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Climate Neutrality of the Economy

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TÜRKİYE'S ENERGY SECURITY CHALLENGES: A THEORETICAL ASPECTS OF SHIFTING FROM HYDROCARBONS TO RENEWABLES

Abstract

Türkiye is one of the most energy-dependent countries, and its energy market is heavily reliant on imported energy sources such as oil, natural gas, coal. The relevancy of this research keeps up with the modern world's number one challenge, green energy transition, in one country's example in terms of costs and carbon emissions. For the purpose of the work, the country's theoretical transition from fossil fuels mainly, coal and natural gas to wind and solar energy in electricity production has been analysed, and the required average transition cost has been determined. To delve into a comprehensive investigation, firstly, the secondary data was employed on energy production and greenhouse gas emissions (as well as carbon emissions), and data showed coal and natural gas were in leading positions in generating electricity. The country's natural gas import by country through statistical data was touched. In this research, hypothetical calculation, correlation, regression, statistical, and comparative analysis methods were borrowed. With the help of the Pearson and Spearman correlation, the relationship between population growth and electricity generation was investigated. Via regression analysis, the potential effect of population growth on electricity produc-

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tion was determined. Additionally, the impact of electricity generation on population growth was also explored. The practical value, as well as the scientific novelty of this study, is that it provides a hypothetical transition road for other researchers to calculate world countries' transition expenses.

Key Words:

hypothetical calculation; electricity production; solar power; wind power; GHG emission; carbon emission (CO_2).

JEL: Q21, Q22, Q27, Q28.

5 figures, 10 tables, 16 references.

Problem Statement and Literature Review

The calculation of green energy transition costs and the formulation of theoretical approaches, that encompass one of the essential targets of this study, are in harmony with the relevant global action. The objective of the study consists of traditional (coal and natural gas) and renewable energy forms and moving from the former to the latter via hypothetical calculation and revealing connection between population growth and electricity production and vice versa. ***The purpose of the research*** is the following:

1. Uncovering the complete replacement costs of fossil fuels in electricity production by means of wind and solar power.

2. Estimating the equivalent of coal and lignite utilized in electricity production by natural gas and demonstrating Türkiye's entire natural gas need.

3. Correlation and regression analysis to illustrate the connection between population growth and electricity production and the opposition.

Weaning off fossil fuels and transitioning to clean and green energy are of enormous importance in the modern world. It is possible to say that renewable energy sources are the fourth energy revolution, following coal, oil, and natural gas, respectively. Paying close attention to green energy-related life demands from all spheres of life integrated-thinking and inclusive action. According to DW Planet A (2023a), carbon-free life is beyond our imagination because the research devoted to wind turbines and solar panels' emissions revealed a small amount of CO2 per kWh. Offshore wind turbines might damage the biodiversity of subsea creations (fish), and flying birds. The literature review displayed in Table 1 comprises the main achievements of scholars in the energy field.

Table 1

Summary of literature review

Study	Time	Country	Result
Kayahan	2023	Türkiye	Studied traditional and renewable energy forms based on global reports
DW Planet A	2021-2023	Germany	Solar and wind energy also emits carbon emissions in electricity production
Tutar & Atas	2022	Türkiye	According to the research, the installation of wind power systems (for total transition) in the country can cover 1.3% of the land area
Madenli, Bekçi, & Ichwani	2023	Türkiye	Examined the richest renewable energy areas of Türkiye: solar – Southeast Anatolia and the Mediterranean regions; wind – the Aegean Sea and the Marmara Sea
Ozbektaş, Senel, & Sungur	2023	Türkiye	The average installation cost of wind (onshore: 1255 USD) and solar (photovoltaic: 810 USD) power per kilowatt was analysed
A. Tleubergenova et.al	2023	Kazakhstan	Assessed the required amount of metals for wind turbines, solar panels, and green hydrogen technology production
Siccardi	2024	Belgium	Foreign policy of Türkiye was studied on the basis of energy security
Dumrul, Bilgili, Zarali, Dumrul, & Kiliçarslan	2024	Türkiye	Determined which energy source is the best for Türkiye
Dinneen	2024	The United Kingdom	Investigated the efficiency of solar panels

Source: made by the author.

It is widely believed that solar and wind powers are the main elements of green and clean life. On the contrary, the latest research unveiled that solar panels emit 40 g per kWh, while wind is 16 g, which is significantly less (DW Planet A, 2021, DW Planet A, 2023b).

Considering the metals used in the production of solar panels and wind turbines, the situation appears somewhat paradoxical. The elements necessary for wind and solar devices are common materials (aluminium, chromium, copper, silicon, etc.), critical metals (gold, molybdenum, titanium, etc.), and rare earth elements (dysprosium, neodymium) (Tleubergenova, 2023). Once these devices reach the end of their life cycle, a huge amount of precious metals is going to be wasted. At this point, reuse and recycling issues arise, necessitating significant financial resources that exceed the cost of production. One of the precious elements of batteries is lithium which enables possible huge carbon emission in the extraction phase.

As to solar panels and their probable efficiency issues, Dinneen's study (2024), which brings this matter to the center stage, proved that the total efficiency of simple solar panel can reach only in laboratory settings to 27%. There is also an opportunity to add extra layers to cells, which is known as "tandem", to increase these panels' efficiency. However, this option also cannot increase the efficiency figure in a favourable way.

The other option is to use perovskite on silicon cells, and tandem cells can increase efficiency to 43%. Nevertheless, implementation of this process results in higher and higher production costs.

Kayahan (2023) discussed carbon capture, utilization, and storage (CCUS) and emphasized that this CCUS can serve as a bridge in the energy revolution in terms of using CO2 in a beneficial way.

Tutar and Atas (2022) studied renewable energy sources, and their research showed Türkiye's wind energy potential: approximately 1.3% of the country's area is suitable for wind turbines. It equates to 48 thousand megawatts of wind power.

Madenli, Bekçi, and Ichwani (2023) noted that in transition to renewables, the Turkish government may face a variety of challenges, especially considering that the country imports energy resources and is dependent on imports nearly 74%. The other main examination of the research is related to the possible areas which have wind and solar energy potential. As such, Southeast Anatolia and the Mediterranean region have high potential in solar energy, while the Aegean Sea and the Marmara Sea are suitable for wind farms.

Ozbektas, Senel, and Sungur (2023) draw attention to the installation costs of wind and solar devices per kilowatt, and with reference to other research and global reports, they noted that wind turbines may cost 1255 USD per kW on shore, while solar might cost lower, precisely, 810 USD.

Energy security is a significant geopolitical issue and demands beneficial foreign policy from both importers and exporters. In this regard, the Turkish foreign policy was scrutinized in conjunction with its energy policy by Siccardi (2024). With respect to the latest geopolitical issues, Türkiye is following a balanced foreign policy, and at this point it is necessary to make a note about natural gas imports, in which Russia is dominant.

Dumrul et al. (2024) studied energy sources for Türkiye, and their research illustrated which energy forms were much more fitting to create and consume in the country. In the first place, solar energy is the best energy option for capacity-building and utilization, the second place belongs to hydraulic, and the last one is wind energy.

After analysing the literature regarding the green energy transition, one most important question arises that how much will the transition to wind and solar energy in electricity production cost in Türkiye? Are there possible carbon emissions from green energy sources? How much gas is needed to replace the entire coal consumption in Türkiye? These questions are of utmost importance for close exploring, and this study is dedicated to finding the keys to the unlocked questions.

Methodology

This study includes Spearman and Pearson correlation, regression, hypothetical calculation, and statistical and comparative analysis. The interconnection between population growth and electricity production was analysed through Spearman and Pearson correlation. The correlation formula is the following (Coskun, Altunisik, & Yildirim, 2019):

$$r = \frac{\sum (x_i - \vec{x}_i)(y_i - \vec{y}_i)}{\sqrt{\sum (x_i - \vec{x}_i)^2 (y_i - \vec{y}_i)^2}}. \quad (1)$$

Where:

r = Correlation coefficient

x_i = Values of the x variable

$\vec{x}_i$ = Mean of the values of x variable

y_i = Values of the y variable

$\vec{y}_i$ = Mean of the values of y variable

After conducting a correlation analysis, it was revealed that there was a strong correlation between variables, then conducted simple linear regression, and the formula is the following (Coskun et al., 2019):

$$Y_i = \alpha + \beta_i + \varepsilon_i. \quad (2)$$

where:

Y = y coordinate

i = observations

α = y intercept

β = slope

ε = error terms

Hypothetical computing method assisted in calculating weaning off coal and natural gas and transitioning to wind and solar energies. The second purpose of the study was realized with the help of the conversion method. Traditionally, statistical, and comparative analysis methods were employed. To implement these methods, statistical data from the Turkish Statistical Institute was employed, which included information on greenhouse gas emissions, carbon emissions, nominal GDP, and electricity production. The picture included in this study displayed the energy import route, while several graphs and tables depicted the various analyses.

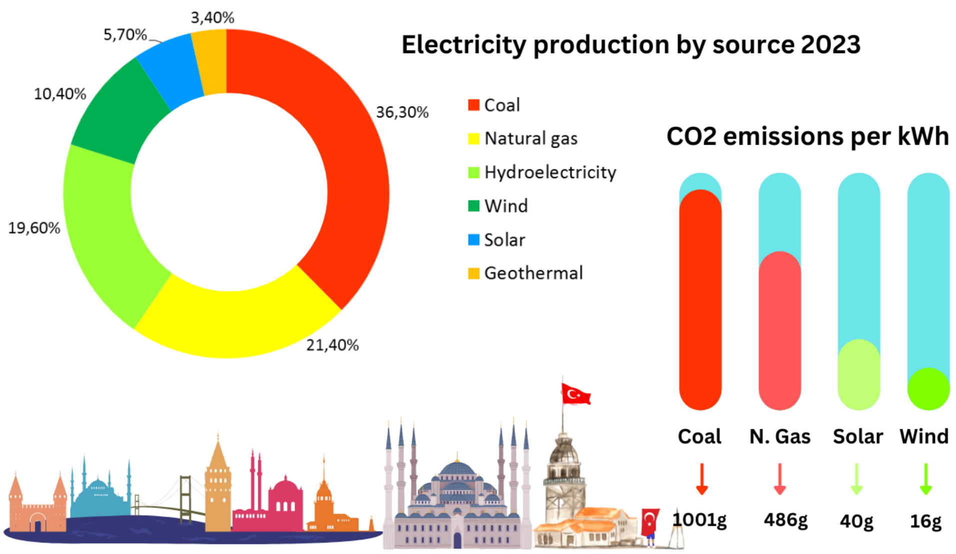
Research Results

Before diving into a thorough theoretical and econometric analysis, the energy production landscape of Türkiye must be examined (see Figure 1).

In 2023, coal hit the highest point in electricity generation with 36.3%, followed by natural gas with 21.4%. According to Figure 1, hydroelectricity is the primary source among renewable energy sources, accounting for precisely 19.6%. The other sources of electricity generation were wind (10.4%), solar (5.70%), and geothermal (3.40%) energy. Regarding the carbon emissions from these sources per kWh of energy generated, it is necessary to note that not only coal and natural gas had the largest share – coal 1001 g and natural gas 486 g per kWh – but also wind and solar energy had a carbon emission share – wind 16 g and solar 40 g per kWh.

Figure 1

Electricity production of Türkiye by sources and their CO2 emissions per kWh



Source: calculated by the author based on TÜİK (TurkSTAT), DW Planet A (2021).

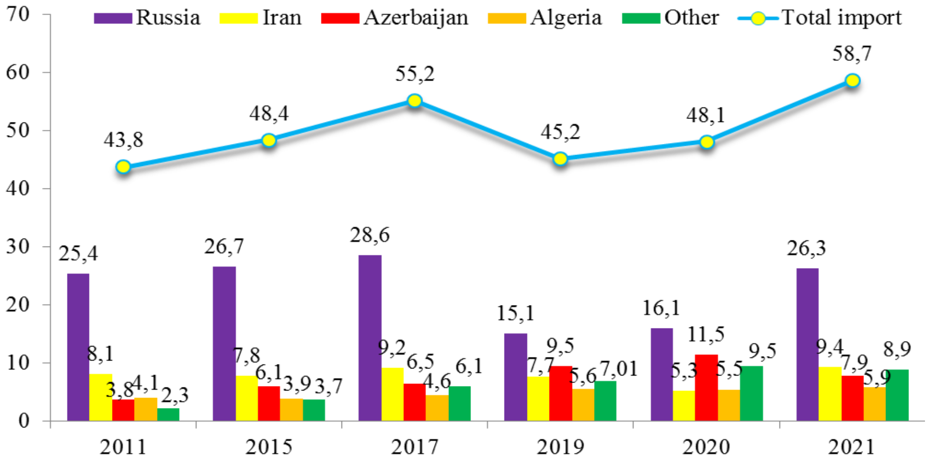
Now, the volume of imported natural gas and its country list and destinations must be analysed (see Figure 2 and Figure 3).

As seen in Figure 2, over the years 2011-2021, Russia dominated Türkiye's gas market with well over 20 billion m^3. The following countries are Iran (8-9 billion), Azerbaijan, which entered Türkiye's gas market for the first time in history in 2007 (6-11.5 billion), and Algeria (3-6 billion). The remaining countries in this category encompassing "other" include Nigeria, Qatar, and others, which represent 2.3-8.9 billion m^3 of natural gas volume. Total natural gas import volume ranges between 43.8 and 58.7 billion m^3, with an increasing trend line.

Natural gas is imported from the main supplier, Russia, via two pipelines: Blue Stream, which became operational in 2003 but was inaugurated two years later and has 16 billion m^3 of capacity, and Turk Stream, which has a maximum 31.5 billion m^3 capacity and likewise the Blue Stream, was built under the Black Sea and consists of two parallel pipelines, one of which ends at the Bulgarian border and the other at the Turkish border (see Figure 3).

Figure 2

Türkiye's natural gas import



Source: calculated by the author based on TÜİK (TurkSTAT).

Figure 3

The route of energy imported

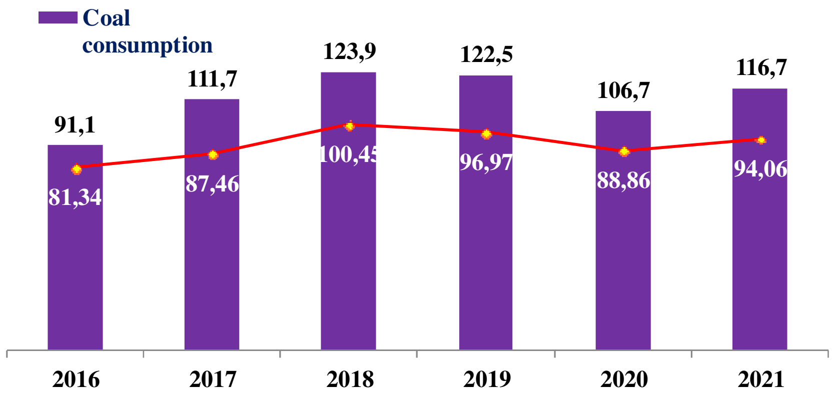
Source: made by the author based on Türkiye's International Energy Strategy.

The Türkiye-Iran natural gas pipeline (or Tabriz-Dogubeyazit) has 10 billion m^3 of annual capacity and started running operation in 2001. The South Caucasus Pipeline (SCP), the Trans-Anatolian Pipeline (TANAP, which is a part of three integrated pipeline systems with a maximum capacity of 32 billion m^3 and is currently under expansion), is delivering natural gas, while Baku-Tbilisi Ceyhan is bringing Caspian oil from Azerbaijan. The other oil pipelines stretch from Iraq to Türkiye, namely, are Erbil-Ceyhan and Kerkuk-Ceyhan.

Now, we need to look at coal production and consumption in Türkiye in 2016-2021 through Figure 4.

Figure 4

Coal production and consumption in Türkiye, MT



Source: calculated by the author based on TÜİK (TurkSTAT).

Upon initial inspection, this figure clearly indicates that coal consumption exceeds its production volume in the country; in 2021, consuming volume was 116.7 million metric tons (MT), of which 79.9 MT was utilised in electricity production while production was 94.06 MT.

After revising statistical data on coal, the hypothetical calculation of coal replacement by natural gas comes to mind (see Table 2). We incorporate a conversion method to calculate the equivalent of coal, lignite, and asphaltite in barrels of oil, which we then convert into natural gas. According to the conversion, one tonne of coal equals five barrels of oil; lignite and asphaltite come to a total of 2.5 barrels of oil. A million barrels of oil equates to 0.16 billion m^3 of natural gas.

Table 2

Hypothetical calculation of the equivalent of coal to natural gas in Türkiye 2021

<table>
<tr><td colspan="3">Coal</td><td>Lignite and asphaltite</td><td>Total (MT)</td></tr>
<tr><td colspan="3">36.7</td><td>80</td><td>116.7</td></tr>
<tr><td colspan="5">Coal consumption in electricity production, MT</td></tr>
<tr><td colspan="3">Coal</td><td>Lignite and asphaltite</td><td>Total</td></tr>
<tr><td colspan="3">19.7</td><td>60.2</td><td>79.9</td></tr>
<tr><td colspan="5">Hypothetical calculation (total coal consumption)</td></tr>
<tr><td></td><td colspan="2">The equivalent of coal to natural gas</td><td>The equivalent of lignite and asphaltite to natural gas</td><td>Total</td></tr>
<tr><td>Hypothetical demand</td><td colspan="2">36.7 MT = 29.36 bln m^3</td><td>80 MT = 32 bln m^3</td><td>61.36 bln m^3</td></tr>
<tr><td colspan="5">The equivalent of coal to natural gas utilizing in electricity generation</td></tr>
<tr><td colspan="2">Coal</td><td colspan="2">Lignite and asphaltite</td><td>Total</td></tr>
<tr><td colspan="2">15.7 bln m^3</td><td colspan="2">24.08 bln m^3</td><td>39.78 bln m^3</td></tr>
</table>

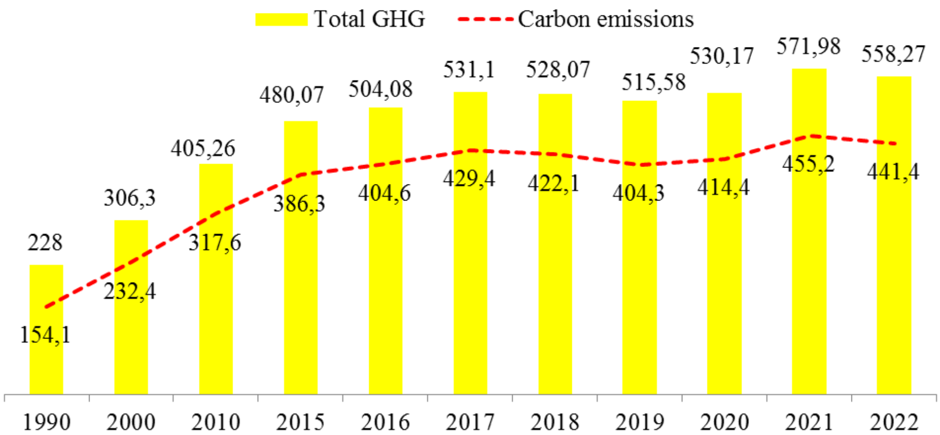
Source: calculated by the author based on TÜİK (TurkSTAT).

The complete transition from coal to natural gas is calculated as follows: the consumed 36.7 MT of coal is equivalent to 29.36 billion m^3 of natural gas, 80 MT of lignite, and asphaltite 32 billion m^3. The complete transition from coal to natural gas is calculated as follows: After conversion, the hypothetical demand indicates that Türkiye needs 61.36 billion m^3 of natural gas to replace coal, which is above the entire import amount. The production of electricity requires 39.78 billion m^3 of natural gas to replace coal, lignite, and asphaltite. At this point, if we combine annual natural gas consumption with total need, the number will stand at 120.06 billion m^3. This scenario might make people rethink doubling the annual import volume of natural gas. However, given the situation, this might not happen due to pipelines, their capacity, and the future commitment of the world with respect to transitioning to renewables. Taking into consideration the country's GHG and carbon emissions, as well as the new realities and transition efforts in the modern world, doubling the current volume of imports would be a waste of resources.

In Figure 5, Türkiye's GHG and carbon emissions have clearly been demonstrated in the years 1990–2022.

Figure 5

GHG and carbon emissions in Türkiye, MT



Source: made by the author based on TÜİK (TurkSTAT).

When it comes to carbon emissions, which are an inseparable part of GHG volume, this number surged, if possible, to say, three times over the years mentioned, and stood at 441.4 MT in 2022.

Now, replacement scenarios for coal and natural gas in electricity production via wind and solar energy have to be examined. Firstly, we must consider coal replacement by solar (see Table 3). 1 MW of solar energy produces nearly 1.700000 kWh of electricity, and installation expenses of this power vary between 730000 and 1 mln USD. Türkiye's electricity generation through coal in 2023 was 118.44 bln kWh, and in this context, Table 3 shows that the country needs 69.700 MW power capacity to substitute coal.

In relation to installation costs, an approximate calculation displays that this process might require a minimum level of 50.88 bln USD, and the maximum level of 69.7 bln USD (see Table 3). Electricity production via coal emitted 118.55 MT of CO2, and if Türkiye had entirely transitioned to solar, the emission figure would have stood at 4.737 MT CO2 or declined 25-fold.

The second theoretical analysis concentrated on substituting coal through wind (see Table 4). 1 MW of wind power generates 2.5-3 mln kWh of electricity, which is higher than solar. However, the creation of this facility also demands much higher financial allocation, roughly 4.34 mln USD. The demand for entire substitution might range from 39.48 to 47.37 MW, and the minimum cost for this would be 118.44 bln USD, the maximum 205.61 bln USD. This whole transition may emit 1.895 MT CO2.

Table 3

Coal replacement through solar energy in electricity production

1 MW solar ≈ 1.700000 kWh	
The average installation price of 1 MW	730.000-1000000 USD
Electricity production through coal in 2023	Approx. 118,44 billion kWh
Demand for solar energy to replace coal (thousand)	69,700 MW
Total cost	(Minimum scenario) 50,88 bln USD
	(Maximum scenario) 69,7 bln USD
Total carbon emissions of solar energy	4,737 mln tons of CO_2
Solar energy CO2 emissions	40 g (per kWh)
Current carbon emissions of coal	118,55 mln tons of CO_2

Source: compiled by the author.

Table 4

Coal replacement through wind energy in electricity production

1 MW wind ≈ 2.5-3 mln kWh	
The average installation price of 1 MW	4.34 mln USD
Electricity production through coal in 2023	Approx. 118,44 billion kWh
Demand for wind energy to replace coal (thousand)	39.48 – 47.379 MW
Total cost	(Minimum scenario) 118.44 bln USD
	(Maximum scenario) 205.61 bln USD
Total carbon emissions of wind energy	1,895 mln tons of CO_2
Wind energy CO2 emissions	16 g (per kWh)
Current carbon emissions of coal	118,55 mln tons of CO_2

Source: compiled by the author.

Table 5

Natural gas replacement through solar energy in electricity production

1 MW solar ≈ 1.700000 kWh	
The average installation price of 1 MW	730.000-1000000 USD
Electricity production through gas in 2023	Approx. 69.82 billion kWh
Demand for solar energy to replace gas (thousand)	41.07 MW
Total cost	(Minimum scenario) 29.98 bln USD
	(Maximum scenario) 41.07 bln USD
Total carbon emissions of solar energy	2.792 mln tons of CO_2
Current carbon emissions of gas	33.93 mln tons of CO_2

Source: compiled by the author.

Table 6

Natural gas replacement through wind energy in electricity production

1 MW wind ≈ 2.5-3 mln kWh	
The average installation price of 1 MW	4.34 mln USD
Electricity production through gas	Approx. 69.82 billion kWh
Demand for wind energy to replace gas (thousand)	23.27 – 27.92 MW
Total cost	(Minimum scenario) 104 bln USD
	(Maximum scenario) 121 bln USD
Total carbon emissions of wind energy	1,117 mln tons of CO_2
Current carbon emissions of gas	33.93 mln tons of CO_2

Source: compiled by the author.

After examining the coal replacement, we must turn to the second major source of electricity production, natural gas, and its substitution scenarios (see Table 5). In 2023, burning natural gas both produced 69.82 bln kWh of electricity and 33.93 MT of CO2. In-demand capacity for total solar transition is 41.07 MW, CO2 emissions of which might be 2.792 MT.

The final calculations consider the moving from natural gas to wind power, and Table 6 clearly illustrates that the establishment of this 23.27-27.92 thousand power infrastructure would swing between 104-121 bln USD. Its CO2 emissions amount comes to a total of 1.117 MT, and this outcome for an energy-intensify country with respect to emissions can be called a favourable situation.

The next stage of the research is dedicated to analysing the relationship between population growth and electricity production in Türkiye. To this end, initially the Pearson correlation was conducted and then, to be more precise, the Spearman correlation (see Table 7 and Table 8).

Table 7

The Pearson correlation between population growth and electricity production

		Total electricity bln kWh	Population mln
Total electricity bln kWh	Pearson Correlation	1	.986**
	Sig. (2-tailed)		.000
	N	13	13
Population mln	Pearson Correlation	.986**	1
	Sig. (2-tailed)	.000	
	N	13	13

Source: compiled by the author.

Table 8

The Spearman correlation between population growth and electricity production

			Total electricity bln kWh	Population mln
Spearman's rho	Total electricity bln kWh	Correlation Coefficient	1.000	.989**
		Sig. (2-tailed)	.	.000
		N	13	13
	Population mln	Correlation Coefficient	.989**	1.000
		Sig. (2-tailed)	.000	.
		N	13	13

Source: compiled by the author.

The tables were formulated on the basis of population growth and electricity production in Türkiye in the 2010-2022 periods. The Pearson correlation demonstrated that relations between the two aforementioned variables were quite strong (0.986), which is almost near 1. Furthermore, the Spearman correlation proved this relation once again, 0.989, higher than that of the Pearson.

After carrying out two correlations, we can confidently perform a regression analysis to uncover and determine relations between these two parameters (see Table 9).

Table 9

Regression analysis between population growth and electricity production

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	-515.789	40.242		-12.817	.000
	Population mln	9.987	.507	.986	19.690	.000

Coefficients [a]. Dependent Variable: Total electricity bln kWh.

Source: compiled by the author.

When Sig. value is less than $p<0.05$ value, it is considered valuable, and in this calculation (Table 9), the value (Sig .000) shows that the interconnection is extremely noteworthy. The simple linear regression analysis means the following:

$$Y = -515.789 + 9.98 \times X + 40.242. \qquad (3)$$

This regression analysis proves that a 1 unit increase in population boosts electricity production by 9.98. Yet, this regression does not mean that the relationship between electricity production and population growth will be the same. In order to look at and scrutinize the relationship, we need to analyse the opposite option, in which the dependent variable is population, and the independent one is total electricity production (see Table 10).

Table 10

Regression analysis between electricity production and population growth

Model		Unstandardized Coefficients		Standardized Co-efficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	52.406	1.376		38.082	.000
	Total electricity bln kWh	.097	.005	.986	19.690	.000

Source: compiled by the author.

The constructed regression analysis shows the reality that the Sig.000 is also less than the $p<0.05$ values and it means the relationship is significant. The primary interpretation of the analysis is the following:

$$Y = 52.406 + 0.097 \times X + 1.376. \quad (4)$$

According to the outcome, a unit increase in total electricity production means bolstering the population growth by 0.097. As for population growth in Türkiye, predictions made by the International Monetary Fund depict an increasing trend line, reaching the number of populations to 90 million until 2028, which currently is 85 million (International Monetary Fund, 2024).

Practical Implementation

The research released average expenses in relation to transitioning to wind and solar power. The results gained by hypothetical calculation demonstrate how much money is needed to build clean energy infrastructure. Besides that, regression analysis has determined the relationship between population growth and electricity production, and Türkiye's government, as well as other countries' researchers, may consider these outcomes for future implementation and explore further, respectively.

Conclusions

Türkiye's hypothetical transition to renewables, especially in the area of electricity production, was the center topic of this research. In addition to this, correlation and regression analyses were performed to unveil the link between electricity production and a number of populations. The main findings of the research are placed below:

1) Transition from coal to solar and wind power is estimated to be 50.88-69.7 bln and 118.44-205.61 bln USD, respectively. With respect to CO_2 amount, even if in solar transition this figure would be 4.737 MT, in wind transition it would be 1.895 MT on condition that the electricity volume generated by coal is stable.

2) In order to stop burning natural gas in electricity production, Türkiye should allocate 29.98-41.07 bln to ensure the entire solar transition, while putting aside 104-121 bln to shift to wind. The approximate CO_2 amount would stand in solar: 2.792 MT, in wind: 1.117 MT, on condition that the electricity volume generated by natural gas is stable.

3) To substitute coal through natural gas not only in electricity production but totally, the required amount of natural gas is 61.36 bln m^3. In electricity production, this amount might stand at 39.78 bln m^3.

4) The Pearson and Spearman correlations were conducted to disclose the connection between population growth and electricity production. The study proved the strong correlation between these two variables, following regression analysis was conducted, and the outcome would be visible: a unit increase in the number of populations elevates electricity production by 9.98.

5) Nevertheless, the regression analysis mentioned above does not prove the connection vice versa, in which electricity production is independent and population growth is dependent. The result showed that a 1% rise in electricity production bolsters population growth by 0.097.

Shifting from fossil fuels to clean energy forms is the objective of heat-debated discussions owing to financing. The scientific novelty of this research casts light on how much finance is needed for the total transition from hydrocarbons (coal and natural gas) to renewables (wind and solar energy), as well as how much natural gas is demanded to stop using coal entirely in one country's example and paves the way for further studies to elaborate on other countries' transition expenditures.

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