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Green Technological Innovation and Human Development in Resource-Dependent Economies: Structural Assessment of Iraq's Sustainable Growth Path

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Abstract
This study investigates the role of green technological innovation in supporting structural economic transformation and human development in Iraq, a resource-dependent economy facing significant environmental pressures and institutional constraints. Using a descriptive–analytical approach covering the period 2014–2024, the research evaluates Iraq's performance across key Human Development Index (HDI) components and selected green technological innovation indicators. The findings indicate that while government expenditure on education (3.9% of GDP) and health (4.2% of GDP) has remained relatively stable, green innovation capacity remains limited, with research and development (R&D) investment averaging only 0.04% of GDP and recycling rates remaining comparatively low. These results highlight a structural gap between social development investments and technological modernization.

Keywords: green technological innovation, human development index (HDI), Iraq, structural transformation, financial sustainability, resource-dependent economies.

JEL Classification: O31; O15; Q55; Q42; O44.

Introduction

The accelerating challenges of climate change, environmental degradation, and natural resource depletion have intensified global attention toward green technological innovation as a key mechanism for achieving sustainable economic development. Green technological innovation encompasses the development and diffusion of environmentally friendly technologies, production processes, and organizational practices that reduce ecological impacts while enhancing economic efficiency and long-term productivity. In recent years, this concept has evolved beyond a purely environmental perspective and has increasingly been recognized as a driver of structural economic transformation, particularly in emerging and

transitional economies seeking to reconcile economic growth with environmental sustainability. Improving resource efficiency, reducing pollution, and fostering new sectors of economic activity, green innovation contributes not only to environmental protection but also to broader development objectives, including employment creation, technological modernization, and improvements in human welfare.

Within this global context, the relationship between green technological innovation and human development has attracted growing attention in both academic research and policy debates. Human development, commonly measured through the Human Development Index (HDI), reflects progress in health, education, and income dimensions, representing a multidimensional perspective on economic and social well-being. The transition toward environmentally sustainable technologies has the potential to influence these dimensions simultaneously by improving environmental quality, strengthening public health outcomes, expanding access to reliable energy and digital infrastructure, and supporting the development of new skills and employment opportunities. Consequently, green technological innovation can serve as a critical mechanism through which countries pursue structural reform, economic diversification, and financial sustainability, particularly in economies characterized by resource dependence and institutional constraints.

In this regard, Iraq represents a particularly relevant case study due to the intensity and interdependence of its environmental, economic, and developmental challenges. Iraq is considered one of the country's most vulnerable to climate change in the Middle East region, facing rising temperatures, water scarcity, desertification, and environmental degradation. These challenges are compounded by extensive environmental pollution associated with oil extraction activities, gas flaring, and limited waste-management infrastructure, as well as by the long-term socio-economic impacts of armed conflict and political instability. At the same time, the Iraqi economy remains highly dependent on the oil sector, making it vulnerable to fluctuations in global energy prices and limiting opportunities for economic diversification, employment generation, and sustainable income growth.

These structural constraints have significant implications for human development outcomes. Environmental degradation and pollution directly affect public health conditions, while economic instability and fiscal volatility constrain the government's capacity to invest consistently in education, healthcare services, and social infrastructure. As a result, improvements in key human development indicators, including life expectancy, educational attainment, and living standards, remain uneven across regions and social groups. Addressing these interconnected challenges requires development strategies that simultaneously enhance environmental sustainability, strengthen technological capabilities, and promote economic resilience.

Within this framework, the transition toward a green economy driven by technological innovation offers a promising pathway for addressing Iraq's structural development challenges. Green technological innovation can improve environmental performance by increasing energy efficiency, reducing emissions, and enabling cleaner production processes across economic sectors. At the same time, it can stimulate economic diversification by promoting new industries related to renewable energy, digital technologies, sustainable agriculture, and circular economy systems. Furthermore, the adoption of green technologies contributes to human capital development by creating new employment opportunities, encouraging the acquisition of technological skills, and integrating sustainability-oriented competencies into educational and training systems.

Despite the strategic importance of green technological innovation, Iraq continues to face significant barriers to its effective adoption and diffusion. Investment in research and development remains extremely limited, technological capabilities are constrained, and institutional and governance challenges hinder the implementation of innovation-oriented development policies. These factors raise important questions regarding the potential role of green technological innovation in improving human development outcomes in resource-dependent economies characterized by structural constraints.

Against this background, the present study investigates the relationship between green technological innovation and human development in Iraq by analysing key indicators of education, health, income, environmental sustainability, and technological capacity over the period 2014–2024. While existing studies have examined green innovation primarily from environmental or technological perspectives, relatively limited attention has been devoted to understanding how innovation-driven sustainability transitions influence broader human development outcomes in resource-dependent economies. Addressing this gap, the present research integrates indicators of green technological innovation with human development metrics in order to assess the structural interactions between technological modernization, environmental performance, and socio-economic welfare. Using a descriptive–analytical approach based on macroeconomic and sustainability indicators, the study evaluates Iraq's progress toward integrating green technologies within its development trajectory and identifies key structural constraints limiting this transition. In doing so, the research contributes to the literature on sustainable development and innovation-driven growth by providing empirical evidence from a resource-dependent emerging economy and by highlighting the role of green and digital technologies in supporting structural reform, economic diversification, and long-term financial sustainability.

1. Literature Review

Green technological innovations are considered to be the key drivers to the development of the economy as well as human beings, especially in the developing countries like Iraq. A large body of academic literature highlights the essential character of green innovation in achieving a sustainable development goal. As an example, Ahmad & Al-Sayyed (2025) examined the enabling power of technological innovation in guiding the shift to the sustainable economy through absorbing carbon emission and improving resource efficiency. Their descriptive research, which was conducted in the circumstances of Egyptian colleges of higher education and which involved the use of statistical inference, revealed that there is a strong association between the innovation variables and economic sustainability of 81.7%.

Green technological innovation is important in achieving sustainable economic development by improving resource efficiency, reducing environmental pollution, and creating new employment opportunities. These innovations contribute to reducing operational costs, enhancing productivity, and lowering energy consumption and carbon emissions, which ultimately improve environmental quality and economic sustainability (Chen et al., 2012; Wang & Zhang, 2025).

Similarly, Kashkool et al. (2025) hypothesized that green digitalisation technologies will simultaneously increase the efficiency and productivity of industries as well as lead to human development. These technologies reduce environmental footprints and place the industrial sectors back on track towards sustainability. They conclude their findings that such

technologies explain 77% of variance in energy efficiency, electronic waste production, carbon emissions, and the use of cloud computing and virtual servers.

In regard to the Iraqi context, Makki & Kadhim (2023) found that adoption of green technology and economic growth have a positive relationship which, in turn, increases human development in Iraq. Their study indicates that green technology increases the value-added in the agricultural sector thus driving the growth in the GDP. Moreover, the agro-industry incorporation of the modern technologies in Iraq by the means of the Foreign Direct Investments (FDI) is considered to be the key to the further sustainable growth and economic revival.

To assess how technological innovation can enable a green economy to become a reality, Abdullah (2025) explored the issue by using international standards. As an illustration, renewable energy breakthroughs enhanced profits in electricity generation in Germany by 46% in 2020 and Denmark supplied half the electricity needs with the wind energy in the same, 2020. Each of the two countries created more than 100,000 new green jobs and either 40 or 50 percent of carbon emissions were reduced in Germany and Denmark respectively. The research therefore suggests that Iraq should capitalize on these international experiences in order to achieve sustainable development, which in this case is by improving human capital.

To sum up, green technological innovation is an effective tool of promoting human development in Iraq. Iraq can take significant steps towards Sustainable Development Goals by intensifying the Research and Development (R&D) investments and implementing government policies that encourage innovation, which will eventually result in complete human development.

2. Conceptual Framework: Green Technological Innovation and Human Development

Green Technological Innovation (GTI) refers to the development and diffusion of new or improved technologies that reduce environmental harm while enhancing economic efficiency and long-term sustainability. In this sense, GTI encompasses product, process, and organizational innovations that generate value simultaneously for economic performance and environmental outcomes. The OECD (2018) conceptualizes technological innovation as the introduction of new products, processes, and business models that improve productivity and generate broader value creation. Extending this view, GTI is increasingly defined as innovation that supports economic competitiveness while minimizing ecological footprints through cleaner production, resource efficiency, and environmentally responsible technologies (Abdullah, 2025; Aguilera-Caracuel & Ortiz-de-Mandojana, 2013) .

GTI is closely associated with the transition to a low-carbon economy, which requires substantial investment in research and development (R&D), institutional support, and the formation of human competencies capable of adopting and scaling green technologies (Barbier, 2012). Beyond environmental benefits, GTI can strengthen firm competitiveness, improve resource allocation, reduce waste-related costs, and support profitability through enhanced efficiency and compliance with environmental standards (Harz Allah et al., 2024; Yang et al., 2022) .

Firms that continuously develop green products and services may also gain strategic advantage through differentiation and responsiveness to consumer demand and regulation (Amore & Bennedsen, 2016) At the macro level, GTI contributes to economic modernization by improving environmental efficiency and supporting sustainable growth trajectories (Liang, 2025) .

In this study, GTI is operationalized through six principal domains, consistent with the literature:

- Renewable energy sources such as solar, wind, hydro, and biomass represent important alternatives to fossil fuels and play a critical role in enhancing energy security by diversifying energy supply and reducing environmental risks associated with traditional energy systems (Dorić, 2024).
- Energy Efficiency technologies that reduce energy input per unit of output, including building insulation and intelligent systems (Leal-Arcas, 2023).
- Waste Management and Recycling technologies enabling circular resource use and waste-to-energy conversion (Musheb, 2018) .
- Sustainable transportation, including electric mobility and intelligent transport systems, plays a significant role in achieving sustainable development by reducing greenhouse gas emissions, improving energy efficiency, and enhancing the efficiency of urban mobility systems (United Nations Development Programme, 2024) .
- Smart Agriculture (IoT, AI, GIS, remote sensing, precision irrigation) aimed at productivity gains and reduced resource intensity (Elijah et al., 2018) .
- Green Digitalization, integrating digital transformation with environmental sustainability via IoT and AI for resource optimization (Kashkool et al., 2025) .

Human development, as articulated by the United Nations Development Programme (UNDP), extends beyond income growth to emphasize the expansion of human capabilities and opportunities through improvements in health, education, living standards, and environmental sustainability. It focuses on enhancing human capital and ensuring inclusive access to resources and services that enable individuals to live productive and dignified lives The historical development of economic thought continues to be relevant for understanding how economic theories evolve and influence contemporary economic policies and frameworks. Recent conceptualizations highlight its ongoing role as a “living laboratory” for theorising, showing that past economic ideas still shape current debates and methodological approaches in economics (McCaffrey et al., 2025).

In measurement terms, human development is commonly assessed through indicators capturing:

- Health and longevity, proxied by life expectancy at birth;
- Knowledge acquisition, proxied by literacy, educational attainment, and education expenditure;
- Standard of living, proxied by GDP/GNI per capita;

The Human Development Index (HDI) is a composite index that reflects a country’s achievements in three key dimensions: a long and healthy life (health), access to education (education), and a decent standard of living (income). It provides a broader measure of human well-being than economic indicators alone and is widely used to compare development progress across countries and over time.

The relationship between GTI and human development operates through multiple reinforcing channels. GTI can reorganize production processes, generate green jobs, and improve productivity, thereby strengthening employment, income stability, and welfare outcomes. It also mitigates environmental pressures through pollution reduction and improved resource efficiency, contributing to better public health and quality of life (Park et al., 2021) . Consequently, GTI can act as an accelerator of sustainable economic expansion by supporting human capital formation and enhancing the effectiveness of development policy interventions (Yang et al., 2022).

This study synthesizes the GTI–human development linkage across three analytical pathways:

- Economic pathway: competitiveness, investment attraction, job creation, and efficiency gains through resource-saving technologies (Jiang & Shen, 2024)
- Health pathway: reduced pollution exposure, improved environmental quality, and more sustainable food systems supporting nutrition and health outcomes (Arrieta & Aguiar, 2023) .
- Education pathway: green education and technical competencies that expand skills for innovation and improve long-term employability (Wals, 2014) .

Research Methodology

Research Design

This study adopts a descriptive–analytical research design to examine the relationship between green technological innovation and human development in Iraq during the period 2014–2024. The analysis combines secondary macroeconomic data with sustainability indicators to evaluate structural trends in human development and green innovation performance.

Data Sources

The analysis relies on secondary data obtained from the Iraqi Central Statistical Organization (CSO), the World Bank, the United Nations Development Programme (UNDP), the Iraqi Ministry of Planning, and international reports such as the Global Innovation Index (WIPO) and the International Energy Agency (IEA).

Indicators and Variables

To assess the relationship between green technological innovation and human development, several key indicators are analysed:

- Human Development Indicators:
  - Education expenditure (% of GDP),
  - Health expenditure (% of GDP),
  - GDP per capita,
  - Human Development Index (HDI).
- Green Technological Innovation Indicators:
  - R&D expenditure (% of GDP),
  - Renewable energy production capacity,
  - Carbon intensity (kg CO_2 per USD of GDP),
  - Water use efficiency,
  - Waste recycling rate.

The study employs a trend analysis approach to evaluate the evolution of human development and green technological innovation indicators over the period 2014–2024. Comparative analysis is used to benchmark Iraq's performance against international standards and regional averages. The analysis focuses on identifying structural relationships between technological innovation capacity, environmental sustainability, and HD outcomes.

3. Results and Discussion

This section reports the empirical evidence on human development and green technological innovation (GTI) in Iraq over 2014–2024. The analysis first examines education, health, living standards, and the Human Development Index (HDI), and then evaluates GTI capacity through R&D investment, innovation-system performance, renewable energy deployment, and key environmental-efficiency indicators. Considered jointly, these metrics reveal structural constraints shaping Iraq's transition toward a more sustainable, innovation-driven development pathway.

4.1. Trends in Selected Human Development Indicators in Iraq

To understand the dynamics of human development in Iraq, this subsection examines three fundamental dimensions: education, health, and living standards, followed by the overall evolution of the Human Development Index (HDI). These indicators provide insights into the capacity of the Iraqi economy to generate improvements in human well-being and to support long-term sustainable development.

Education

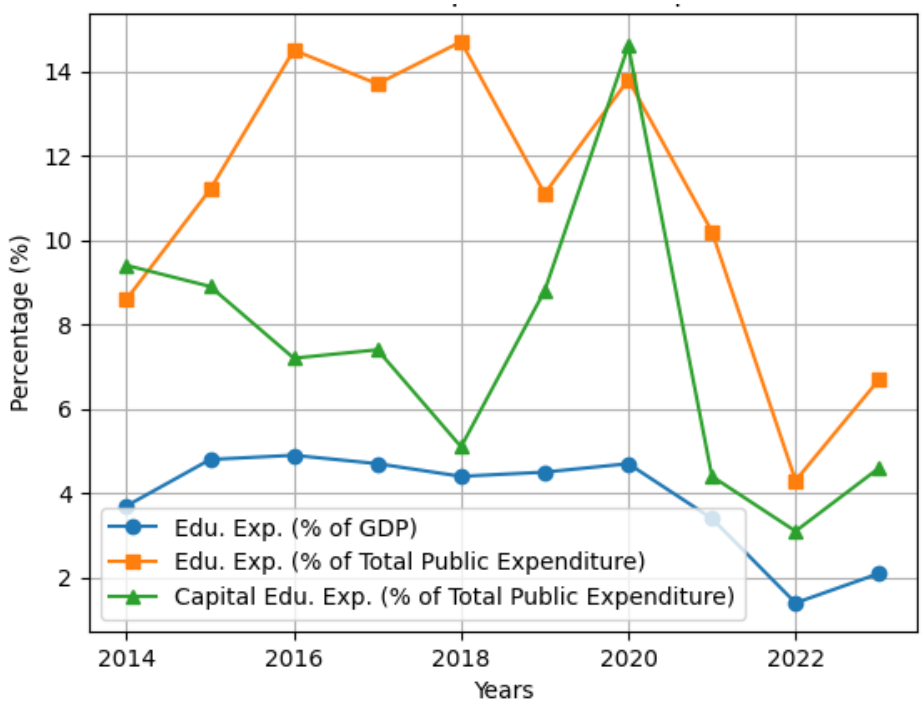
Education expenditure is a central determinant of human capital formation and long-term development capacity. Over the period 2014–2023, education spending in Iraq exhibited substantial volatility. As reported in Table 1 and illustrated in Figure 1, expenditure peaked at 4.9% of GDP in 2016, declined sharply to 1.4% in 2022, and partially recovered to 2.1% in 2023, yielding a period average of 3.9%, below the UNESCO benchmark of 4-6% (UNESCO, 2016). Education expenditure as a share of total public expenditure also fluctuated considerably, reaching 14.5–14.7% during 2016–2018 before declining to 4.3% in 2022 and increasing to 6.7% in 2023. The period average (10.9%) remains below UNESCO's recommended 15–20% range (UNESCO, 2016). Capital education expenditure displayed additional instability, peaking at 14.6% in 2020 but falling to 3.1% in 2022 and 4.6% in 2023, with an average of 7.4%. Overall, these trends indicate inconsistent investment in education infrastructure and technology, which may constrain the long-term development of human capital.

Table 1: Education Expenditure in Iraq for the Period (2014–2023)

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Average (%)
Edu. Exp. (% of GDP)	3.7	4.8	4.9	4.7	4.4	4.5	4.7	3.4	1.4	2.1	3.9
Edu. Exp. (% of Total Public Expenditure)	8.6	11.2	14.5	13.7	14.7	11.1	13.8	10.2	4.3	6.7	10.9
Capital Edu. Exp. (% of Total Public Expenditure)	9.4	8.9	7.2	7.4	5.1	8.8	14.6	4.4	3.1	4.6	7.4

Source: Central Statistical Organization (CSO), Iraq; UNESCO Institute for Statistics.

Figure 1: Trends in Education Expenditure in Iraq (2014–2023)



Source: Author's compilation based on CSO data.

Health

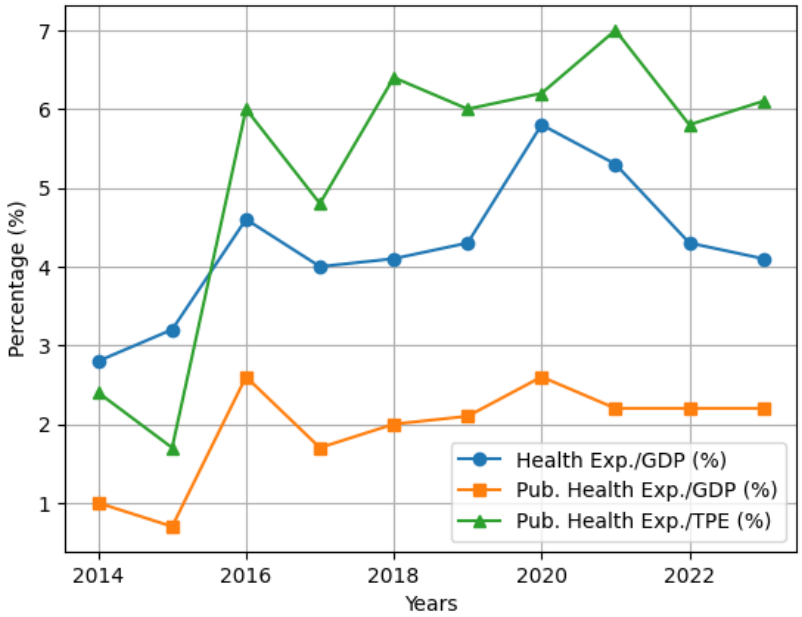
Health expenditure is a key component of human development, reflecting the capacity of public institutions to provide accessible and effective healthcare services. As illustrated in Table 2 and Figure 2, an upward trend in total health expenditure (% of GDP) from 2.8% (2014) to 5.8% (2020), followed by a decline to 4.1% (2023); the period average is 4.2%, below the global middle-income benchmark of 6.5% (WB, 2024) and the WHO reference range of 5–6% associated with progress toward universal health coverage (WHO, 2019). Public health expenditure remained low, ranging from 0.7% (2015) to 2.6% (2020), averaging 2.0%, below the 3%–4% regional average reported for Middle East countries (WB, 2024). Public health expenditure as a share of total public expenditure ranged from 1.7% (2015) to 7.0% (2021), with a mean of 5.2%. Collectively, these indicators point to constrained fiscal prioritization of health and potential vulnerabilities in service quality and access, especially in rural and conflict-affected regions. From a GTI perspective, innovations in smart agriculture, digital health infrastructure, and sustainable energy supply to facilities represent plausible levers for strengthening health resilience and reducing inequality in service delivery.

Table 2: Health Expenditure in Iraq for the Period (2014–2023)

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Average (%)
Health Exp./GDP (%)	2.8	3.2	4.6	4.0	4.1	4.3	5.8	5.3	4.3	4.1	4.2
Pub. Health Exp./GDP (%)	1.0	0.7	2.6	1.7	2.0	2.1	2.6	2.2	2.2	2.2	2.0
Pub. Health Exp./TPE (%)	2.4	1.7	6.0	4.8	6.4	6.0	6.2	7.0	5.8	6.1	5.2

Source: World Bank; Iraqi Ministry of Planning; CSO.

Figure 2: Trends in Health Expenditure in Iraq (2014–2023)



Source: Author's calculations based on CSO and World Bank data.

Living Standards

Living standards are commonly proxied by per capita GDP, which reflects the overall economic capacity of households and the availability of resources for education, health, and social welfare. As presented in Table 3 and Figure 3 show substantial volatility in per capita GDP (constant 2007 prices). Per capita GDP declined to 5.5 million IQD (2015) and 5.4 million IQD (2020), corresponding to annual contractions of −25.7% and −23.9%, respectively, before rebounding to 7.4 (2021) and 9.9 (2022) million IQD, with growth of 37.0% and 33.8%. In 2023, per capita GDP fell to 8.2 million IQD (−17.2%). The period average is 6.9 million IQD. These dynamics are consistent with Iraq's reliance on oil revenues and exposure to external shocks (oil price cycles and the COVID-19 period), with implications for household capacity to invest in education and health and, by extension, for sustained improvements in human development outcomes.

Table 3. Per capita GDP in Iraq (2014–2023, constant 2007 prices, 100 = 2007)

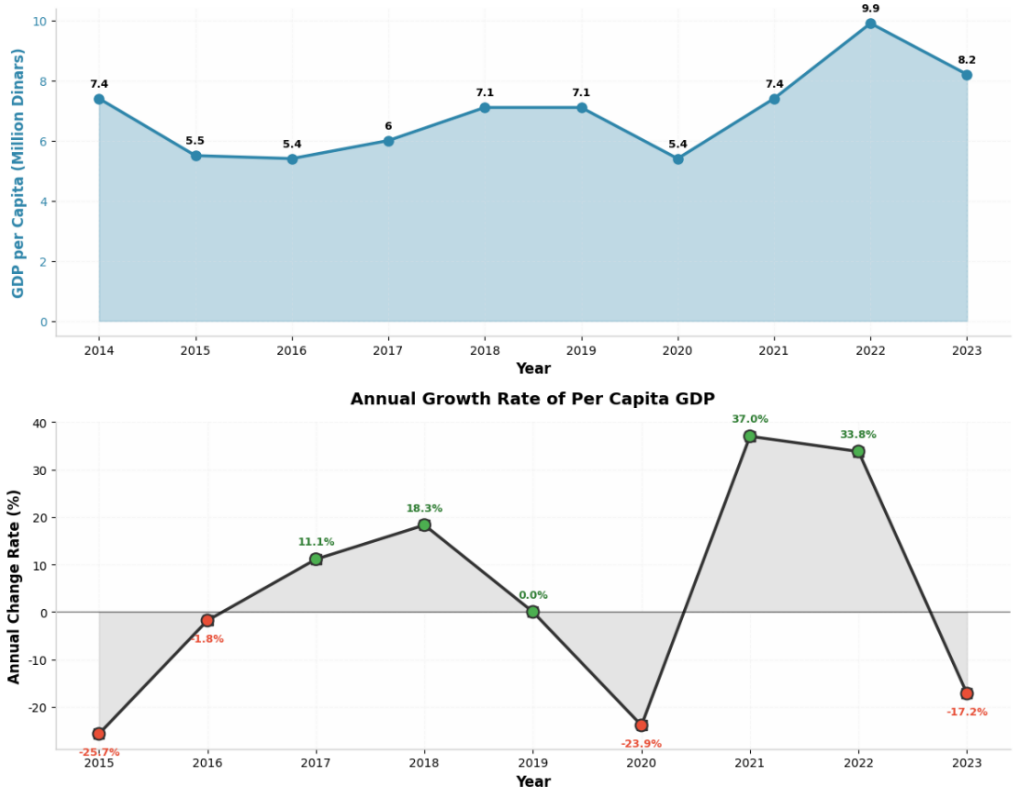
Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Avg
Per capita GDP (million IQD)	7.4	5.5	5.4	6.0	7.1	7.1	5.4	7.4	9.9	8.2	6.9
Annual change (%)	–	-25.7	-1.8	11.1	18.3	0.0	-23.9	37.0	33.8	-17.2	–

Note: GDP values are reported in constant 2007 Iraqi dinars (IQD) to ensure comparability across years.
Source: Central Statistical Organization (CSO), Iraq.

It is noteworthy that the average per capita GDP of Iraq is relatively low, and thus limits the ability of the households to invest in their core areas such as education and health and hence has a detrimental impact on the Human Development Index by reducing the standard of living and increasing the poverty and unemployment. Therefore, the potential solution to these issues is to diversify the economy, improve food security, generate employment, and mitigate the housing and income situation all of which lie within the green technological innovation. This could be achieved by introducing sustainability-oriented policies that utilise

technology and thus leading to human development in Iraq and thus improving the situation of human development in the long run-in terms of Human Development Index and human capital.

Figure 3: Trends in Per Capita GDP (2014-2023, constant 2007 prices, 100 = 2007)



Source: Author's calculations based on CSO.

Human Development Index (HDI)

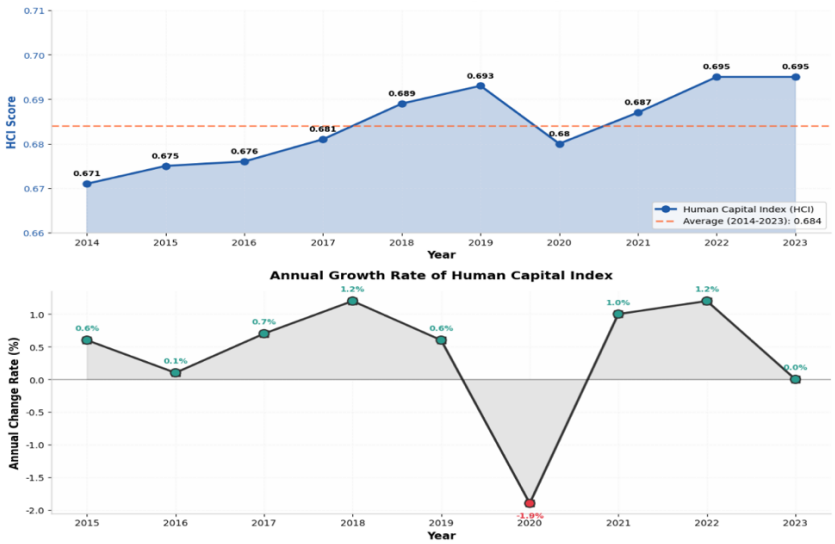
The Human Development Index (HDI) integrates key dimensions of development, education, health, and income, into a composite measure of societal progress. As reported in Table 4 and Figure 4 show a gradual improvement in Iraq's HDI from 0.671 (2014) to 0.695 (2023), with a marked decline in 2020 (0.680; −1.9%), consistent with the pandemic and macroeconomic stress. The period average is 0.684, placing Iraq in the medium human development category and below some regional peers (e.g., Jordan 0.754 and Qatar 0.886 in 2023) (UNDP, 2023). The post-2020 recovery to 0.695 (2022–2023) suggests partial stabilization, although the absence of further improvement in 2023 may indicate slowing progress amid persistent structural constraints. These constraints include high oil dependence, governance and security challenges, and uneven regional development, all of which shape education, health, and income trajectories. In this context, GTI, particularly precision agriculture, renewable energy expansion, and water treatment systems, can support both sustainability and capability expansion through improved services and productivity.

Table 4: Evolution of the Human Development Index (HDI) in Iraq (2014–2023)

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Avg (%)
HDI (Score)	0.671	0.675	0.676	0.681	0.689	0.693	0.680	0.687	0.695	0.695	0.684
Annual Change Rate (%)	—	0.6	0.1	0.7	1.2	0.6	-1.9	1.0	1.2	0.0	—

Note: HDI values reflect composite indicators of health, education, and income dimensions.
Source: United Nations Development Programme (UNDP).

Figure 4: Evolution of the Human Development Index (HDI) in Iraq (2014–2023)



Note: Trajectory of HDI values over the study period.
Source: Author's compilation based on UNDP data.

Across education, health, income, and HDI, Iraq exhibits gradual improvement punctuated by major shocks and fiscal volatility, underscoring structural vulnerability and the importance of stable, capability-enhancing public investment.

4.2 Iraq's Trajectory Towards Green Technological Innovation

Green technological innovation is a central pathway within which Iraq can become a country of sustainable development. It requires a concerted action to reduce the reliance on fossils, encourage their adoption of renewable sources of energy, and ensure that the efficiency of resource-use is maximized. Therefore, to determine the direction of change of the country to a more sustainable economy through the spread of green innovations, the following indicators should be evaluated:

Research and Development Expenditure

R&D expenditure represents a core input indicator of national innovation capacity. Given the observed volatility in human development financing, analysing R&D investment provides insight into Iraq's capacity to build and diffuse green technologies. All these shortcomings are reflected in worsening the overall economic performance, thus, hindering the ability of Iraq to attain the Sustainable Development Goals, particularly Goal 3 and Goal 4, which will ensure healthy living, enhance well-being of all people at all ages, and guarantee inclusive, equitable, quality education and lifelong learning opportunities to all people (UN, 2015).

Table 5 indicates that R&D spending in Iraq remained exceptionally low during 2014–2022, fluctuating narrowly between 0.03% and 0.05% of GDP, with an average of 0.04% and no sustained upward trend (Table 5). This level is substantially below regional comparators such as Saudi Arabia (0.88%), the UAE (1.31%), Qatar (0.53%), and Turkey (2.12%) (World Bank, 2014–2023). Persistently low R&D investment constrains innovation capacity, slows diffusion of green technologies, and limits human capital development required for an innovation-driven transition.

Table 5: Expenditure on Research & Development as a % of GDP in Iraq (2014–2022)

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average (%)
Expenditure on R&D (% of GDP)	0.04	0.04	0.04	0.05	0.04	0.03	0.04	0.04	0.04	0.04

Source: World Bank; UNESCO Institute for Statistics.

Financing Sustainability of Innovation and Innovation-System Performance

The constant shortages in the supply of such funds create a big challenge to the research institutions and innovators across the world. As a result, the government should be a player in terms of mobilising, and providing financial resources to support innovation by focusing on sectors that would ensure economic sustainability as well as environmental sustainability. In addition, diverse foreign and local initiatives deploy funding solutions such as intellectual property markets, participatory financing models, and fintech solutions, to encourage the creation and distributions of environmentally friendly innovations (Al-Moussawi et al., 2024).

Figure 5 shows Iraq's pillar rankings: human capital and research (93), infrastructure (124), knowledge and technology outputs (125), institutions (127), market sophistication (128), creative outputs (129), and business sophistication (132) (WIPO, 2022). This configuration suggests that innovation outcomes are constrained not only by spending levels but also by ecosystem factors affecting translation of capacity into productive outputs.

Figure 5: Iraq's GII Pilar Performance (2020-2022) Compared to Regional/Global Averages

Note: Rankings reflect Iraq's position across innovation system according to Global Innovation Index.
Source: World Intellectual Property Organization (WIPO), Global Innovation Index.

Despite substantial oil revenues (over 45% of GDP and 87.8% of public revenues in 2014–2024) (Central Bank of Iraq, 2014–2024), innovation financing appears insufficient to generate competitive outcomes. Iraq's weak innovation-system performance is reflected in the Global Innovation Index: in 2022 Iraq ranked 131st, with a score of 11.9 and very low positions across major pillars (WIPO, 2022).

4.3. Efficiency of Green Technological Innovations Use in Iraq

Green technological innovation use is a critical tool of improving sustainability of the Iraqi economy as it will help in the increased green innovation application in increasing the efficiency of natural resources and energy consumption and the reduction of harmful emissions. Through sustainable technologies Iraq would be able to attain sustainable economic growth that does not compromise the environment and growth of the economy. It also improves the competitiveness of different sectors in the economy hence providing new avenues of growth and development.

Renewable Energy production Capacity

The first pillar of the process of attaining economic and environmental sustainability in Iraq is the renewable energy (solar, hydroelectric, wind).

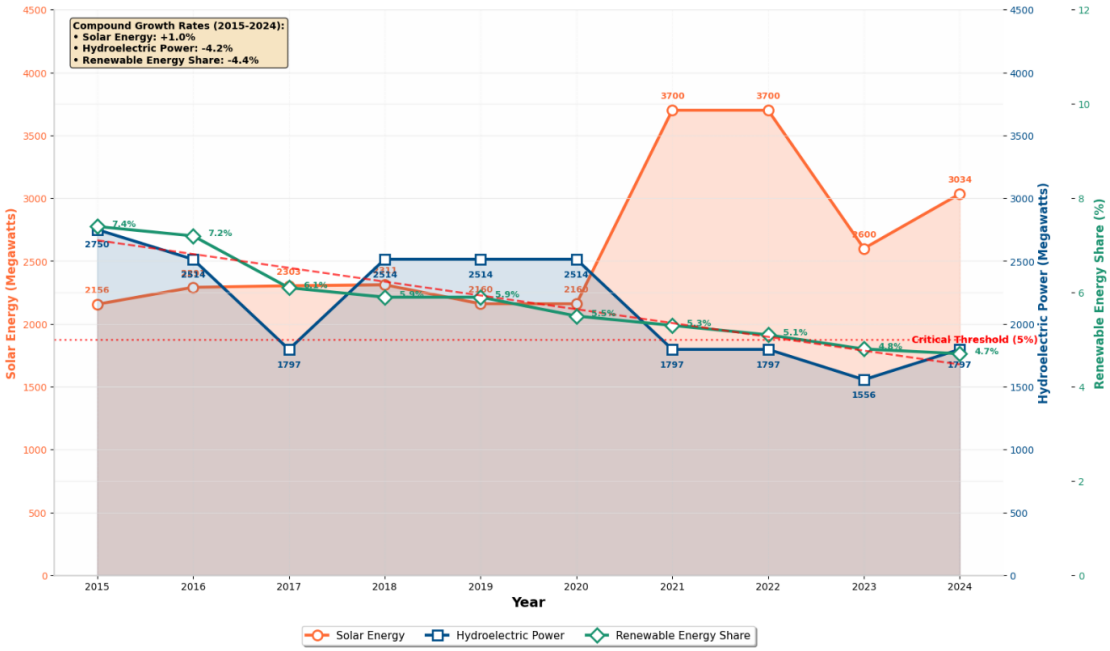
Table 6 and Figure 6 indicate limited renewable energy expansion. Solar production showed modest growth (compound 1.0%), with notable peaks in 2021–2022 (3,700 MW) and 3,034 MW (2024), yet remains below Iraq's solar potential (2,000–2,500 kWh/m² in Summer) (Wannan, 2022). Hydroelectric capacity declined overall (compound −4.2%), falling from 2,750 MW (2015) to values as low as 1,797 MW, reflecting reduced river inflows and climate-related constraints; hydropower accounted for only ~2% of national electricity generation in 2018 (International Labour Organization, 2023). Surplus energy storage remained constant at 240 MW, indicating limited investment in storage infrastructure. Renewable energy share decreased from 7.4% (2015) to 4.7% (2024) (compound −4.4%), implying that renewable deployment has not kept pace with rising demand and continued fossil reliance.

Table 6: Renewable Energy Production Capacities in Iraq (2015–2024)

Years	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Compound Growth Rate (%)
Solar Energy (Megawatts)	2,156	2,291	2,303	2,311	2,160	2,160	3,700	3,700	2,600	3,034	1.0
Hydroelectric Power (Megawatts)	2,750	2,514	1,797	2,514	2,514	2,514	1,797	1,797	1,556	1,797	-4.2
Surplus Electrical Energy Storage (Megawatts)	240	240	240	240	240	240	240	240	240	240	—
Renewable Energy Share (%)	7.4	7.2	6.1	5.9	5.9	5.5	5.3	5.1	4.8	4.7	-4.4

Source: Iraqi Ministry of Electricity; International Energy Agency (IEA).

Figure 6: Trends of Renewable Energy Production Capacities in Iraq (2015–2024)



Source: Author's calculations based on national energy statistics.

Carbon Intensity

Carbon intensity (kg CO_2-equivalent per USD of GDP) increased overall, rising from 0.851 (2014) to 0.989 (2024) with a compound growth rate of 1.4% (Table 7, Figure 7). After declining to 0.803 (2016), consistent with disrupted production and lower oil prices, carbon intensity rose sharply in 2017 (0.889; 10.8%) and continued increasing through 2018–2024. This trajectory indicates delayed progress in decarbonization and persistent dependence on fossil-fuel-based production, reinforced by low R&D spending (0.04% of GDP, Table 5). Rising carbon intensity also implies higher health burdens linked to pollution and increased costs of mitigation, which can indirectly constrain human development performance.

Furthermore, the growth of CO2 emissions during the consumption of fossil fuels and traditional extraction and production technologies is unfavourable to the population health in Iraq which may make the process of building and equipping hospitals more expensive and the extension of health services as the number of respiratory infections rises. This, consequently, can decrease the life expectancy of Iraqi people. Moreover, the scarcity of the production of clean electricity limits the use of e-learning technologies and the possibility of the educational institutions to obtain sufficient energy resources to enhance educational and scientific performance. Electricity production through the use of the private diesel generators also increases the cost of living in the households further feigning the level of poverty.

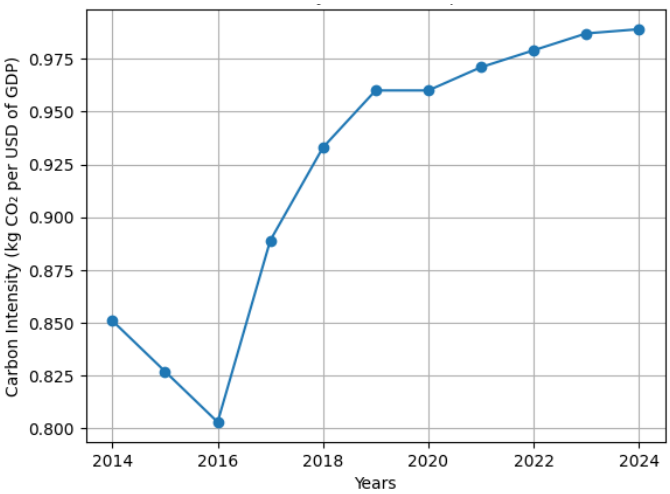
All these eventually have an impact on the Human Development Index (HDI). Moreover, the growth of the economy that is mainly propelled by the influx of oil can result in losses to the Iraqi economy, as a result of inefficient use of resources and energy, increased pollution mitigation expenditure, and increased costs of electricity generation. Hence, increased application of clean and green technologies and reinforcement of reliance on renewable sources of energy would lead to the increase of resource and energy efficiency, decrease in carbon intensity and sustainable development of the economy in Iraq. The result of such progress would be in the form of better HDI in terms of improved healthcare and educational services and better living standard.

Table 7: Carbon Intensity in Iraq 2014–2024

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Compound Growth Rate (%)
Carbon Intensity	0.851	0.827	0.803	0.889	0.933	0.960	0.960	0.971	0.979	0.987	0.989	1.4
Annual Rate of Change (%)	—	−2.8	−2.9	10.8	5.0	2.8	0.1	1.1	0.9	0.8	0.2	—

Note: Carbon intensity is measured as kilograms of CO_2 emissions per USD of GDP.
Source: International Energy Agency (IEA); World Bank.

Figure 7: Carbon Intensity Trends in Iraq (2014–2024)



Source: Author's calculations based on international energy data.

Water Use Efficiency

Table 8 and Figure 8 show increasing total water consumption from 1,108,000 to 2,452,041 million m³/year (2014–2022), driven largely by "economic sectors" consumption, averaging 74.9% of total water use. Agricultural consumption averaged 23.8%, with volumes between 307,106 and 470,850 million m³/year and shares shifting from 31.8% to 14.0%, indicating inefficiencies associated with traditional irrigation practices. UNEP (2023) reports per-capita water availability in 2023 at ~800 m³/year, below the scarcity threshold (1,000 m³), with climate stress and basin-level constraints affecting supply (UNEP, 2024; Republic of Iraq, 2024). Industrial water use averaged 1.3%, with declining shares consistent with weak industrial activity. These trends underscore the need for modern irrigation, recycling, and infrastructure upgrades to improve resource sustainability and reduce downstream impacts on health, education, and living standards.

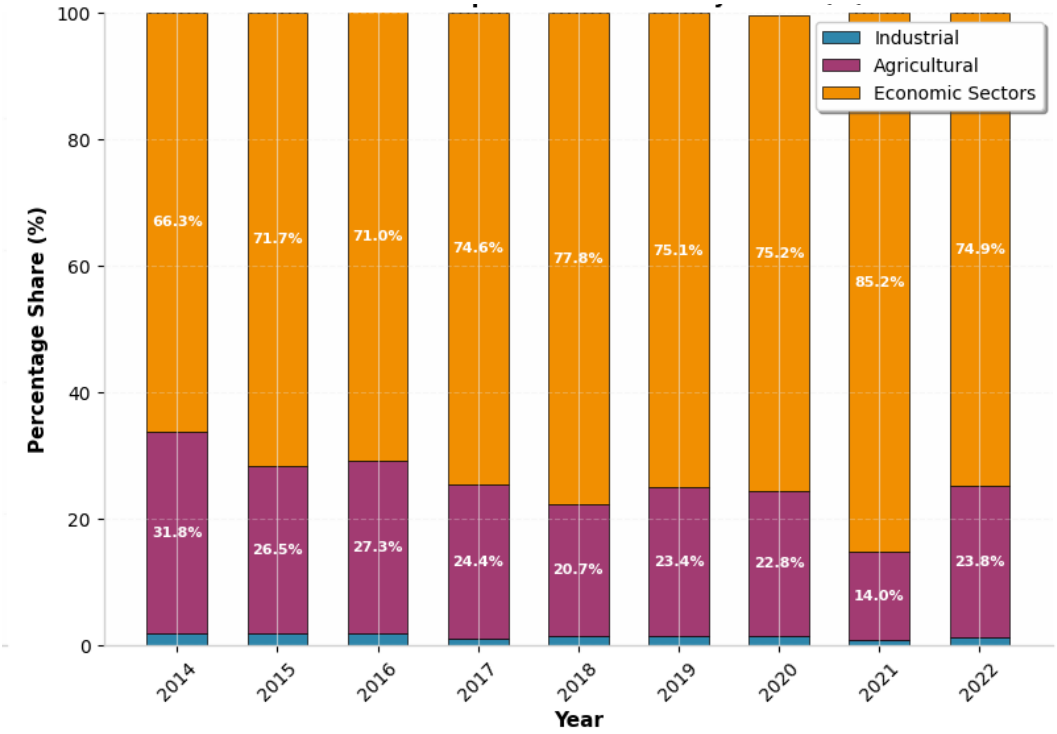
In line with this, there is a falling efficiency in the consumption of water in Iraq. Thus, there is a significant need to invest in intelligent irrigation and drip irrigation systems, work on the national strategic water plans, increase the water recycling, and decrease the losses by updating the infrastructure and investing in it. Also, it is important to train human resource in water management. All these are intended to optimize water usage and shift it to useful economic areas.

Table 8: Water Consumption Distribution (million m³/year) in Iraqi Economic Sectors (2014–2022)

Variable	2014	2015	2016	2017	2018	2019	2020	2021	2022
Industrial Sector (million m³/year)	20,500	25,434	30,967	14,899	22,304	28,575	21,758	3,085	20,518
Industrial Share (%)	1.9	1.8	1.8	1.0	1.5	1.5	1.5	0.8	1.3
Agricultural Sector (million m³/year)	352,700	368,166	470,850	378,188	307,106	442,341	326,874	311,692	342,964
Agricultural Share (%)	31.8	26.5	27.3	24.4	20.7	23.4	22.8	14.0	23.8
Economic Sectors* (million m³/year)	734,800	995,863	1,225,684	1,153,865	1,152,933	1,420,221	1,056,936	1,049,517	2,088,559
Economic Sectors Share (%)	66.3	71.7	71.0	74.6	77.8	75.1	75.2	85.2	74.9
Total Consumption (million m³/year)	1,108,000	1,389,463	1,727,501	1,546,952	1,482,343	1,891,137	1,405,568	1,364,294	2,452,041

Source: Iraqi Ministry of Water Resources; UNEP reports.

Figure 8: Water Consumption Distribution (million m³/year) in Iraqi Economic Sectors (2014–2022)



Source: Author's compilation based on national water statistics.

In addition, the lack of clean water supply to the human population contributes to the rise in diseases (including cholera), which consequently decreases the life expectancy of Iraqi people. The disruption of water supplies in schools, both urban and rural, can raise the rates of student dropout and absenteeism which eventually impact the number of school years. In addition, the decreasing degree of water supply to the industrial and agricultural sectors in Iraq will lead to reduced production hence relying on foreign imports to ensure consumption of agricultural and industrial products. This will reduce the standards of living since prices of imported commodities will increase hence decreasing HDI values. Hence, green technology could be appropriate to economic and human changes. This can be done by implementing smart irrigation and water recycling that will make water resource more efficient in terms of use, which will improve agricultural and industrial production capacity as well as decreasing costs. This results in reduced poverty and better HDI to greater levels.

Recycling Rate

Recycling performance remains limited. In 2021, Iraq had around 90 waste treatment/recycling facilities, but only 20 were operational, while 70 functioned as informal or temporary dumping sites; only four facilities conducted sorting and recycling (Iraqi Ministry of Planning, 2024). Table 9 and Figure 9 show recycled quantities declining from 7,955 tons/year (2017) to 873 (2023) (compound −25.2%). The recycling rate was 10.0% (2017–2019), reached 13.1% (2020 and 2022) and averaged 11.2%, far below the World Bank's reported 33% benchmark (World Bank, 2020). Inefficient waste management implies environmental losses and fiscal pressure through higher clean up and health costs, strengthening the case for technology-enabled recycling systems and circular-economy investment.

All these inadequacies are a combination of things. There is lack of infrastructure and there is modest technological advancement in the recycling sector. Iraq is not experienced in turning waste to make good economic products. At the same time, the population is ever-increasing, which magnifies the amount of garbage and the recycling process is still far behind. The administration is also plagued by corruption which further negatively affects efficiency of waste-management. All these problems undermine economic and environmental sustainability. Fiscal unsustainability is sharp: costs of waste-management will eat 0.8% of GDP by 2030, a rise on 0.5% today, with urbanization increasing and landfills filling up (World Bank, 2023).

Iraq is in dire need of investing on state-of-the-art recycling investment whereby waste is converted to energy thus supporting the green economy and enhancing the sustainability agenda. This kind of investment is in direct correlation to the concept of financial sustainability, as it converts a financial liability into a source of revenue. Waste-to-energy plants would be able to cover 5 to 7% of the electricity requirements of Baghdad and will save the municipality about 120 million dollars per year of waste transportation and disposal (IRENA, 2023). This reorganization of the economy waste disposal to a cycle of resource recovery reduces the fiscal consequences of the state in the long run, and at the same time, it improves the humanization of the state by boosting the quality of the environment and human health indicators.

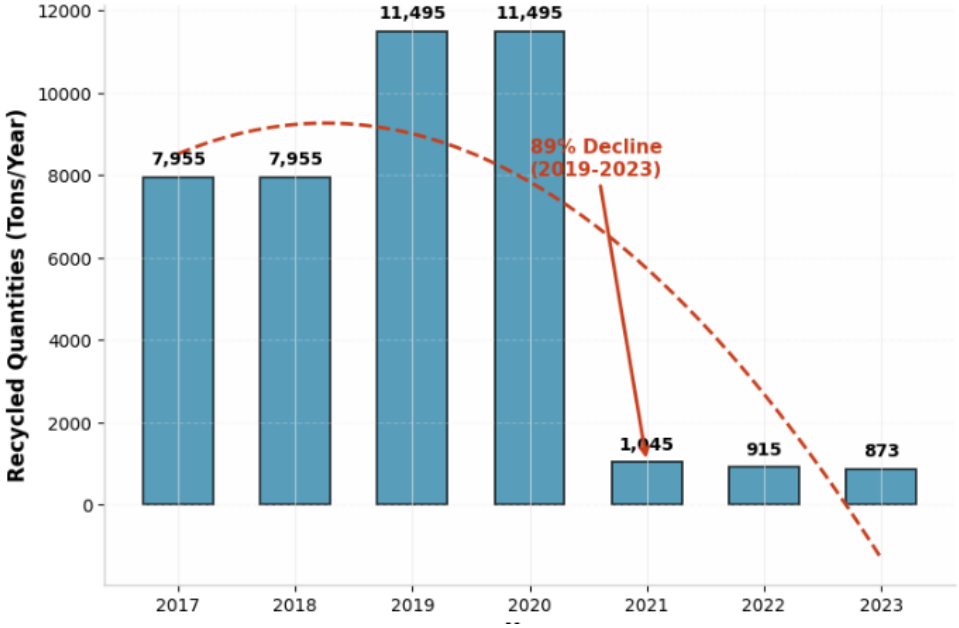
These effects are not only limited to economics. Lack of good recycling encourages the development of garbage that spreads diseases like poisoning and lack of life span. In places where the waste is collected in close proximity to schools, health of students becomes poor and school attendance reduces. In poor and informal settlements, garbage bins augment the cost of living and enhance poverty hence reducing the Human Development Index. Fiscal costs are also very drastic, with productivity losses caused by waste illnesses costing the economy between 400 and 600 millennia in absenteeism and inefficiency in labour every year, and disruptions in education contribute to poverty through generations and contribute to multiplying the burden of spending on social-welfare spending (UNDP, 2022). That is why, it is urgent to ensure that the green-economy framework is incorporated with innovative technologies and modern approaches. More efficient waste recycling and conversion into other products would improve the economy of Iraq and increase the HDI values. More importantly, such gains have a two-fold fiscal payoff immediate cost savings in the delivery of public-services, as well as revenue enhancement in the long run, by recovering resources and generating employment opportunities grounded on financial sustainability.

Table 9: Waste Recycling Quantities and Recycling Rate in Iraq (2017-2023)

Variable	2017	2018	2019	2020	2021	2022	2023*	Compound Growth Rate (%)
Recycled Quantities (Tons/Year)	7,955	7,955	11,495	11,495	1,045	915	873	-25.2
Annual Recycling Rate (%)	10.0	10.0	10.0	13.1	12.1	13.1	11.2	—

Source: Iraqi Ministry of Planning; World Bank.

Figure 9: Trends Waste Recycling Quantities and Recycling Rate in Iraq (2017-2023)



Source: Author's calculations based on national environmental statistics.

3.4. Improving Human Development in Iraq Through Green and Smart Digital Technologies

The evidence indicates that Iraq's green transition is constrained by low R&D spending (0.04% of GDP) (Table 5), limited renewable energy expansion (Table 6), rising carbon intensity (Table 7), and persistent inefficiencies in water and waste systems (Tables 8–9). Strengthening GTI therefore requires coordinated investment in renewable energy, smart agriculture, water efficiency, and waste management, supported by digital technologies for monitoring, prediction, and system optimization.

Green Technologies: Renewable Energy Potential

A sustainable Iraqi economy can be achieved through the implementation of green technological solutions in the production of renewable energy and support the indicators of Human Development Index (HDI). This has the effect of improving the health condition by cutting down on pollution caused by the use of fossil fuels, improving education by supplying electricity to institutions and schools that face the problem of inadequate electricity supply, and increasing living standards by lowering the cost of energy. It also supports sustainability of the environment as it helps in diversification of energy sources rather than high reliance on fossil fuels.

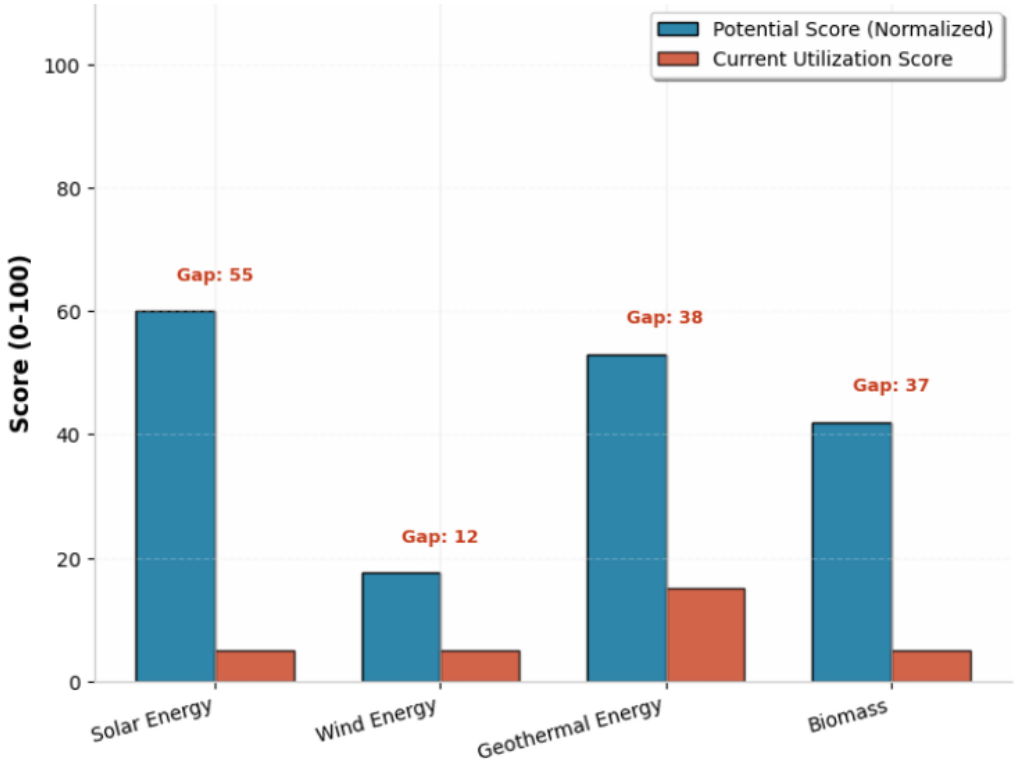
Despite low current utilization, Iraq has substantial renewable energy potential (Table 10; Figure 10). Solar potential is estimated at 1,000–5,000 GW (current utilization: <1%), wind 250–1,500 GW (<1%), geothermal 300–5,000 GW (1–3%), and biomass 200–4,000 GW (<1%). Expanding clean energy supports health outcomes through reduced emissions, improves education and service delivery via more reliable electricity, and contributes to higher living standards through lower energy costs and job creation (Republic of Iraq, 2024). These objectives align with international climate commitments emphasizing emission reductions and scaled investment in clean energy technologies (UN, 2015).

Table 10: Potential of Renewable Energy Sources in Iraq

Type of Energy	Potential Capacity (GW)	Current Utilization	Potential Applications
Solar Energy	1,000–5,000	Less than 1%	Homes, industry, agriculture
Wind Energy	250–1,500	Less than 1%	Electricity generation, water desalination
Geothermal Energy	300–5,000	1–3%	Electricity generation
Biomass	200–4,000	Less than 1%	Organic waste

Source: Republic of Iraq energy reports; International Renewable Energy Agency (IRENA).

Figure 10: Renewable Energy Potential in Iraq



Source: Author's compilation based on national energy strategy documents.

As it is revealed by Table (10), Iraq is endowed with a huge untapped potential hence forming a great potential in the drawing of investments in high-technological solutions to address the enduring issues of power shortages in the process of electricity generation. Use of these untapped resources can increase water resources to irrigate as well as domestic use, cut down the reliance on fossil fuels and improve the health of the people by cutting the yearly emissions of CO 2. Besides, a wider availability of dependable power translates into better education results- especially in institutions where the lack of sufficient illumination is a problem and at the same time, increases the quality of life by lowering the energy expenses.

Moreover, the enhanced utilization of renewable and clean energy technologies is the key to the fulfilment of the goals expressed in the Paris Climate Agreement that stipulates the decrease in the level of greenhouse gas emissions to 45% by 2030 compared to that of today and, at the same time, to multiply investments in clean energy technologies and secure the flow of financial means and technological assistance to the developing countries to help them change to the conditions of sustainable energy sources (UN, 2015).

This point of view is supported by empirical evidence based on previous research. As Bina (2013) showed, increased investment in clean energy technologies and green hydrogen production stimulate sustainable economic development through green development strategies, which cause structural changes in the production and consumption patterns. Such changes, in their turn, contribute to the improvement of growth rates through promotion of the use of the technologies that are resource-efficient and environmentally friendly. These investments also promote human development through enhancing quality of life, creating new jobs, decreasing levels of poverty, and eliminating the dependence on traditional energy sources (Mensah et al., 2019; Hajim,).

Digital technologies can amplify GTI effects by improving resource efficiency (energy/water), strengthening planning capacity, and enabling smart service delivery (Khalid, 2025). In agriculture, IoT and remote sensing support precision irrigation and monitoring, which is particularly relevant under increasing water scarcity in central and southern Iraq (Ye, Cao, & Wang, 2024; Al-Hamamy, 2024). AI-enabled systems can improve energy efficiency and predictive maintenance in industrial contexts, reducing downtime and resource waste (IEA, 2023; Khasawneh et al., 2025; Al-Darraji et al., 2024). In waste management, AI, IoT, and blockchain can increase sorting efficiency, reduce leakage, and enhance transparency in carbon tracking and circular systems (Tayal et al., 2021; Olawade et al., 2024; Abdallah et al., 2020; Upadhyay et al., 2021). Overall, the strategic integration of green and digital technologies is positioned to support human development by improving environmental quality, expanding green jobs, strengthening service reliability, and enabling more resilient economic diversification.

Conclusions

This study examined the role of green technological innovation in supporting structural economic transformation and human development in Iraq, a resource-dependent economy facing significant environmental and institutional challenges. Using a descriptive–analytical approach covering the period 2014–2024, the analysis evaluated key indicators of human development, including education, health, and income, alongside selected measures of green technological innovation. The findings reveal that although Iraq has achieved moderate progress in human development, reflected in stable public expenditure on education and health and an average Human Development Index (HDI) of 0.684, the country continues to face significant structural constraints related to limited innovation capacity and low investment in green technologies.

The empirical results highlight a clear imbalance between social development spending and technological modernization. While government expenditure on education and health reached averages of 3.9% and 4.2% of GDP respectively, investment in research and development remains extremely limited at only 0.04% of GDP. At the same time, indicators of environmental efficiency, including renewable energy deployment, recycling performance, and carbon intensity, suggest that Iraq's transition toward a green and sustainable economic model remains at an early stage. These findings indicate that the country's development trajectory continues to be constrained by structural dependence on fossil fuels, institutional limitations, and insufficient technological infrastructure.

Overall, the study confirms that green technological innovation represents a critical driver for advancing sustainable development and strengthening human development outcomes in resource-dependent economies. Expanding investment in green innovation systems, renewable energy infrastructure, and sustainable resource management can contribute to economic diversification, improved environmental performance, and enhanced social welfare. In this context, integrating green technological innovation into national development strategies is essential for supporting structural reform and achieving long-term financial sustainability in Iraq.

Policy Implications

Based on the empirical findings, several policy priorities emerge for supporting the transition toward a sustainable and innovation-driven economy.

First, investment in research and development must be significantly expanded. Increasing R&D expenditure toward 1% of GDP would align Iraq more closely with international innovation benchmarks and enable the development of domestic technological capabilities.

Second, governments should promote green investment and renewable energy deployment, particularly in solar and wind technologies, which represent largely untapped resources in Iraq. Expanding renewable energy infrastructure could reduce dependence on fossil fuels while improving environmental performance and energy security.

Third, circular economy policies, including improved recycling systems and waste-to-energy technologies, should be prioritized to enhance environmental sustainability and reduce economic losses associated with inefficient waste management.

Fourth, human capital development must accompany technological transformation. Integrating green and digital competencies into higher education and technical training programs, particularly in areas such as artificial intelligence, Internet of Things applications, and sustainable energy management, would strengthen the labour market foundations of a green economy.

Finally, governance reforms and transparency mechanisms are essential for ensuring the effective implementation of green investment programs and minimizing corruption risks in infrastructure projects.

Limitations and Future Research

While this study provides important insights into the relationship between green technological innovation and human development in Iraq, several limitations should be acknowledged. The analysis relies primarily on macro-level indicators, which may not fully capture regional disparities or sector-specific dynamics within the Iraqi economy. In addition, data limitations restricted the ability to conduct more advanced econometric modelling of the causal relationship between technological innovation and human development outcomes.

Future research could extend this analysis by examining regional-level variations, particularly in rural and conflict-affected areas, where development challenges remain particularly severe. Further empirical studies using econometric modelling or panel data analysis could also provide deeper insights into the long-term causal relationships between green innovation policies, environmental sustainability, and human development outcomes.

Credit Authorship Contribution Statement

Nadia Mahdi Abdul Kader is the sole author of this study and was responsible for the conceptualization of the research, literature review, data collection, methodology design, analysis and interpretation of results, writing of the manuscript, and final approval of the published version.

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Conflict of Interest Statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

The data used in this study are derived from publicly available sources, including the Central Statistical Organization of Iraq (CSO), the World Bank, the United Nations Development Programme (UNDP), the International Energy Agency (IEA), and the Global Innovation Index (WIPO). All datasets are accessible through the respective institutional databases and official reports cited in the reference list.

Ethical Approval Statement

This research is based exclusively on secondary data obtained from publicly available databases and official statistical reports. No human participants, personal data, or confidential information were involved in the study. Therefore, formal ethical approval was not required.

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