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Green transition for Turkey: Growth, employment, and trade deficit effects

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A B S T R A C T

This study examines the potential economic impacts of Turkey's energy transition by focusing on the effects of solar and wind energy investments. With Turkey aiming for "net zero" emissions by 2053, this research evaluates the impacts on total emissions, economic growth, employment, and the trade deficit under various scenarios. Utilizing input-output analysis and the employment factor approach, we analyze the macroeconomic and emission outcomes of a 10-year clean energy investment project targeting the transformation of the energy sector. Our findings indicate that investing in solar and wind energy could reduce Turkey's greenhouse gas emissions by 28–77 percent of 2020 emission levels. These investments are projected to enhance economic growth, contributing an additional 0.6%–1.8% of 2020 GDP annually on average. The employment effects are also significant, with total potential job creation amounting to a total of 1.3%–3.4% of Turkey's labor force in 2020. Furthermore, the investments are expected to improve the trade balance by 6.9–14.6 billion dollars over 10 years. The results suggest that green energy investments can simultaneously achieve environmental goals and promote economic stability through job creation and improve trade balances.

1. Introduction

Turkey declared its intention to achieve "net zero" by 2053 (Turkish Presidency, 2023; Republic of Turkey, 2023). Few studies analyzed the potential economic impacts of a green transition for Turkey. Some focused on related issues, such as the impact of adopting an environmental tax (Bouzaher et al., 2015) or coal subsidies (Acar and Yeldan, 2016). Studies focusing on employment effects overlooked the negative employment effects from the contraction in the coal industry and reported gross employment effects (Çetin and Eğrican, 2011; Yılmaz, 2014, International Labour Organization and United Nations Development Program, 2022). More recently, Acar et al. (2023) employed a computable general equilibrium framework to analyze some of the employment and growth effects of a green transition.

In this study, we contribute to the literature by estimating the potential effects of a clean energy investment program composed of investment in solar and wind power on total emissions, economic growth, employment, and current account deficit under different scenarios. After identifying country-specific input parameters and policy targets, we use input-output analysis and employment factor approach to analyze the effects of green transition under a base scenario of a 10-year project transforming the energy industry towards solar and wind. We then use alternative scenarios with different assumptions for robustness.

We investigate two main scenarios under which total investment in solar and wind power over 10 years amount to 23.6 and 62.4 billion USD. On an annual basis these numbers correspond to 0.3% and 0.9% of Turkey's 2020 gross domestic product (GDP). We find that over 10 years these investments could reduce annual greenhouse gas emissions by 28%–77% from their 2020 levels. These investments are expected to contribute to economic growth annually between 0.6% and 1.8% of the 2020 GDP. The investments also have a significant positive impact on employment, potentially generating jobs equivalent to 1.5%–3.9% of Turkey's total employment in 2020. Furthermore, these investments are projected to improve the trade balance by $6.9 to $14.6 billion in ten years. However, an opposite impact is likely to occur due to rising imported components of solar energy and wind energy power plant investments, with an increase in imports by 7.8–21 billion USD in ten years. Switching to renewable energy does come with an initial cost, as it requires importing technology and equipment. However, this is a short-term expense that mainly happens during the investment phase. In the long run, the benefits outweigh these costs—reducing coal imports will lead to lasting improvements in the trade balance, as renewable energy plants continue to operate for 20 years or more. Over time, the impact on foreign trade becomes more positive, since the reliance on imported

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technology fades after construction, while the savings from lower fossil fuel imports continue to accumulate.

The paper is organized as follows. We briefly present the main characteristics of Turkey's energy outlook in Section 2. In Section 3, we discuss the earlier studies on Turkey as well as studies for other economies that undertake similar analyses. After discussing data and methodology in Section 4, we present our results under different scenarios in Section 5. We conclude in the last section by discussing the implications of these results as well as their limitations and discuss further research possibilities.

2. Turkey's energy and emissions outlook

Turkey's energy sector is highly dependent on imported fossil fuels, with coal, natural gas and oil making up a significant portion of the country's energy mix. In 2022, approximately 79% of total primary energy supply was met through imports, making energy security a major policy concern. Meanwhile, renewable energy sources such as wind, solar and geothermal have gained considerable increase in their share of electricity generation and heat. While Türkiye has strong solar and wind power potential, coal-based power stations still occupy a large share of its electricity production. In 2023, wind and solar energy contributed significantly to Türkiye's electricity production, generating 52.7 TWh, which accounted for 16.3% (solar PV: 5.8% and wind onshore: 10.5%) of the total electricity produced. Domestic coal energy accounted for % 14.2 of total electricity produced, with 45.8 TWh, and imported coal accounted for %22.4, with 72.1 TWh (TETC, 2023b). Hydro energy resources account for %19.4, natural gas accounts for %20.9, and biomass and waste account for 6.1% of the total electricity production in Turkey as of 2023.

Fig. 1 shows that Turkey's primary energy supply has been heavily weighted towards imported energy, including significant amounts of coal, oil, and natural gas. The country's substantial energy imports highlight its vulnerability to global market shifts and price increases and show the need for Turkey to adopt a more strategic energy policy that minimizes reliance on imports and increases the resilience of its energy economy.

Given Turkey's favorable climate conditions, wind and solar energy have strong deployment potential. The country's high solar radiation levels and wind corridors along the Aegean and Marmara regions create a strong case for expanding these energy sources.

The Wind Energy Potential Atlas of Türkiye (REPA-V1) was prepared by the Ministry of Energy and Natural Resources in 2006, by using a medium-scale numerical weather prediction model and a micro-scale wind flow model. According to the REPA-V1 data, the total capacity of wind power plants that can be established in Turkey was calculated to be 47,849.44 MW with an annual average wind speed of over 7.5 m/s (Ministry of Energy and Natural Resources of the Republic of Türkiye, 2024a). However, the Wind Energy Potential Atlas of Türkiye has been updated recently with European Union funding and support from the European Bank for Reconstruction and Development. Recent reports from the ministry show that wind potential is approximately 100,000 MW under current technology and conditions, which can be increased to levels of up to 150,000 MW (Ministry of Energy and Natural Resources of the Republic of Türkiye, 2024b).

The Solar Energy Potential Atlas (GEPA) is developed by the Ministry of Energy and Natural Resources to identify and promote the potential for solar energy production in Turkey. This atlas provides the most suitable solar energy power plant locations using data on solar radiation, temperature, and other meteorological factors. The atlas is an important tool used in planning and optimization of solar power plants by the ministry (Ministry of Energy and Natural Resources of the Republic of Türkiye, 2024c). Fig. 2 shows the solar ration map and Fig. 3 shows daily average sunshine duration. These figures demonstrate that due to its advantageous geographical position, there is substantial capacity for solar energy production for Türkiye. According to the data provided by GEPA, the average annual total sunshine duration is 2741 h and annual total radiation value is 1527.46 kWh/m^2 (Ministry of Energy and Natural Resources of the Republic of Türkiye, 2024d).

However, the potential in both solar and wind onshore energy can be influenced by land availability and competing uses of land. The deployment of solar and wind onshore energy projects, particularly large-scale solar systems, require significant land resources, raising concerns about land-use competition with agriculture, urban development, and natural ecosystems. Turkey faces significant challenges in land-use competition due to rapid urbanization and industrial expansion

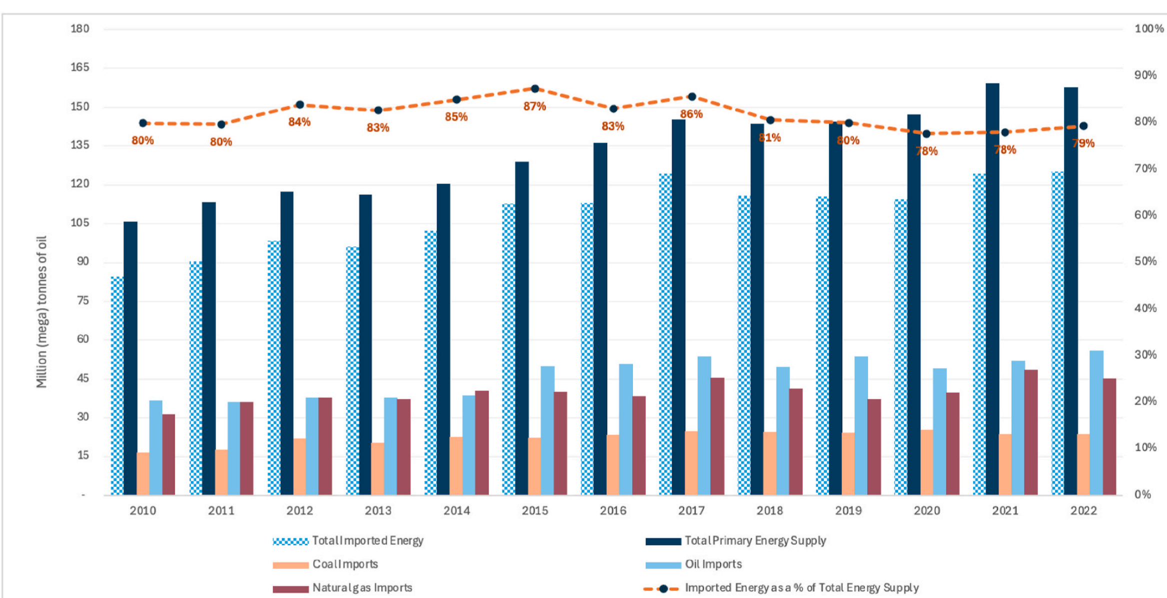

Fig. 1. Total primary energy supply and imported energy of Turkey, 2010–2022 **Source:** Ministry of Energy and Natural Resources of the Republic of Turkey MENR, 2022b **Notes:** (1) Imported Energy as a % of Total Energy Supply = (Imported Energy in tonnes of oil eq.)/(Total Supplied Energy in tonnes of oil eq). (2) Total primary energy supply includes domestic production, net imports, and statistical discrepancy. (3) Total imported energy includes coal, coke, coal tar, crude oil, petroleum products, natural gas, and a negligible amount of electricity (1%).

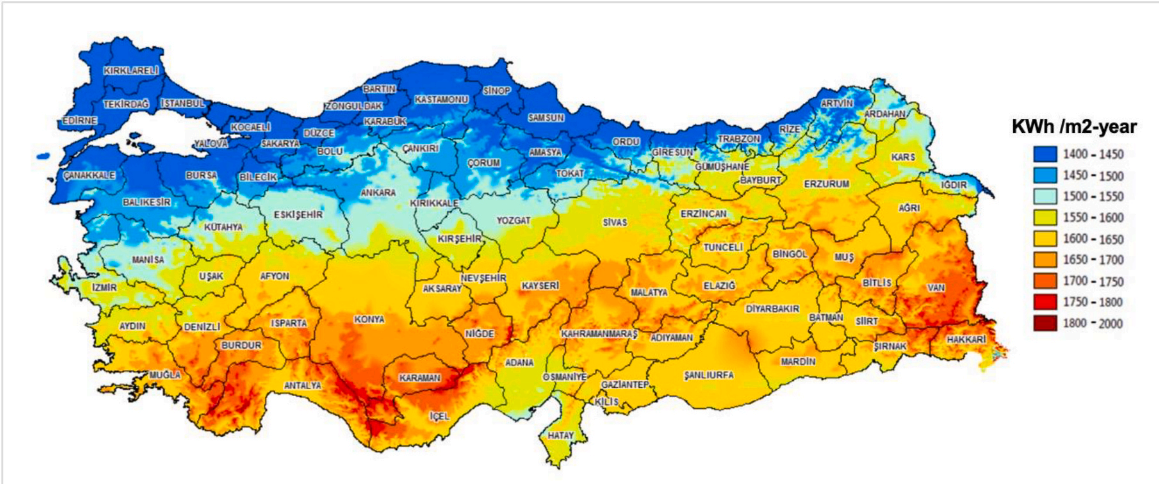

Fig. 2. Total Solar Radiation KWh/m2 in Türkiye **Source:** Republic of Türkiye, Ministry of Energy and Natural Resources, Solar Energy Potential Atlas, https://gepa.enerji.gov.tr/Default.aspx, last accessed July 15, 2024.

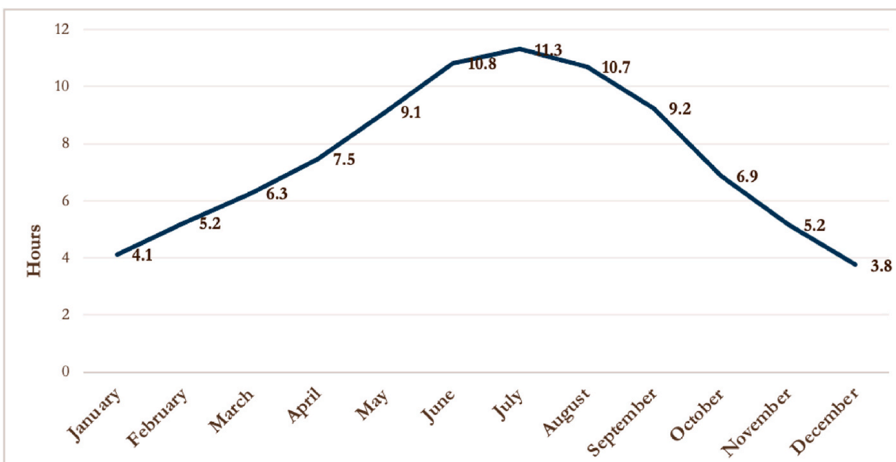

Fig. 3. Daily Average Solar Radiation KWh/m2 in Türkiye
Source: Ministry of Energy and Natural Resources of the Republic of Türkiye (2024a), https://gepa.enerji.gov.tr/Default.aspx, last accessed July 15, 2024.

(Ustaoglu, 2024; Yılmaz et al., 2021). Over the past decades, agricultural lands have been increasingly converted for urban or industrial uses, creating intense pressure on available land resources. Specifically solar energy projects, while environmentally beneficial, often require substantial land for photovoltaic (PV) installations, which can overlap with agricultural activities, grazing lands, and ecologically sensitive areas (Yücer, 2020).

To mitigate these challenges, Turkey has taken several steps to balance land-use priorities with renewable energy development. Turkey implemented YEKA (Renewable Energy Resource Areas) tenders to designate large-scale renewable energy zones. These tenders prioritize local content requirements and sustainable land use, minimizing conflicts between solar and wind energy projects and other land uses using the Solar Energy and Wind Energy Potential Atlas, which identify suitable sites for installations, emphasizing areas with lower agricultural or ecological value Additionally, The Soil Conservation and Land Use Act (Official, 2005) and related directives restrict renewable energy projects on highly productive agricultural lands, requiring specific approvals from the Ministry of Agriculture and Forestry (Ağır et al., 2023). Moreover, emerging solutions like Agrivoltaic (AgroPV) systems, which integrate solar energy production with crop cultivation, are being explored as a means to optimize land use and reduce competition (PricewaterhouseCoopers, 2024; Ağır et al., 2023). These systems, though promising, require significant policy support and institutional frameworks to scale up implementation.

Therefore, while we assume in the analysis below that land availability and land-use competition are not constituting any obstacles in front of green investment, it should be kept in mind that these constraints could imply an overestimation bias in our investment scenarios.

Despite the strong potential in solar and wind power, coal-based power stations still occupy a large share in electricity production. In 2023, wind and solar energy contributed significantly to the country's electricity production, generating 52.7 TWh, which accounted for 16.3% (solar PV: 5.8% and wind onshore: 10.5%) of the total electricity produced. Domestic coal energy accounted for %14.2 of total electricity produced with 45.8 TWh and imported coal accounted for %22.4, with 72.1 TWh (TETC, 2023b). Hydro energy resources account for %19.4, natural gas accounts for %20.9, and biomass and waste account for 6.1% of the total electricity production in Turkey as of 2023.

Turkey's energy sector is the predominant source of the nation's greenhouse gas (GHG) and carbon dioxide (CO_2) emissions, contributing 70% to GHG and 85% to CO_2 emissions as of 2020. United Nations Framework Convention on Climate Change (UNFCCC) data, presented in Fig. 4, illustrate GHG emissions across various sectors such as energy, industrial processes, agriculture, and waste industries including the share of electricity production. The UNFCCC Emissions Inventory

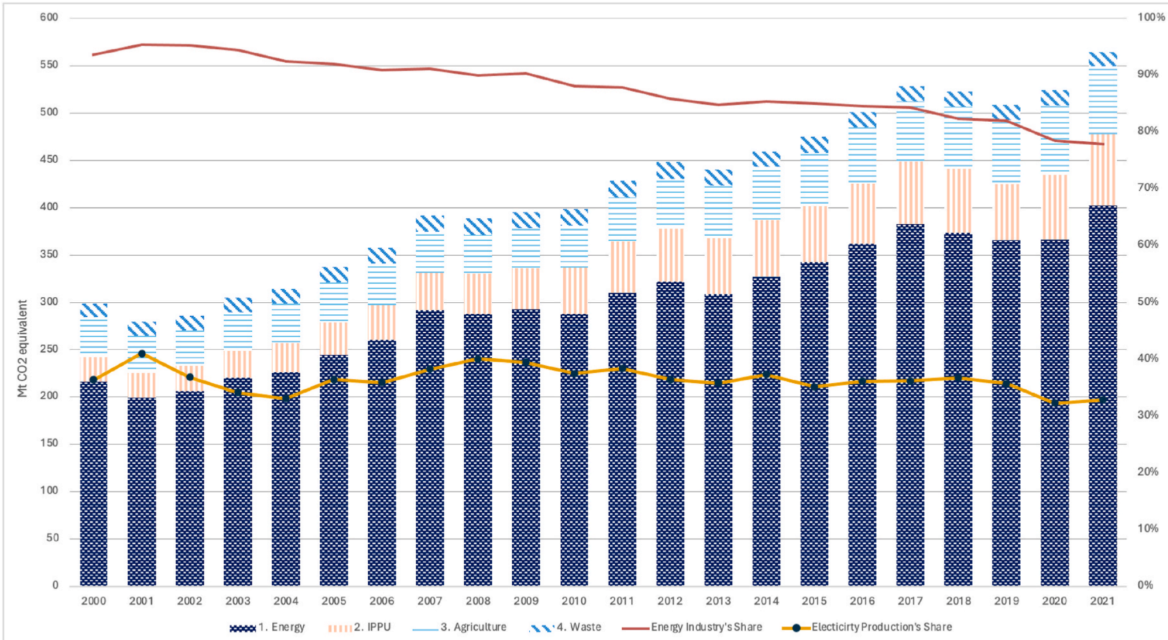

Fig. 4. Aggregate GHG emissions without LULUCF, Turkey, 2000–2021 **Source:** United Nations Framework Convention on Climate Change, UNFCCC, (United Nations Framework Convention on Climate Change) https://di.unfccc.int/detailed_data_by_party, last accessed June 22, 2024. Note: All numbers reported in gigatonnes of CO2 equivalent.

reveals that, since 2007, public electricity and heat generation (the energy industry's share) has accounted for 30% of Turkey's GHG emissions, a trend mirrored in CO_2 emissions as well.

Renewable energy solutions are important for decreasing the reliance on imported energy sources while providing clean energy and reducing greenhouse gas (GHG) emissions. As Table 1 shows, Turkey has a chronic trade deficit. The large deficit in goods balance is made up, to a certain extent, when revenues from tourism are considered, as reflected by the goods and services balance. Energy imports constitute a significant portion of the trade deficit. Transitioning to renewable energy sources could both contribute to decreasing imports and hence improve the trade balance in addition to enhancing national energy security, especially during global crises such as the one exacerbated by the Russia-Ukraine conflict (Yalçın and Yalçın, 2021; Ari et al., 2022; Aslantürk, 2020). Specifically, Turkey's coal imports bill hits to 5.3 billion USD in 2022, according to Alparslan (2023), underlining the economic benefits of investing in renewables. Yet, as we discuss below, investment in solar and wind power also requires imported components and the net trade balance result of a green transition would depend on whether Turkey can increase domestic components of these investments.

Fig. 5 illustrates the annual average electricity demand growth predictions over the next twenty years, according to the Ministry of Energy and Natural Resources (Ministry of Energy and Natural Resources of the Republic of Turkey, 2019). With a 2.9% annual electricity demand growth rate, annual total electricity demand will reach 427 TW-hour (TWh) in 2030 and 487 TWh in 2035. The projections are built on three distinct scenarios: low-demand, reference, and high-demand scenario, with electricity demand growing at an annual average rate of 2.9–3.7 % over the next two decades. We use the low-demand scenario to measure the differential effect of growing electricity demand on macroeconomic variables.

The government declared to achieve an increase of 1 GW (GW) in solar photovoltaic (PV) and wind onshore energy sources in the Green Reconciliation Action Plan (Republic of Turkey, 2021) and the Strategy Plan of the Ministry of Energy and Natural Resources for 2019–2023 (Republic of Turkey, 2019). We use this official target as a premise for the moderate-level capacity increase scenarios below. Moreover, a study by Shura Energy Transition Center (2018) proposed that electricity

Table 1
Energy imports and Turkey's trade balances (in billion USD).

	Exports	Imports	Goods Balance	Goods and services balance	Goods balance excluding energy imports	Energy imports	Energy exports	Energy trade balance
2014	173.3	239.9	−66.6	−25.4	−10.4	56.2	7.5	−48.7
2015	154.9	203.9	−49.0	−13.1	−10.4	38.7	5.1	−33.5
2016	152.6	192.6	−39.9	−14.5	−12.5	27.5	3.4	−24.1
2017	169.2	227.8	−ī58.6	−26.9	−20.9	37.7	4.8	−32.9
2018	178.9	219.6	−40.7	−4.3	2.9	43.6	5.8	−37.8
2019	182.2	199.0	−16.8	26.0	25.0	41.7	8.4	−33.3
2020	168.4	206.3	−37.9	−22.7	−8.9	28.9	4.7	−24.2
2021	224.7	254.0	−29.3	3.3	21.4	50.7	8.5	−42.2
2022	253.4	342.9	−89.6	−37.5	7.0	96.5	16.4	−80.1
2023	251.0	337.3	−86.3	−29.6	−17.2	69.1	16.4	−52.7
2014–23 Annual Average	**190.9**	**242.3**	**−51.5**	**−14.5**	**−2.4**	**49.1**	**8.1**	**−40.9**

Note: Energy imports and exports refer to Harmonized System code 27 in Foreign Trade Statistics and include mineral fuels, mineral oils, and products of their distillation; bituminous substances; mineral waxes. **Source:** Central Bank of the Republic of Turkey.
Source: Balance of Payments, Central Bank of the Republic of Türkiye and Foreign Trade Statistics, Turkstat

Fig. 5. Annual average electricity demand growth rate - Turkey, 2020–2040 **source:** Republic of Turkey, ministry of energy and natural resources, Turkey electricity energy demand projection report, 2020–2040.

transmission and substations in Turkey can meet a total capacity of 40 GW in solar PV and 40 GW in wind onshore energies. The advanced capacity increase scenarios comply with the capacity limits of existing electricity infrastructure.

Turkey has also implemented the Renewable Energy Support Mechanism (YEKDEM) to promote the development and utilization of renewable energy sources. YEKDEM provides financial incentives, feed-in tariffs, and other supportive measures and alongside strict local content requirements to attract investments in renewable energy projects, including wind, solar, hydro, and biomass.

In solar energy, there are now many facilities focusing on cell and panel production. Major firms focusing on cell and panel production are Kalyon and Smart Güneş, and battery investments are Pomega and Aspilsan (PricewaterhouseCoopers, 2024). However, Kalyon Energy is the only firm with a fully integrated solar panel production facility, increasing the domestic content rate over 80 percent. Other than the critical raw material polysilicon, which is generally imported from Chinese firms, Kalyon Energy is the first and only facility in Turkey and Europe to integrate its upstream and downstream in solar panel production. The domestic content rate of the industry ranges from 65 to 75% (PricewaterhouseCoopers, 2024).

Most of the equipment used in large-scale onshore wind power plants in Turkey is imported, with major suppliers including Siemens (%11.79), GE (%20.11), Nordex (%29.31), and Vestas (%17.58), Enercon (%19.18) (Turkish Wind Energy Association, Turkish Wind Energy Association, 2023). However, recently launched wind power plants with a utility-scale production capacity owned by government are equipped with around %65 domestic input use. Alaçatı wind power plant is equipped with the first locally produced wind turbines (produced by Aselsan) with a tower height of 100 m and a rotor diameter of 136 m. The power plant is also equipped with power converters and generators produced by Aselsan. The turbines produced by Aselsan show that the development of local wind turbine production is seen as a strategic priority. The Alaçatı RES project and several other initiatives aim to enhance local production capabilities, addressing supply challenges and increasing domestic content requirements to at least 65% (Aselsan, 2023).

3. Literature

Research on the employment effects of green policies and energy transition in developing countries, particularly Turkey, is limited (International Labour Organization and United Nations Development Program, 2022; Bouzaher et al., 2015). Factors such as outdated input-output tables and insufficient reliable data, coupled with the recent development of the renewable energy sector, contribute to this scarcity (Acar et al., 2023). Despite these limitations, existing studies on Turkey generally indicate net positive employment impacts, although they often focus only on gross effects (Çetin and Eğrican, 2011; Yılmaz, 2014; Özenç and Özen, 2020). Research has primarily examined the expansion of renewable energy production capacity (Bölük, 2013; International Labour Organization and United Nations Development Program, 2022), with less attention to the impacts of a carbon tax (Bouzaher et al., 2015). Some studies adopting computable general equilibrium (CGE) models have predicted positive employment outcomes from carbon taxes when the revenue is reinvested in research and innovation (Bouzaher et al., 2015). Other research assessed the employment effects of increasing capacity in wind and solar energy without considering the decline of the fossil fuel industry (Özenç and Özen, 2020). Most recent research using a macro-econometric input-output model suggests that transitioning from fossil fuels to renewable energy sources results in net positive employment impacts for Turkey (International Labour Organization and United Nations Development Program, 2022).

The input-output (I-O) model is a key tool for evaluating the employment impacts of green and brown energies, particularly through direct, indirect, and induced employment multipliers. Renewable energy industries, such as solar PV and wind onshore technologies, have higher labor intensity, leading to higher direct and indirect employment multipliers compared to fossil fuel industries (Garrett-Peltier et al., 2015; Fankhauser et al., 2008). The model relies on employment multipliers, which are calculated by multiplying the Leontieff inverse matrix with the labor intensities of industries, to estimate the labor required for the construction and installation of power plants (direct employment), the manufacturing and supply of inputs used in construction and installation (indirect employment), and the increased consumption in the economy due to changes in income (induced employment) (Garrett-Peltier et al., 2015).

Although the input-output model is increasingly applied in developing countries, challenges such as immature renewable energy technologies and outdated input-output tables persist (Acar et al., 2023; International Labour Organization and United Nations Development Program, 2022). To address these challenges, methods like the Ratio-to-Average Sampling (RAS) technique or the cell-updating approach are used to update input-output tables based on recent industry data (Miller and Blair, 2009; Wang et al., 2015). However, since renewable energy industries are not explicitly specified in input-output tables,[1] leading to the use of the augmented approach, which integrates renewable energy sectors as new industries, and the synthetic industry approach, which introduces renewable energy investments as a demand shock without altering the existing production technology (Garrett-Peltier, 2017; O'Sullivan and Edler, 2020). Both approaches may require a sensitivity analysis to validate the results due to assumptions in the industrial structure of renewable energies (Silva et al., 2013; Dell'Anna, 2021).

The literature on the employment impacts of renewable energy investments demonstrates positive outcomes across various countries and scenarios. Studies such as Dell'Anna (2021) and O'Sullivan and Edler (2020) show that increasing the share of renewables leads to significant job creation. In the United States, Garrett-Peltier (2017) found that renewable technologies created 7.49 full-time equivalent (FTE) jobs per million dollars invested, compared to only 2.65 FTE in fossil fuel industries. Similar positive employment impacts are observed in developing countries, with studies like Pollin (2015) estimating a net employment increase equal to 0.5–1.5% of the labor force by investing an additional 1.0–1.5% of GDP in clean energy over 20 years. The literature consistently indicates that renewable energy investments generate more jobs per unit of energy produced than fossil fuel counterparts, with a higher share of indirect effects in the total generated employment (Fankhauser et al., 2008; Garrett-Peltier et al., 2015).

The employment factor approach (EFA) is a method used to estimate labor required for energy transition-related activities, particularly in renewable energy sectors. This approach, which emphasizes direct job creation or "green jobs," is known for its simplicity and reliance on empirical data (Malik et al., 2021). Studies have consistently shown that renewable energy industries are more labor-intensive than fossil fuel industries, resulting in higher employment factors and more job opportunities in the construction, installation, and manufacturing stages (Rutovitz et al., 2015; Wei et al., 2010). Research in developing countries often involves calibrating employment factors to reflect their labor-intensive nature, leading to higher job forecasts (Yılmaz, 2014; Rutovitz, 2010). While findings generally indicate positive employment effects from renewable energy investments, some studies underestimate employment potential due to the exclusion of multiplier effects (Global Climate Network, 2009; Bowen, 2012).

Macroeconomic models are also used to evaluate the macroeconomic impacts of environmental policies, such as carbon pricing instruments, renewable energy, and energy efficiency investments (Breitschopf and Winkler, 2019). These studies include applied general equilibrium models, macro-econometric models, and hybrid models and assess changes in GDP, employment, and emissions levels resulting from different environmental policies. CGE type equilibrium models provide market equilibrium prices and are utilized to assess carbon-pricing impacts (Bouzaher et al., 2015; Rivers, 2013; Böhringer et al., 2013). In contrast, macro-econometric models, which are demand-driven and not bound to equilibrium conditions, and hybrid models, combining features of both macroeconometric and equilibrium models, offer alternative perspectives. The overall impact on employment varies significantly across studies, with macro-econometric models generally generating higher employment opportunities than equilibrium models. System-dynamics-based hybrid models often report higher employment opportunities than models based on neoclassical principles (Duscha et al., 2014; Breitschopf and Winkler, 2019). The financing scheme adopted in the analysis significantly affects the overall employment impact, with the distribution or reuse of revenue derived from carbon taxes engendering positive employment impacts (Böhringer et al., 2013; Mu et al., 2018; Bouzaher et al., 2015). Research employing macroeconomic models is predominantly conducted for developed countries, with studies on developing countries still growing and yielding inconclusive net impacts regarding the energy transition.

In the United States, Garrett-Peltier (2017) found that renewable technologies generate 7.49 full-time equivalent (FTE) jobs per million dollars invested, compared to only 2.65 FTE in fossil fuel industries. Similar positive employment impacts are observed in developing countries, with studies like Garrett-Peltier et al., (2015) estimate a net employment increase of 0.5–1.5% of the labor force by investing an additional 1.0–1.5% of GDP in clean energy annually.

The employment and economic effects of renewable energy transitions vary by country but show a common trend of net employment gains despite labor market restructuring challenges. Guo et al. (2024) estimate that China's transition to a renewable-dominated power system will generate 463 thousand to 630 thousand more jobs in their greener scenarios compared to the business-as-usual scenario where coal power expansion is dominating. The program includes investments in solar, wind, energy storage, and grid expansion until 2030 and 2060. Sauma Chacón et al. (2023) analyze the employment implications of Costa Rica's transition to a net-zero economy by 2050, using a regional input-output model combined with a bottom-up technology-rich model. Their study finds that under baseline assumptions, Costa Rica's decarbonization efforts could create additional 135,000 jobs, with 23,000 being direct, 70,000 indirect and 40,000 induced jobs, compared to a business-as-usual scenario, which are primarily in the renewable energy, commerce, and transportation sectors. The employment gains derived in 30 years amount to %7 of the employment in Costa Rica by 2017. Their results underscore the importance of regional employment redistribution and policy flexibility under different economic conditions. Similarly, Černý et al., 2024 show that a 100% renewable energy transition in Europe leads to a temporary employment boom, particularly in construction and manufacturing, but creates long-term labor shortages in low-skill sectors. These studies highlight the need for labor market planning and workforce adaptation policies to maximize the economic benefits of clean energy investments.

A summary of the literature for each methodology, including policy instruments and adopted countries, is given in Table 2.

4. Data and method

We use a vast array of data sources. Given the lack of detailed sector-level data on renewable energy investment costs, we estimate parameters based on industry reports and policy documents. We employed 2012 Input-Output Table and updated it to 2020 values to analyze how changes in energy investments affect different sectors' emission, employment and output and value-added levels. All data sources are presented in Table 3.

4.1. EFA method

The employment factor approach is a methodology that can be used to measure the direct employment impact of energy investments. This approach is based on employment factors, which represent the number of jobs needed per unit of installed capacity increase. However, employment factors specific to developing countries are often not calculated, leading to the adoption of alternative practices in the literature.

The total employment impact is calculated in two main steps. First, employment factors for each energy industry, along with other potential factors such as regional factors, domestic content, and the decline rate, are determined. Second, the projected capacity increase of each energy source, as derived from scenarios, is multiplied by the factors

[1] While our analysis relies on the Turkish national input-output tables, we acknowledge that EXIOBASE offers detailed and granular input-output data for renewable energy sectors, including environmental and global trade linkages. Utilizing this fine data could provide additional insights into the renewable energy sector in Turkey. However, incorporating EXIOBASE into the current framework is beyond the scope of this study and is left for future research.

Table 2
Summary of the literature.

Methodology	Policy Instruments	Country	Results	Studies
The EFA	Renewable Energy and Energy Efficiency Investments	United States, Europe, Organization for Economic Co-operation and Development (OECD), South Africa	Lower employment multipliers in developed countries	Kammen et al., (2004); Wei et al., (2010); Rutovitz (2010); Maia et al., (2011); Ortega et al. (2015); Malik et al., (2021); Çetin and Eğrican (2011)
The I-O Method	Renewable Energy, Energy Efficiency Investments	Portugal, Greece, United States, Australia, S. Korea, Brazil, Indonesia, Germany, Italy, South Africa, Turkey	-The transition increases employment by 1–1.5% despite the retrenchment in the coal industry (Garrett-Peltier et al., 2015). -Higher indirect employment effects than direct employment effects. -Higher impact on employment in developing countries compared to developed countries.	Tourkolias and Mirasgedis, 2011; Silva et al., (2013); Malik et al., (2014); Garrett-Peltier et al., (2015); Garrett-Peltier (2017); O'Sullivan and Edler, 2020; Dell'Anna, 2021; International Labour Organization and United Nations Development Program, 2022; Guo et al., 2024; Sauma Chacón et al., 2023; Černý et al., 2024
Complex Macroeconomic Models	Taxing pollution, commodity vs. lump-sum tax, consumption tax, caps & dividends, feed-in-tariff policy with consumer tax, and subsidies for renewables.	Canada, Turkey, Malaysia, Nigeria, China	The results vary depending on assumptions employed in the models or the values of specific parameters, such as not recycling the tax revenue (both positive and negative).	Böhringer et al., (2012); Bouzaher et al. (2015); Chatri et al., (2018); Mu et al., (2018); Omoju et al., (2020)

determined in the first step. Jobs are computed for manufacturing, construction, and operation & maintenance phases. Fig. 6 illustrates the method used to calculate the total jobs created/lost for each type of power plant in detail.

We adopt the OECD employment factors for Turkey by applying a regional multiplier, reflecting the relative productivity differences between OECD and Turkey (Rutovitz, 2010; Yılmaz, 2014; Acar et al., 2023). This approach takes into account predicted productivity and GDP growth in industry sectors to derive specific regional multipliers. Lastly, we use a domestic content parameter to adjust for the import dependency of manufacturing sectors in energy projects, which we derive from input-output tables and sectoral investment compositions. The machinery and equipment necessary to implement the power plants are rarely produced within domestic resources. Consequently, the job creation potential of the manufacturing industry declines when the machinery is imported instead of producing it domestically. To abstain from overestimating problems, we incorporated the domestic content parameter into the analysis. The data calculation methods and technical details on the methodology are provided in Appendix A. The descriptions of the indices used in Fig. 6 are as follows:

- Annual Deployed Capacity: This provides information on the annual newly commissioned installed capacity for each type of power plant as detailed in the Scenarios section. For the estimate of annual operation and maintenance jobs, the cumulative newly added installed capacity is used instead of the annual newly added installed capacity for each energy technology.
- Employment Factor $^{\text{OECD}}$: Represents the employment factor during the manufacturing, construction, and operation and maintenance stages for countries within the Organization for Economic Co-operation and Development (OECD).
- Regional Factor $^{\text{M/C/O\&M}}$: Gives the estimated annual proportional labor productivity ratio between OECD countries and Turkey for manufacturing, construction, and general industry. Regional factors are calculated using OECD value-added and employment figures Organization for Economic Co-operation and Development (OECD), 2016, Organization for Economic Co-operation and Development (OECD), 2021.
- % Domestic Content Rate: Represents the percentage of output produced using local resources in the manufacturing industry for Solar, Wind, and Coal technologies.
- % Decline Rate: Calculates the projected decline in employment factors over the next ten years.

4.2. I-O method

We use the input-output analysis to calculate the employment, output, and emission effects derived from the implementation of renewable energy technologies and the consequent contraction in the coal industry. The analysis involves three steps: 1. Updating the 2012 Turkish Input-Output Table to reflect 2020 conditions. 2. Measuring the employment, output, and emission multipliers using the Leontieff Inverse Matrix. 3. Determining the cost components within total costs to ascertain the final demand vector for each energy investment.

4.2.1. The update of the input-output table

The commonly used Ratio to Average Sampling (RAS) technique updates technical coefficients based on recent economic data, preserving fixed relationships between sectoral transactions and value-added (Wang et al., 2015). The RAS technique relies on the update of the technical coefficients, the coefficients of the A matrix that show the interindustry relation, based on the target year's gross output, total inter-industry sales, and total interindustry purchases (Wang et al., 2015).

This study employs a variation of RAS technique employed by Acar et al. (2022), to adjust the technical coefficients of the A matrix according to 2020 sectoral gross value added and total inter-industry transactions. First, the gross value-added part of the 2012 I-O table has been restructured where total value-added equals the sum of employee compensation, net taxes, and net payments to capital for each sector, and total production equals the sum of total intermediate production and total value added. The sum of total production and imports gives the total supply. Second, we derived the technical coefficients of 2012 input-output table by dividing total value-added of each sector to the total sales of each sector. The technical coefficients reflect the fixed relation between a sector's output and its inputs Miller and Blair (2009). Using 2020 sectoral value added, total subsidies and taxes data, and total consumption, investment, government and import and export expenditures, we estimated the interindustry transactions, factor payments, and expenditures of 2020. The discrepancy between the total use and supply has been eliminated by adjusting gross payments to capital, and labor compensation items.

In updating the input-output table, the intersectoral matrix was revised from a 64x64 matrix to a 62x62 sector matrix. In terms of sector classification, the services provided by households as employers of domestic staff (represented by sector T) and other personal services (represented by S96) were merged into a single sector under S96+T. The sectors for owner-occupied housing receiving imputed rent (L68A) and real estate services (L68B) were consolidated under sector L68.

Table 3
Data sets and sources used in the study.

Data Sets	Data	Source	Objective
Data Set 1	2012 Input-Output Table • Technical Coefficients of inter-sectoral relationship	Turkstat (Turkish Statistical Institute. National Accounts, 2012)	To analyze the effect of demand changes according to inter-sectoral input-output relationships and to examine their overall economic impact. To ensure the consistency of results with two different input-output tables
Data Set 2	2020 Input-Output Table (Calculated) • Sectoral Value Added • Sectoral GDP • Sectoral Value Added • Central Government Budget Revenues (Value-added Tax and Excise Tax) • Sectoral Value Added	Turkstat (Turkish Statistical Institute, 2020) Ministry of Treasury and Finance	To update the 2012 Input-output table to 2020 values.
Data Set 3	2020 Sector-Based (Nace Rev2-2 digit) Employment Data • Employment/Production Coefficient	Eurostat	To convert the input-output table into an employment requirement table
Data Set 4	2012 Import & Domestic Input-Output Table • Domestic content of the industries	Turkstat (Turkish Statistical Institute, 2012a, Turkish Statistical Institute, 2012b)	To analyze the reduction in the domestic content rate of industries involved in energy investments.
Data Set 5	2020 Sector-Based (Nace Rev2-2 digit) Value-Added Data • Value-Added/Production Coefficient	Turkstat(Turkish Statistical Institute, 2020a, Turkish Statistical Institute, 2020b)	To convert the input-output table into a value-added requirement table
Data Set 6	2020 Sector-Based (Nace Rev2) Emission Data Emission/Production Coefficient	Eurostat,(Eurostat, 2023) Turkstat(Turkish Statistical Institute. Air Statistics, 2024)	To convert the input-output table into an emission requirement table.
Data Set 7	2020 - Production, import, export, delivery, and stock change quantities of solid fuels	Turkstat(Turkish Statistical Institute, 2023)	To estimate the reduction in imported coal usage.
Data Set 8	2020 Marginal Emission Factors	Ministry of Energy and Natural Resources(Ministry of Energy and Natural Resources of the Republic of Turkey, 2022)	To calculate the emission reduction effect of electricity production from renewable energy sources.
Data Set 9	Employment Factors • Employment coefficients for Manufacturing/ Construction/Operation and Maintenance Sectors (Solar/Wind/Coal/Natural Gas)	Literature	To calculate employment factors that will be used to estimate potential direct jobs resulting from increasing installed capacity in solar and wind energy and the shrinkage in fossil energy sectors.
Data Set 10	2032 Gross Electricity Demand Projection • 2032 electricity demand (TWh) • Annual increase rate of electricity demand for 2020–2040 (%)	Ministry of Energy and Natural Resources - Turkey Electricity Energy Demand Projection Report, 2020–2040 (Ministry of Energy and Natural Resources of the Republic of Turkey, 2019)	To calculate the increase in installed capacity for solar and wind energy alongside the decrease in installed capacity for fossil sectors and to meet the estimated electricity demand for 2030.
Data Set 11	Installed Capacity Report by Primary Sources • Installed capacity information by source for the year 2022 (Megawatt-MW)	Turkish Electricity Transmission Company(Turkish Electricity Transmission Corporation, 2022; Turkish Electricity Transmission Corporation, 2023)	To calculate the increase in installed capacity for solar and wind energy alongside the decrease in installed capacity for fossil sectors and to meet the estimated electricity demand for 2030.
Data Set 12	2020–2022 National Energy Balance Table • Imported energy by source for the year 2020/2022 (Thousand tonnes-of-oil equivalent - TOE)	Ministry of Energy and Natural Resources(Ministry of Energy and Natural Resources of the Republic of Turkey MENR, 2022b)	To calculate the increase in installed capacity for solar and wind energy alongside the decrease in installed capacity for fossil sectors and to meet the estimated electricity demand for 2030.
Data Set 13	2022 Electricity Production Consumption Report • Electricity production information by source for the year 2020/2021 (TWh)	Turkish Electricity Transmission Company	To calculate the increase in installed capacity for solar and wind energy alongside the decrease in installed capacity for fossil sectors and to meet the estimated electricity demand for 2030.
Data Set 14	2020 National Energy Balance Table • Imported energy by source for the year 2020/2022 (Thousand TOE)	Ministry of Energy and Natural Resources	To calculate the changes in imported energy quantity and amount according to capacity increase and domestic/ imported input usage scenarios.
Data Set 15	• Current Account, Non-Monetary Gold, and Energy Foreign Trade	Republic of Turkey -Central Bank - Electronic Data Delivery System	To calculate the changes in imported energy quantity and amount according to capacity increase and domestic/ imported input usage scenarios.
Data Set 16	Import according to the International Standard Industrial Classification (SITC, Rev.4) • Mineral fuels, oils, and alkaline products	Turkstat	To calculate the changes in imported energy quantity and amount according to capacity increase and domestic/ imported input usage scenarios.
Data Set 17	Energy Technologies Investment Cost Vectors • Cost Components of Solar, Wind, and Coal Technologies	Literature, Sectoral Reports	To generate demand vectors for the input-output methodology.

4.2.2. *Leontieff inverse matrix & derivation of requirement matrices*

The methodology pursued to update the 2012 input-output table and derivation of the Leontieff Inverse Matrix, employment/emission/value-added/production requirement matrices are detailed in Appendix B.

4.2.3. *Determining the sectoral composition of energy investments*

We derive the investment costs and cost components with their respective weights for each energy source from International Renewable Energy Agency (IRENA), the Ministry of Industry and Technology, and Turkish sectoral reports such as the Izmir Development Agency. These costs cover all expenses until the plant is operational. The operation and maintenance costs include equipment, labor, and management costs necessary to sustain the plant's productivity.

We allocated the investment expenditures for each energy source to specific sectors, determining their share within the total expenditures, and creating a final demand vector for the related sectors. Revealing the cost structure of energy investments provides valuable insights about the industries involved in the production process. Investments in wind and solar energy, for example, will facilitate the production of electrical and mechanical equipment, increase construction activities, or alter the demand for land use and engineering services. The unit investment cost for each technology for each power plant investment is provided in Table 4.

We further compare expenditure items with NACE Rev2 Industry

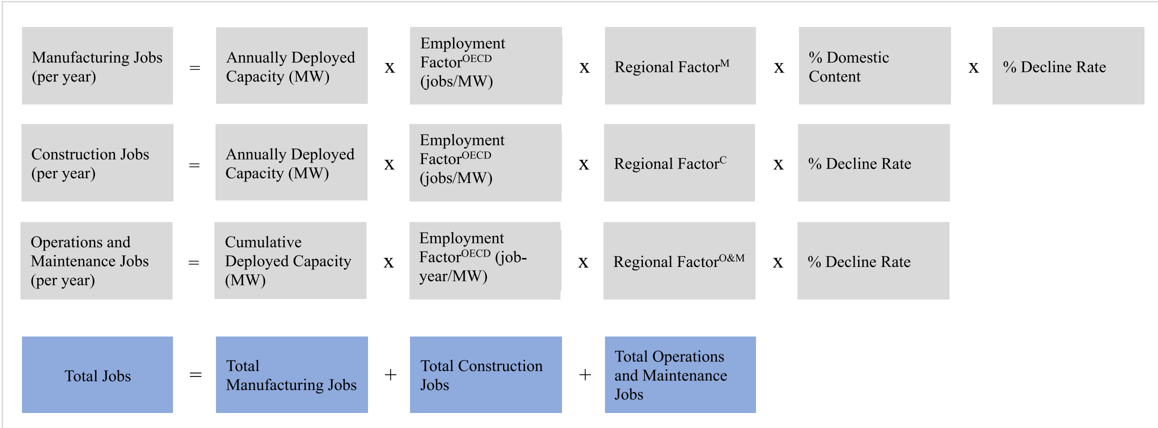

Fig. 6. Employment factor approach: methodology overview **Source:** Author's depiction based on the methodology by Rutovitz (2010).

codes to match current sectors within the input-output table. The weights and corresponding NACE Rev2 Industry codes are presented in Tables 5–7 For each energy type, the cost composition has been determined for both investments costs and operations and maintenance costs separately. Moreover, the operations and maintenance activities in the coal power plants are further differentiated for domestic coal-fired thermal power plants and imported coal-fired thermal power plants.

4.3. Analytic methods

The National Energy Balance Tables, prepared by the Ministry of Energy and Natural Resources, include crucial data on the electricity generated by the power plants using hard coal and the installed capacities of these coal power plants. We measure the total impact on the current account deficit by calculating the total amount and cost of hard coal in those facilities. The procedure adopted through the analysis is detailed in Appendix C.

Although the emission impact of renewable energy investments is analyzed with the I-O method, which is generated through the domestic production of equipment and installation activities from power plant investments, the reduction in emissions derived from the reduced coal-based electricity consumption is calculated separately. One method commonly used in the literature for this calculation is emission factors. Combined marginal emission factors are used to calculate the amount of carbon dioxide emissions reduced by power plants and show the amount of carbon dioxide reduced per unit of electricity consumed (1 kW-hour - KWh) in tons. The details of the method are provided in Appendix C.

5. Results and discussion

5.1. Scenarios

We present five different scenarios considering four main variables: the intensity of investment, the type of coal power plants reserved for capacity reduction, the projection of energy demand—whether it is to remain stable or exhibit an upward trajectory—and the industrial policy, which may either adopt an expansionary or conservative approach depending on the level of reliance on imports. Each scenario is detailed in Table 8 alongside the variables considered. As Fig. 5 in Section 2 above shows electricity demand is expected to increase between 2% 4 %

Table 4
Investment costs of energy technologies.

Technology	Installed Cost	Installed Cost	O&M Cost	O&M Cost
	$/KW	$/MW	$/KW-year	$/MW-year
Solar PV	939.01	939,007.73	15.89	15,892.57
Wind Onshore	1420.53	1,420,527.36	33.25	33,247.19
Coal Domestic	1463.64	1,463,636.36	54.02	54,016.00
Coal Imported	1563.46	1,563,457.32	128.34	128,341.67

Table 5
Investment and maintenance cost components for solar power plants.

Cost Category	I-O Table Sector Code	Sector Detail	(IRENA, 2021)
Investment Cost	C28	Manufacture of machinery and equipment not elsewhere classified	44.00%
	F	Construction works and construction activities	6.00%
	C25	Manufacture of fabricated metal products (excluding machinery and equipment)	–
	C27	Manufacture of electrical equipment	17.00%
	C26	Manufacture of computers, electronic and optical products	4.00%
	J62-J63	Computer programming, consultancy and related activities & Information service activities	1.00%
	C24	Basic metals industry	7.00%
	M71	Architectural and engineering activities; technical testing and analysis activities	–
	M74-M75	Other professional, scientific and technical activities	17.00%
	K66	Auxiliary activities for financial services and insurance activities	4.00%
Cost Category	**I-O Table Sector Code**	**Sector Detail**	**Pollin et al. (2014)**
Operations and Maintenance Costs	C27	Manufacture of electrical equipment	–
	C28	Manufacture of machinery and equipment not elsewhere classified	–
	C33	Installation and repair of machinery and equipment	25.00%
	F	Construction	25.00%
	K66	Auxiliary activities for financial services and insurance activities	–
	L68B	Real estate services	–
	N80-N82	Security and investigation services; landscape services; office management, office support and other business support services	50.00%

Table 6
Investment and maintenance cost components for wind onshore power plants.

Cost Category	I-O Table Sector Code	Sector Detail	(İzmir, 2021)
Investment Cost	C25	Manufacture of fabricated metal products (excluding machinery and equipment)	15.00%
	C26	Manufacture of computers, electronic and optical products	6.82%
	C27	Manufacture of electrical equipment	11.60%
	C28	Manufacture of machinery and equipment not elsewhere classified	35.66%
	D35	Electricity, gas, steam, and air conditioning supply	–
	F	Construction	20.35%
	K66	Services of insurance, reinsurance, and pension funding, except compulsory social security	8.22%
	M71	Architectural and engineering services; technical testing and analysis services	1.25%
	M72	Scientific research and development services	1.10%

Cost Category	I-O Table Sector Code	Sector Detail	Pollin et al. (2014)	Tourkolias and Mirasgedis, 2011
Operations and Maintenance Costs	C22	Rubber and plastic products	-	5.00%
	C33	Installation and repair of machinery and equipment	25.00%	45.00%
	F	Accommodation and food services	25.00%	–
	I	Telecommunication services	-	2.00%
	J61	Auxiliary activities for financial and insurance services	–	1.00%
	K66	Security and investigation services; landscaping services; office management, office support, and other business support services	-	17.00%
	L68	Real Estate Services	–	30.00%
	N80-82	Security and investigation services; landscape services; office management, office support and other business support services	50.00%	–

Table 7
Investment and maintenance cost components for coal power plants.

Cost Category	I-O Table Sector Code	Sector Detail	(U.S. Energy Information Administration, 2022)
Investment Cost	C25	Manufacture of fabricated metal products (excluding machinery and equipment)	37.87%
	C27	Manufacture of electrical equipment	6.73%
	C28	Manufacture of machinery and equipment not elsewhere classified	6.49%
	C33	Installation and repair of machinery and equipment	0.81%
	D35	Electricity, gas, steam, and air conditioning supply	0.11%
	F	Construction	9.84%
	H49	Land transport services and transport services via pipelines	0.20%
	K66	Services of insurance, reinsurance, and pension funding, except compulsory social security	10.71%
	L68	Real estate services	0.38%
	M69-M70	Legal and accounting services; management consultancy services	5.80%
	M71	Architectural and engineering services; technical testing and analysis services	21.05%

Cost Category	I-O Table Sector Code	Sector Detail	Pollin et al. (2014)	World Wide Fund for Nature & Sürdürülebilir Ekonomi ve Finans Araştırmaları Derneği, 2020
Operations and Maintenance Costs	B	Mining/Coal Import	17.2%	59%
	D35	Electricity, gas, steam, and air conditioning supply	82.8%	13%
	E37-E39	Sewerage services; sewage sludge; waste collection, treatment and disposal services;	–	23%
	H49	Land transport services and transport services via pipelines	–	5%

Notes: The operation and maintenance cost weights corresponding to Pollin et al. (2014) has been employed for domestic coal-fired power plants, while World Wide Fund for Nature & Sürdürülebilir Ekonomi ve Finans Araştırmaları Derneği, 2020) wights have been employed for imported-coal fired power plants. Moreover, while 17.2% of total O&M costs have been assigned to mining activities for domestic coal-fired power plants, for imported coal-fired power plants, 59% of total costs have been assigned to the coal import. This cost has not been taken into consideration during the analysis.

annually. This would delay the contraction in fossil fuels.

The moderate capacity increase scenarios examine the official targets set by the Ministry of Energy and Resources while assuming constant electricity demand. The moderate capacity increase scenario raises the total installed capacities of the wind onshore and solar PV to 21.4 and 19.4 GW, respectively, by 2032. The advanced capacity increase scenarios examine an ambitious investment policy while accounting for the increase in electricity demand. This advanced scenario anticipates 45 and 25 GW of installed capacities for wind onshore and solar PV energy sources by 2032.

Each scenario includes the net employment impact under an expansionary and conservative industry scenario. The industry dimension analyzes whether the investments will generate a domestic production scale-up in various industries or keep the reliance on imports constant. Scaling up domestic production corresponds to an aggressive industrial policy that seeks to expand the domestic capacity of the industry. The alternative is the conservative industrial policy, which relies on imports to meet the increased demand. In literature, the industries with 90% or higher domestic content have been treated as nontradeable (Lombardo and Ravenna, 2012; Garrett-Peltier et al., 2015). The nontradeable industry products are assumed to be produced and consumed in the domestic market and cannot be easily traded. In contrast, tradeable industry products can be easily exported or imported. We assume a 20% reduction in the domestic content of the tradeable industries, consistent with the previous literature (Garrett-Peltier et al., 2015; Pollin et al., 2009).

Table 8
Scenarios.

Scenario ID	Capacity Increase	Capital Investment Value (Billion USD)	Contraction in Fossil Fuels	Electricity Demand
Scenario S1.1	Solar GW: 10 GW Wind Onshore: 10 GW	23.6	10.8 GW reduction in Domestic Coal	Fixed Electricity Demand
Scenario S1.2	Solar GW: 10 GW Wind Onshore: 10 GW	23.6	7.8 GW reduction in Imported Coal	Fixed Electricity Demand
Scenario S2.1	Solar GW: 15.6 GW Wind Onshore: 33.6 GW	62.4	11.4 GW reduction in Domestic Coal 8.2 GW reduction in Imported Coal	Fixed Electricity Demand
Scenario S2.2	Solar GW: 15.6 GW Wind Onshore: 33.6 GW	62.4	5.7 GW reduction in Domestic Coal	Increasing Electricity Demand
Scenario S2.3	Solar GW: 15.6 GW Wind Onshore: 33.6 GW	62.4	4.2 GW reduction in Imported Coal	Increasing Electricity Demand

5.2. Results and discussion

The analysis results are provided in Table 9 and discussion on emissions, production, employment and current account impacts are detailed in each subsection below.

5.2.1. Emissions

Investing in renewable energy for electricity aims to reduce carbon dioxide emissions, but it is important to note that the investment process itself can generate some greenhouse gas emissions. Based on different scenarios and the degree of increased capacity, we estimate that between 158.2 and 408.3 million tons of carbon dioxide emissions could be prevented from entering the atmosphere. This estimated reduction represents the emissions saved compared to the total emissions that would occur during the project's lifespan. This amount is equivalent to about 2.8%–7.7% of Turkey's annual total greenhouse gas emissions as of 2020, indicating a significant impact on the country's overall emissions.

5.2.2. Production

The estimation of the net production and value-added effects of solar and wind energy investments has been exclusively conducted using the input-output methodology, anticipating an annual increase in value-added ranging from 42.6 to 129.9 billion USD. These investments are projected to generate an annual net increase that corresponds to 0.6%–1.8% of Turkey's GDP in 2020. The comparison between the aggressive and conservative industrial scenarios highlights the role of imported inputs in shaping the overall economic impact. In the aggressive industrial scenario, we assume that firms maintain their current level of domestic content despite the scale of investments, meaning that the share of imported inputs does not increase. Conversely, in the conservative industrial scenario, the reliance on imported inputs grows with investment magnitude, leading to a 20% reduction in the domestic content of tradeable industries. This shift results in a slightly lower overall production volume and value-added effect—approximately 2% less than in scenarios where domestic content remains stable, implying that the relative impact of increased imported inputs on output and value-added remains marginal.

5.2.3. Employment

The results of both analyses indicate that coal energy investments generate higher employment opportunities than renewables, both through the installation of the power plants and through the operations and maintenance activities. However, because the scale of renewable energy deployment in the scenarios compensates for the decline in coal-related employment, even though individual coal plants have higher labor intensity, the larger expansion of wind and solar capacity creates a net positive impact on employment. This difference suggests that employment-generating potential of the renewable sources are enough to meet the job losses in coal energy, even though all the coal-fired thermal power plants are shut down. Despite the higher employment-generating potential of the coal industry compared to renewables, the results of the analyses propose a net positive impact on employment resulting from the energy transition of Turkey if the capacity increase in the renewable energy investments is met by an equal reduction in the total electricity output of the coal industry.

5.2.4. Trade balance

The impacts of investments on the trade balance have been calculated by considering the expected decrease in the electricity production capacity of thermal power plants reliant on imported coal and, consequently, a reduction in these plants' coal imports. The analysis forecasts a total decline of 97.23 million tons in imported coal (hard coke). However, when the projected increase in electricity demand is considered, the effect of the reduction in imported coal is estimated to be limited to 46.15 million tons. According to these figures, the highest positive impact of the reduction in coal imports on the trade balance is calculated to be approximately 14.6 billion USD. Similarly, when the anticipated increase in electricity demand is considered, this benefit is expected to be confined to 6.9 billion USD. On the other hand, increased investments have also a negative impact on foreign trade through the rise in import use during production. The corresponding negative impact of import use during the investments is provided in the seventh column of Table 6. The domestic content rate of the new investments are assumed to be 70% for solar energy and 65% for wind energy for these calculations. Moreover, if we consider the lifetime impact on foreign trade, assuming that both solar PV and wind onshore power plants have 25 years of lifetime, the net impact on the foreign trade balance is given

Table 9
Analysis results under different scenarios.

Scenarios	Net Emissions (mtCO2 equivalent)	Net Output (Billion USD)	Net Employment - EFA- (Thousand People)	Net Employment – I/O (Thousand people)	Reduction in Energy Imports (Billion USD)	Increase in imported components of solar and wind power (Billion USD)	Net Foreign Trade through the lifecycle of the power plants (Billion USD)
S1.1	−158.2	42.6	179.8	390.1	N/A	7.8	N/A
S1.2	−150.1	47.9	182.1	403.7	−13.9	7.8	−44.1
S2.1	−408.3	122.4	376.5	1013	−14.6	21.1	−33.3
S2.2	−401.8	127.2	387.8	1029	N/A	21.1	N/A
S2.3	−397.8	129.9	389.0	1036	−6.9	21.1	−6.0

Note: For each scenario we report the total outcomes at the end of 10 years.

in the last column of Table 6.

6. Conclusion and policy implications

Investments in green energy are not only a vital step towards achieving Turkey's net-zero emission goals, but despite the anticipated losses in jobs, production, and value-added in coal-fired thermal power plants, they also reduce fossil fuel dependence and enhance the sustainability of energy production, contributing to long-term economic stability. These investments stimulate the development of innovative technologies and sectors while offering new and diversified employment opportunities in the labor market. Furthermore, expenditures on green energy infrastructure are observed to create positive value-added across various industries and, may have a favorable impact on the trade balance if domestic component ratio of green investments can be increased.

In the literature, depending on the employed methodology, employment and GDP impacts can be negative or positive. Garrett-Peltier et al. (2015), who use a similar method for the US, for example, estimate a net employment increase of 0.5–1.5% of the labor force by investing an additional 1.0–1.5% of GDP in clean energy over 20 years. Our findings suggest that annual spending equal to 0.3%–0.9% of GDP generates 0.1%–0.4% increase annually in employment compared to 2020 employment levels, consistent with the broader literature on the employment impacts of renewable energy investments. Acar et al. (2023), employing a computable general equilibrium model for Turkey, estimate a 4 % annual increase in GDP in response to 12.3 billion USD investment annually, consisting of renewable energy, energy efficiency investments and carbon tax applications. Our findings suggest that annual spending equal to 6.2 billion USD generates 1.8% increase in 2020 GDP annually. They also report total employment to be 32.9 million people as a result of 10 year of investment, which makes the total generated employment by the green transformation scenario equal to 2.2 million whereas our findings suggest that 27.8 million people to be employed by the end of 10 years, equivalent to an employment of 1 million people. The emission impacts cannot be readily compared among Acar et al. (2023) and ours' since the former reports the total level of GHG emissions at the end of the project. International Labour Organization and United Nations Development Program, 2022 using supply-and-use tables, measures the impact of a greener transformation compared to a business-as-usual case, however, do not report the of results of a green transformation and business-as-usual scenario separately, thus we cannot compare our findings. Moreover, the results from global studies highlight key employment and economic dynamics relevant to Turkey's green transition. (Sauma Chacón et al., 2023)finds that the employment gains of a transition to a net-zero economy in 30 years amount to %7 of the employment in Costa Rica by 2017, which makes average annual increase to be almost 0.2%. However, Guo et al. (2024) estimate that China's transition to a renewable-dominated power system will generate 463 thousand to 630 thousand more jobs in their greener scenarios compared to the business-as-usual scenario where coal power expansion is dominating, but the analysis includes power grid and energy storage investments altogether, which makes it hard to make a comparison. On the other hand, Yılmaz, 2014 adopting employment factor approach finds that, 300 MW of installed capacity increase annually in solar PV generate 5638 to 7891 jobs and 1650 MW of capacity increase annually in wind onshore energy generates 15,110 to 27,209 jobs depending on the imported input use, in total generating 20,748 to 35,100 jobs annually. Our analysis results suggest 20,295 to 20,528 jobs annually which also include the contraction of the coal industry.

Černý et al., 2024 further stress the importance of workforce skill adaptation, as the European transition to 100% renewables faces skill shortages despite initial employment surges. Additionally, similar to Europe, Turkey will need educational and vocational training policies to ensure a skilled workforce for the green transition. These findings suggest that while renewable energy transitions generally lead to net employment gains, their effectiveness depends on sectoral reallocation, workforce adaptation, and localized industrial policies.

In addition to renewable energy investments, studies into the economic effects of energy efficiency are crucial. According to analyses, the anticipated increase in electricity demand adversely affects the projected employment, production, value-added, and emissions impact. Addressing this growing demand through enhanced building insulation, energy-efficient lighting, and the development and implementation of advanced technologies to reduce industrial electricity consumption not only mitigates greenhouse gas emissions but also optimizes the benefits of these investments. Furthermore, socioeconomic research that explores the financing mechanisms for these investments and investigates the transition strategies to offset losses in fossil fuel sectors is critical for achieving an equitable green transformation in Turkey.

Moreover, ongoing technological advancements, decreasing prices of solar and wind equipment, and shifts in the global energy market following COVID-19 could introduce biases in our results. Uncertainties related to supply chain disruptions, policy shifts, and fluctuating energy input prices may increase or decrease total investment costs, while technological progress in green energy sources could enhance their efficiency and competitiveness. These factors could lead to employment and value-added effects that differ from our estimates. However, such dynamics are not fully captured within our current scenarios.

CRediT authorship contribution statement

Kübra Atik Gözkün: Writing – original draft. **Özgür Orhangazi:** Writing – review & editing.

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Declaration of competing interest

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Appendix A. Supplementary data

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Data availability

Data will be made available on request.

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