers, since they only pay when negligence is proven. Consequently, in strict liability regimes, minor harms are often excluded—explicitly or implicitly—because the cost of compensation outweighs the benefit in low-value cases.

From an incentive perspective, in scenarios where activity levels remain constant, both strict liability and negligence can induce optimal care. For instance, if the expected accident cost is 100 and the precaution cost is only 60, failure to take precaution would be considered negligent. Conversely, if the precaution cost is 140, not taking precaution may be deemed reasonable. However, overly strict negligence rules may result in excessive care, which surpasses the efficient level encouraged by strict liability.

A notable issue in tort law is the treatment of pure economic loss—financial loss that is not accompanied by physical or property damage. Most tort systems do not compensate for such losses, while contract law may allow recovery, highlighting a key divergence in how legal frameworks assign responsibility.

Another challenge arises with the concept of the multi-tasking agent, where an individual is responsible for several tasks. Increasing incentives for one task may undermine performance in others. Moreover, attempting to enforce full performance across all tasks leads to high transaction costs, reducing overall efficiency.

Ultimately, the economic analysis of tort law aims to develop legal rules that balance fairness, minimize transaction costs, and promote socially responsible behavior, without imposing excessive burdens on either party.

6- Criminal Law: Key Concepts and Debates

- Deterrence vs. Incapacitation

Criminal law grapples with balancing deterrence (preventing crime through threats of punishment) and incapacitation (physically restricting offenders' ability to reoffend). This tension is reflected in the distinction between *ex ante* and *ex post* approaches. *Ex ante* measures, such as banning firearms, aim to prevent harmful acts before they occur. In contrast, *ex post* measures, like imposing sanctions for theft, focus on addressing harm after it has materialized. These frameworks shape how legal systems prioritize prevention versus punishment.

- Gary Becker's Economic Analysis

Economist Gary Becker revolutionized criminal law theory by framing crime as a rational cost-benefit calculation. He argued that monetary sanctions (e.g., fines) are preferable to nonmonetary punishments (e.g., imprisonment) because they impose lower social costs while maintaining deterrence. Becker's model posits that a rational offender will commit a crime if the benefit (B) exceeds the expected cost, calculated as the probability of apprehension ($*p*$) multiplied by the sanction (S). To minimize enforcement costs, he advocated for maximizing sanctions (S), which allows lowering the apprehension rate ($*p*$) without sacrificing deterrence.

- Carrots vs. Sticks in Incentives

Legal systems often rely on incentives to shape behavior, either through "carrots" (rewards) or "sticks" (punishments). While carrots, such as subsidies for compliance, are increasingly common in modern policy, theorists argue that sticks—like criminal penalties—are inherently superior. This is because effective deterrence relies on the *threat* of punishment rather than its frequent application. However, the practical shift toward carrots reflects a growing emphasis on positive reinforcement in governance.

- The Damages Lottery and Compensation

Traditional tort law creates a "damages lottery," where only victims who successfully identify and sue a liable party receive compensation. This randomness undermines fairness, particularly for those unable to attribute harm to a specific actor. Solutions include expanding first-party insurance (e.g., health or property insurance) and strengthening *ex ante* regulations (e.g., traffic speed controls) to reduce harm at its source.

- **Corruption: Causes and Remedies**

Corruption is often rationalized as a perverse incentive structure: officials may demand bribes to supplement low wages, arguably motivating efficiency. However, this view is contested. Empirical studies, such as those focusing on Latin America, suggest that raising judges' salaries can reduce corruption by diminishing the financial incentive to accept bribes. Yet, systemic poverty remains a root cause, implying that anti-corruption efforts must address broader economic inequities.

- **Organized Crime and Drug Policy**

The "war on drugs" highlights the challenges of combating organized crime. When eradication proves impossible, some scholars propose tolerating monopolistic drug markets as a second-best solution. A monopolist, unlike competitive markets, may restrict supply to maximize profits, potentially reducing overall drug availability and associated violence.

- **Do Sanctions Deter Crime?**

A recent empirical study challenges the assumption that harsher sanctions deter crime, finding little correlation between sanction severity and offense rates. This suggests that non-monetary punishments (e.g., imprisonment) may be less effective than often assumed. In response, scholars recommend prioritizing monetary fines, which align better with Becker's cost-effective deterrence model while avoiding the social and economic costs of incarceration.

7- **Contract Law: Key Principles and Economic Challenges**

Contract law addresses the relationship between contracting parties from both legal and economic perspectives, aiming to balance efficiency and fairness, as well as commitment and flexibility. This overview highlights the main concepts and challenges related to contract terms and labor markets.

- **Contractual Efficiency and Protection of the Weaker Party**

Contract clauses are efficient when they create mutual benefits and rejected if they harm one party more than they benefit the other. For example, a clause benefiting the seller by +1 but harming the buyer by -3 is inefficient. Although some parties sign contracts without reading them, legal systems deal with this through presumptions of agreement, banning unfair clauses (blacklists and greylists).

In settings where the state is absent, such as the "Hobbesian" state of nature, parties may rely on informal enforcement like hostage exchanges to ensure commitment. Under formal legal systems, mechanisms like penalties, rewards, and reputation play a role in aligning incentives, especially in scenarios resembling the "prisoners' dilemma."

- **Contract Enforcement, Disclosure, and Nature of Obligation**

Enforcement remedies range between monetary damages and specific performance, with the optimal choice depending on whether breach benefits society or causes harm. Furthermore, a party possessing valuable information must disclose it if doing so is cost-effective and the information is verifiable, distinguishing it from mere opinions or entrepreneurial insights that may not require disclosure.

- **Long-Term Contracts, Risk Allocation, and Incentive Analysis**

Long-term agreements face challenges from unforeseen changes and relationship-specific investments, exposing parties to opportunism. Solutions include third-party governance and renewal-based contracts. Effective contract design requires careful analysis of incentives, minimizing transaction costs, and allocating risks according to parties' risk tolerance, while assigning residual claims to the party best positioned to monitor performance and reduce opportunistic behavior.

- **Employment Contracts: Balancing Flexibility and Protection**

Employment contracts represent a special category due to difficulties in verifying performance and the presence of specific skill investments. Enforcement of sanctions is limited by evidentiary challenges, leading to behaviors like the "You Quit First" scenario. Employment regimes vary by market structure:

- **At-will employment** fits competitive markets with low monitoring costs.
- **Just-cause termination** suits monopolistic or specialized labor markets where job-specific investments justify stronger protections.

Notice periods reduce frictional unemployment by protecting reliance interests, especially in specialized roles. Employers typically bear workplace accident risks as they are best positioned to mitigate them through wages, insurance, and safety measures. Finally, workers are not inherently the weaker party; bargaining power depends on market conditions before and after contracting, and weakness arises mainly when workers invest in non-transferable skills.

This synthesis demonstrates how law and economics intertwine in contract design, reflecting a delicate balance between contractual freedom, protection, and efficiency.

8- Litigation Dynamics: Settlement, Trial, and Legal System Differences

Litigation often requires a strategic decision between settling a dispute out of court or proceeding to trial. One key factor influencing this decision is the level of optimism each party holds regarding the outcome. When at least one party is overly optimistic, the settlement range may become negative, meaning no mutually acceptable settlement can be reached, leading to more trials. In legal systems characterized by clear and well-defined rules, parties tend to be overly optimistic about their chances, resulting in increased litigation. Conversely, in systems based on vague and less predictable legal standards, parties tend to be more cautious or pessimistic, which encourages settlement rather than trial.

In the United States, litigation costs are notoriously high, raising questions about whether too much is spent on litigation. Despite these expenses, the deterrent effect of the legal system often relies more on the threat of going to trial than on actual court proceedings. Moreover, the common law system in the U.S. is credited with fostering faster economic growth due to stronger protections of property and contract rights. Compared to civil law countries, common law jurisdictions are known for having less procedural formalism. Civil law systems, on the other hand, exhibit systematically higher procedural formalism, especially regarding trust-related matters, adding complexity and rigidity to legal processes.

9- Auction Theory: Types and Challenges

Auction theory studies different mechanisms for selling goods or contracts by competitive bidding. The English auction starts at a low price and increases as bidders compete, ending when the highest bid is placed. In contrast, the Dutch auction begins with an unrealistically high price that gradually decreases until a bidder accepts. Another form is the sealed-envelope auction, where all bidders submit offers secretly without knowledge of competitors' bids; the highest offer wins. The Vickrey auction is a variation where the highest bidder wins but pays the second-highest bid price. In some cases, auctions focus not on price but quality, as in beauty contests for radio frequencies or architectural design, where the highest quality bid wins.

Auctions face challenges when bidders have imperfect information about the value of the object, often leading to the "winner's curse," where the winning bid exceeds the true value. This can be mitigated by providing full information about the object. Participation costs also influence auction design; public auctions require time and effort from bidders, making them more suitable when the seller is unsure of market price, when bidders' opportunity costs are low, or when corruption risks are high. A special form, the all-pay auction, requires every bidder to pay their bid regardless of winning, a model applicable to real-world scenarios such as elections where candidates incur costs regardless of the outcome.

10- Behavioral Law and Economics: Challenging Rationality Assumptions

In traditional economics, people are assumed to be rational decision-makers; however, behavioral law and economics recognize that individuals often act irrationally. For example, people struggle to make rational choices when it comes to risk, tending to overreact to small losses while underestimating the impact of large losses.

11- Risk Analysis and Insurance in Contracts

People often show little interest in purchasing insurance for non-pecuniary risks because the financial compensation cannot replace what is truly lost. For example, if a child does not die, parents might save around \$1,000 a year, but if the child dies, they may receive \$500,000 more in compensation. However, this extra money cannot bring the child back; it can only be spent on material goods. In contracts, insuring against unforeseeable or consequential losses is generally undesirable, as compensation for such losses is often difficult to quantify and may encourage moral hazard. Furthermore, contracts can inadvertently create additional risks, such as gambling clauses like penalty provisions for absolute impossibility, or risks stemming from legal errors, such as misinterpretation of contracts by judges. These legal risks can be mitigated by introducing additional evidence and incurring litigation costs.

Risk allocation is a key function of contract design and insurance mechanisms. Remedies can serve as tools for distributing risks, affecting production costs by shifting risk burdens higher or lower. Corporations often purchase insurance despite shareholders being risk-neutral because managers tend to be risk-averse. Additionally, the transaction costs associated with obtaining insurance may be lower than those incurred through bankruptcy, making insurance a cost-effective way to manage corporate risks.

12- Rents and Market Dynamics

Rent is the profit that cannot be earned in a perfect market; it represents the portion of a price that exceeds the true costs of a product. Quasi-rents, however, are not true rents—they are compensations for costs incurred at an earlier stage. In transparent markets, monopolies and oligopolies tend to be short-lived because high profits attract new entrants until supply pushes prices back to true cost levels.

Ricardian rents arise from the absolute scarcity of resources and do not necessarily cause income inequality unless the legal system is imperfect. Structural monopolies or oligopolies occur due to economies of scale, where the market can only sustain a limited number of companies, such as a single bakery in a small village becoming a local monopolist without attracting competitors.

Network externalities create rents by increasing the value of a product as more people use it, like telephones becoming more valuable as their user base grows. Information rents are earned by exploiting superior information, explaining why sales professions are among the best-paid, as sellers acquire expertise that allows them to advise or exploit customers.

Certain business models involve selling a primary product at a low price to attract customers, then profiting from complementary or consumable products sold later. Upselling is a legal form of monopoly pricing where customers are encouraged to purchase more expensive items or add-ons for a higher profit. In seemingly competitive markets, oligopolies can maintain higher prices by monitoring competitors and avoiding price wars.

Lock-in effects occur when companies make it very difficult for customers to switch, resulting in monopoly pricing and increased search and information costs, which are economically harmful. One-sided contracts are common in competitive markets because

customers avoid reading lengthy contracts to save time, often leading to imbalanced agreements.

Legal corruption involves collusion between agents and third parties to enrich themselves at the expense of uninformed principals. Kickbacks, a form of corruption, may lower fees for clients and incentivize brokers to work harder but also cause market failures by encouraging actions against a party's interest.

Wages are influenced by employees' outside options, and pay-for-performance contracts are necessary to incentivize effort, as employees have superior information about their own costs. In monopolistic companies, some rents leak to high-level employees who can exploit their information advantage over owners.

Finally, firms often act as tools to hide cost structures and capture rents, demonstrating that businesses are not only about generating profits but also about managing information and cost-related risks.

13- Carrots vs. Sticks

Sticks tend to be more effective than carrots, which is why institutions rely on them more heavily. In fact, about 99% of laws function as sticks. Overpaying someone can be seen as a carrot, but if the person fails to perform their duties, they risk losing that overpaid position.

Carrots, on the other hand, are mostly exceptions—patent laws are a good example of carrots in the legal system.

Sticks are generally better because they result in lower transaction and administrative costs (TAC) and pose less risk to society. Conversely, carrots usually involve higher TAC and greater societal risk. However, sticks don't have to be applied all the time, while carrots often require more frequent use.

We resort to carrots when expectations are unclear or unknown. When it's difficult to predict what to expect from others, carrots help encourage cooperation. Additionally, if a task is too difficult and most people are unlikely to comply, relying on sticks would mean punishing many individuals, which raises TAC on the sticks' side—making carrots a more practical choice in such situations.

14- Choosing the Right Instrument

Choosing the appropriate instrument to solve a problem is challenging because an instrument may be effective on one side but cause issues on the other. For example, when dealing with contract breaches, it is difficult to decide whether expectation damages or the no-damages rule is better. Expectation damages provide optimal incentives to fulfill contracts, while the no-damages rule promotes reliance incentives. Therefore, theoretically, it is unclear which rule is superior. The only way to resolve this uncertainty is by analyzing empirical data on the social costs of over-breaching and over-reliance, but such data are often unavailable.

The principle of "N Problems Require N Instruments" suggests that the best results come from having one rule per problem. In practice, this means using fault-based rules that require faulty behavior to be verifiable with sufficient certainty in court. If the behavior is not verifiable, strict liability may be the second-best option since the court only needs to know the extent of harm without determining whether the actor's behavior was reasonable. However, if multiple problems are non-verifiable, a compromise strict liability rule may be necessary to address more than one issue simultaneously, which decreases effectiveness significantly as the less important problem diminishes in significance.

There is a distinction between a direct instrument, which targets a single problem precisely, and a compromise instrument, which attempts to address multiple problems at once. Using one instrument for multiple problems can lead to reduced effectiveness because it cannot fully solve problems that conflict with each other. It also causes indeterminacy,

requiring empirical information on the relative social importance of the problems, which translates into high economic costs such as increased information and error costs.

A rational legal system will use fewer instruments to solve multiple problems under two conditions. First, when a direct instrument cannot work in practice due to the underlying behavior being nearly non-verifiable, meaning the unwanted behavior cannot be proven in court. For instance, if courts cannot observe whether the promisor overbreached or the promisee over-relied, it may make sense to use a compromise instrument such as strict liability that shares losses between parties. Second, the relative social importance of the problems must not be too unequal.

Compromise instruments often lead to inefficiency and indeterminacy because they depend on empirical data about the importance of the problems. The implication is that relatively unimportant, non-verifiable problems should be ignored.

The recommended three-step method involves first increasing the number of instruments to match the number of problems, then checking the verifiability of behavior, and finally assessing the social importance of each problem. The last step is only necessary when verifiability issues are serious. If one problem is much less important than another, the rule of thumb is to ignore the minor problem and use the instrument to fully address the major problem.

15- Tax Law and Economics

In tax law, it is essential to use direct instruments because relying on indirect instruments causes greater distortions. The goals of tax law include minimizing consumption distortion, following the principle of Ramsey pricing. This principle means the government wants to raise revenue without significantly altering people's behavior. For example, TVs should be taxed more than home cleaning services because people will buy TVs regardless of the tax, while high taxes on home cleaning services might lead people to clean their homes themselves. Another goal is minimizing total administrative costs by taxing what is easily observable, such as agriculture or imported income goods.

Redistributing wealth is also a key objective. Sales tax creates double distortions, whereas income tax causes only a single distortion, making income tax a superior and more direct instrument due to the ease of observing income. Regarding wealth and property taxation, wealth tax is preferable over property tax because property tax involves double distortions, while wealth tax involves only one. The legal system often uses property tax because it is easier to observe property than overall wealth, but in systems with better wealth information, wealth tax is more effective.

The deep pocket rule means that wealthier individuals pay more after accidents, while poorer individuals may receive additional money. This rule distorts incentives for care because wealthy people tend to be more careful, and poorer people less so. In tax law, the deep pocket rule disturbs work incentives: if you work hard and earn more, you pay more, while if you do not work and are poor, you may receive extra money. Therefore, the tort system should not be used for wealth redistribution since the deep pocket rule causes double distortions.

Comparing labor tax to capital tax, labor taxation creates a single distortion by affecting the incentive to work. Capital taxation causes double distortions because it affects both the incentive to work and the incentive to invest capital.

Conclusion

In concluding this analysis, it becomes evident that the scientific integration between microeconomics and law is not merely an academic intersection but a fundamental pillar for constructing legal systems that foster prosperity and economic growth. Through the lens of

economics, law transforms into an intelligent tool designed to incentivize individual behavior toward collective welfare and spare society the costs of conflicts and wasted resources.

Economics grants law the language of efficiency, while law endows economics with the conscience of fairness. Whether in contract design, property protection, crime prevention, or the complexities of litigation, the shared goal remains achieving a delicate balance between individual incentives and social welfare. Yet this integration is not without challenges: human limitations in foresight, the intricacies of human behavior, and clashing interests remind us that the optimal model remains an evolving goal requiring continuous refinement.

The paramount lesson here is that law, when inspired by economic logic, transcends mere rules—it becomes a dynamic system that interacts with reality, converting abstract theories into tangible policies that enhance human well-being. True development begins when legal justice allies with economic wisdom to craft a world that is more stable, equitable, and productive.