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How Realistic Are Coal Phase-Out Timeline Targets for Turkey?

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Abstract: Coal phase-out is considered to be critical to the success of energy transition for all countries. Yet, recent assessments indicate that energy security aspects may affect phase-out plans and/or commitments and jeopardize energy transition ambitions. This study aims to question to what extent coal phase-out targets for Türkiye are realistic. Although previous research has mainly focused on direct emission reduction targets and just transition aspects, we include a down-to-earth discussion of the potential challenges before coal phase-out. The interaction between phasing-out coal power generation and energy security aspects is also analyzed. To understand the coal phase-out timeline targets, its limitations, and constraints within the framework of future power projections, a supply–demand model with different scenarios was developed. In addition, energy storage was also discussed as an option. Analysis revealed that energy storage, in the short- and medium-term, may not be the panacea, as it may not be deployed in the scale to substitute the energy security that coal provided. Moreover, our findings indicate that phasing-out is not as simple as assumed. A target timeline is certainly not realistic considering the energy security aspect and challenges. On the other hand, economically nonviable and technically nonavailable coal-fired power plants in the power system may retire gradually (as a natural phase-out process). This may occur even without waiting for the target timeline, if there would ever officially be one.

Keywords: energy security; coal-fired power generation; variable renewable energy; coal phase-out; coal exit; energy storage

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1. Introduction

Fossil fuels, namely, oil, gas, and coal, have been the main energy sources for several centuries. Currently, more than 8 billion tons of coal are mined in more than 40 countries annually. For power generation, coal has been the preferred source. It served more than half of the additional power demand in 2021, growing faster in absolute terms than renewable energy for the first time since 2013. Coal power's share today accounts for nearly the same as two decades ago [1]. In OECD countries, the share of electricity generation from coal fell to 25.2% in 2018, down from 44.4% in 1985 [2]. However, in 2021, coal-fired power generation reached an all-time high globally, increasing by 8% and reversing the declining trend over the previous two years. Today, coal accounts for close to 40% of electricity generation worldwide [3]. It has achieved its pre-eminence based on its stable, reliable, cheap sourcing, easy logistics, and wide availability. In other words, it has a high score regarding energy security. Recently, various factors, like higher gas prices and sanctions on Russia, as well as unexpected weather conditions that led to lower hydro and nuclear power generation, caused a surge in coal usage.

On the other hand, coal-fired power plants are responsible for about 80 percent of the energy sector's CO_2 emissions. Coal is thus at the forefront of the priority sectors that are subject to energy transition. Increasing awareness of the consequences of climate change flamed the discussion of coal phase-out. The EU aims to be climate-neutral by 2050 and Türkiye commits to achieving net zero emissions by 2053. It does so with the awareness of the requirements for major changes in many economic sectors, as well as the deep decarbonization of the power sector. At the United Nations Framework Convention on Climate Change 26th Conference of Parties (UNFCCC COP26), more than 40 countries pledged to end all investment in new coal-fired power generation domestically and internationally. The International Energy Agency (IEA) highlights that global unabated coal use in the energy sector must fall 55% by 2030 and be phased out entirely by 2040 to reach net zero emissions by 2050 [4]. The diminishing cost of solar and wind as well as new storage technologies, together with the need to comply with the Paris Agreement's 1.5 °C limit, led to a momentum to phase-out coal for power generation in Europe. Belgium, Austria, and Sweden have already abandoned coal. Germany agreed to this goal for 2038, but discussions are ongoing to terminate it by 2030. Other declared dates include the Czech Republic by 2033, Hungary by 2053, Italy by 2025, Greece by 2028, the Netherlands by 2029, and Poland by 2049 [5,6]. Türkiye projects that electricity generation by coal-fired power plants, which has had a share of 34.5%, will decrease by 2035 [7].

Although limiting fossil fuel consumption and transitioning away from coal to a renewable-based energy system for compatibility with the Paris Agreement and Sustainable Development Goals (SDGs) are considered to be a pivotal issues, there are, however, serious challenges to be faced before coal phase-out timelines can be achieved, thus jeopardizing energy transition ambitions. Furthermore, "the importance of coal for energy security" is at the center of the debate. As defined by the IEA [8], energy security enables "the uninterrupted availability of energy sources at an affordable price". Diversification of resources and ensuring the protection from external shocks are also important dimensions of the concept [9,10]. In the wake of the Ukrainian conflict, and the ensuing energy crisis, the role of coal for energy security has risen to the prominence in public discourse. Although a large deployment of energy storage can be a solution, it is no panacea in the short- and medium-term to replace the energy security that coal has so well provided. Additionally, coal phase-out requires an enormous shift in resources and employment. Its effect on the electricity market should not be ignored. The single most important source of electricity in the third decade of the 21st century is still "old king coal".

Although studies in the literature are limited, the research on coal phase-out has mostly focused on direct emission reductions targets and the just transition aspect. The World Bank Report, "Global Perspective on Coal Jobs and Managing Labor Transition out of Coal" [11], analyzes the status of coal phase-out around the world. It includes Türkiye, affirming the magnitude and character of coal mining jobs and their spill-overs in the local economies, and the challenges associated with future labor transition. Concerning the future of coal in Türkiye, there are several studies (with some even including phase-out target years). The first study, First Step in the Pathway to a Carbon Neutral Turkey: Coal Phase out 2030 Report [12], reflects a think-tank's perspective and foresees a coal exit by 2030 by claiming that the carbon emissions from the power sector would be decreased by 82.8% in 2035, leaving the emissions at 27.6 million tons of CO_2 by 2035. The Türkiye National Energy Plan [7], published at the beginning of 2023, reveals the country's official view, with no mention of phase-out, but rather an emphasis on market conditions. The Shura Report [13], published during the final stage of this study, forecasts a phase-out by 2035. It anticipates a gradual reduction in the operation of the least efficient coal power plants by 2030, with the complete cessation of coal usage soon after. Apart from other studies, this study will focus on the role of coal in the Turkish power system, with an acceptance that the reduction in coal-fired power emissions may indeed be necessary for climate policy, but it should also make sense with a view to the electricity market and energy security.

To sum up, this study aims to discuss the mentioned coal phase-out timelines for Türkiye by questioning to what extent such target years for Türkiye are realistic. The study includes a comprehensive discussion of the challenges before phase-out, with the focus on the interaction between phase-out and energy security aspects. As a novel approach, we reflect on the outcome of a thorough assessment of the lifetimes of coal power plants.

Perspectives of policy makers and legislation in force are also brought to light. Sometimes we use the "phase-out" and "exit" terms interchangeably, but they may also be used as nonidentical terms. This is to highlight the differences between them by showing that economically nonviable and technically nonavailable coal-fired power plants will be retired naturally regardless of a target timeline.

The study also attempts to examine the relationship between coal capacity and energy storage requirements. In this context, several scenarios were developed to understand the limits of coal phase-out within the framework of future power demand projections, expectations, and targets. All relevant technical parameters, past data on electricity generation, possible technological advances, market developments, and current and prospective policy choices were used in our analysis.

This paper is presented in four sections. Following the Introduction, Section 2 explains the coal-fired power generation–energy security interaction from a historical and analytical view, including a description of coal consumption patterns in the Turkish power market. The challenges ahead of an assumed coal phase-out are discussed in Section 3. Section 4, after clarifying the official policy of Türkiye for the future power structure, deeply engages in the coal phase-out question and introduces scenarios accordingly. Finally, it discusses the results of the scenarios and presents its findings and conclusions regarding the factuality of phase-out/exit timeline targets for Türkiye.

2. Literature Review

2.1. Coal-Fired Power Generation

2.1.1. Coal Power from a Historical Perspective (Globally and in Türkiye)

Coal has been used as an energy source for over 4000 years, but its utilization for power generation began in the US only in the 1880s [2]. Coal became the main source of electricity globally in the last century as more and more central large power stations were erected after World War II [14]. Over time, the output (from 1 to 900 MW) and efficiency (from 1.6% to 45%) of the plants have been improved [15]. In 1949, global power generation was 840 TWh, two-thirds (531 TWh) being from thermal (mostly coal) sources. As of 1973, after the inception of gas and nuclear power, coal had kept its dominance by 38%, nearly the same as today [16]. In the US, the 1970s energy shocks inspired coal to claim the title of "the great Black Hope of America", and many oil and gas plants switched to coal [17]. Coal was equated with the national energy security concept [18]. It still meets 22% of power demand, even higher than fast-growing renewables [19]. Coal also played a major role in the history of the European Union. It had firmly established itself in the foundations of the European Coal and Steel Community in 1952, and became the fuel of choice for power. With the Kyoto Protocol, however, the EU committed to an 8% cut in its greenhouse gas emissions (GHGs) by 2012, and promoted renewables, culminating in coal phase-out policies. Since 2017, although renewables have been the dominant power source, coal still has a sizable (16%) share [3].

Coal has always been an important energy source in Türkiye. Figure 1 shows Türkiye's primary energy supply amounts and ratios over time [20].

Coal for power generation has always been significant, and until the 1970s, it had a share of more than 50% in the market. The main sources and their shares in the Turkish power mix in the last four decades are shown in Figure 2 [21].

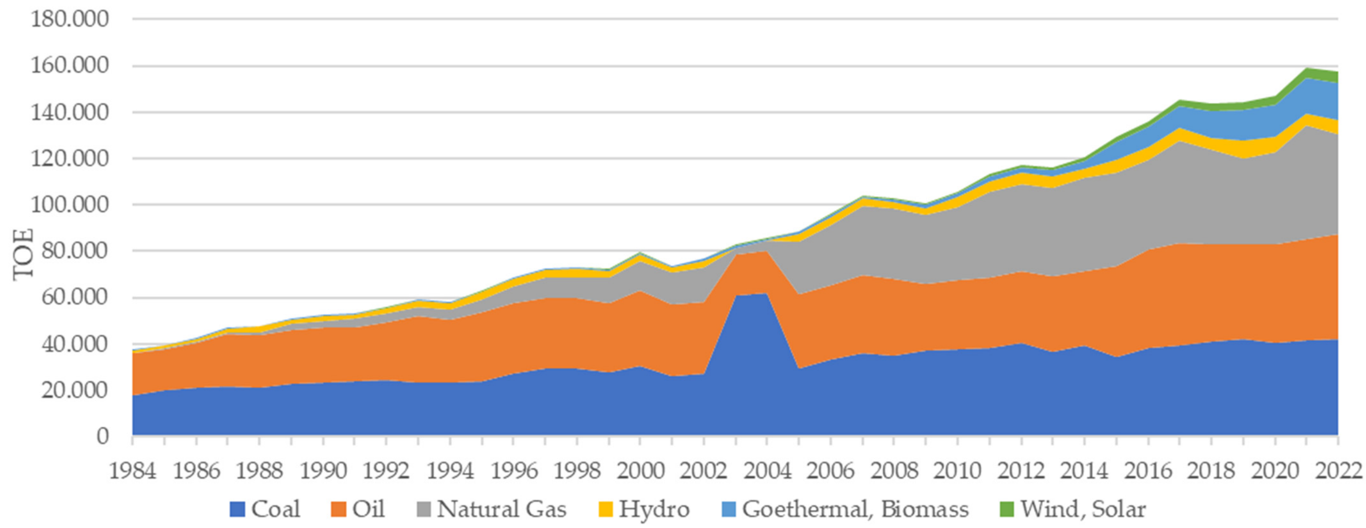

Figure 1. Primary energy supply of Türkiye (1984–2022).

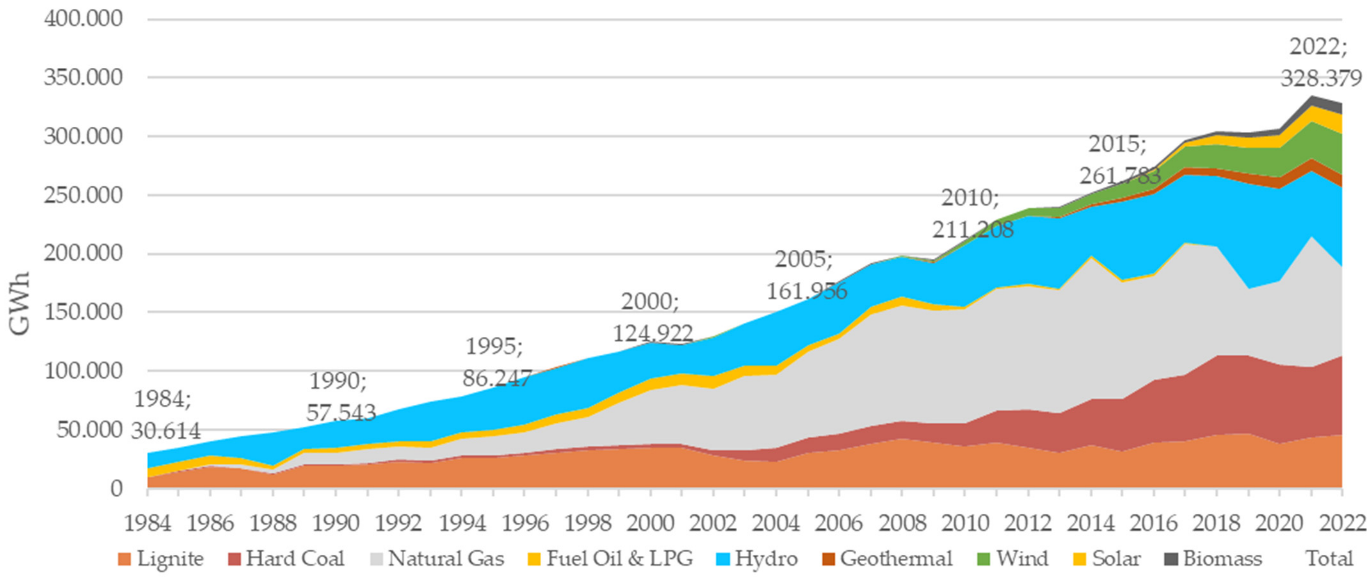

Figure 2. Electricity generation and fuel composition of Türkiye (1984–2022).

Although coal mining can be traced back to the late 19th century, modern and well-documented lignite exploration activities started in the 1970s [22]. The significance of coal became evident during the oil crisis of the 1970s. Annual coal production totaled 12 million tons in the 1970s, 18 million tons in 1980, 47 million tons in 1990, and further increased to 63 million tons in 2000. Driven by the government's strategy to utilize domestic resources, coal production surged to 94 million tons in 2022 [20]. The coal reserves of Türkiye are quite dispersed, but mostly located in Marmara, the Aegean, and the upper Mediterranean regions. Hard coal is mined only in the Zonguldak basin. The total reserve is reported as 20.8 billion tons [23], more than 90% of which is low-rank coals [24]. However, some industry analysts approach reserve figures with caution and warn that these may not be sound [25]. Table 1 lists the major reserve areas that are deemed suitable for electricity generation.

Table 1. Major coal fields in Türkiye, including those recently explored.

Basin Name	Total Reserve *Thousand Tons*	Owner and Operator	Used in Electricity Generation
Afşin-Elbistan	4,807,500	EUAS–TKI	√
Konya-Karapınar	1,832,816	EUAS	-
Eskişehir-Alpu	1,453,000	EUAS–TKI	-
Çayırhan	410,300	EUAS	√
Afyon-Dinar	941,440	EUAS	-
Tekirdağ-Merkez	211,520	EUAS	-
Manisa-Soma	800,000	TKI–Private	√
Adana-Tufanbeyli	323,329	TKI	√
Kırklareli-Vize	271,186	TKI	-
Tekirdağ-Saray	143,729	TKI	-
Kütahya-Tunçbilek	117,000	TKI	√
Bingöl-Karlıova	103,662	TKI	-
Konya-Ilgın	143,000	Private	-
Edirne	99,000	Private	-
Çankırı-Orta	94,390	Private	√
Tekirdağ-Hayrabolu	73,000	Private	-
Kırklareli-Pınarhisar	67,700	Private	-
Amasya-Suluova	64,000	Private	-
Adıyaman-Gölbaşı	32,000	Private	-
Total	**11,988,572**		

The first large coal-fired power plants were commissioned in the late 1950s in two major lignite basins, Soma and Tuncbilek. Coal-fired power plants have always been a must-have part of the Turkish electricity grid. In the decades from the 1970s to the 2010s, the local coal-fired generation capacity consistently increased. Recently, however, imported hard coal plants had a high rate of increase, reaching 10 GW and with a generation amount of 66 TWh in 2022, surpassing the generation amount of local coal, which is 44 TWh [20]. They are considered to have higher efficiency, better environmental compliance, and more flexibility to run based on market conditions. Figure 3 illustrates the development of domestic and imported coal capacity in Türkiye over time.

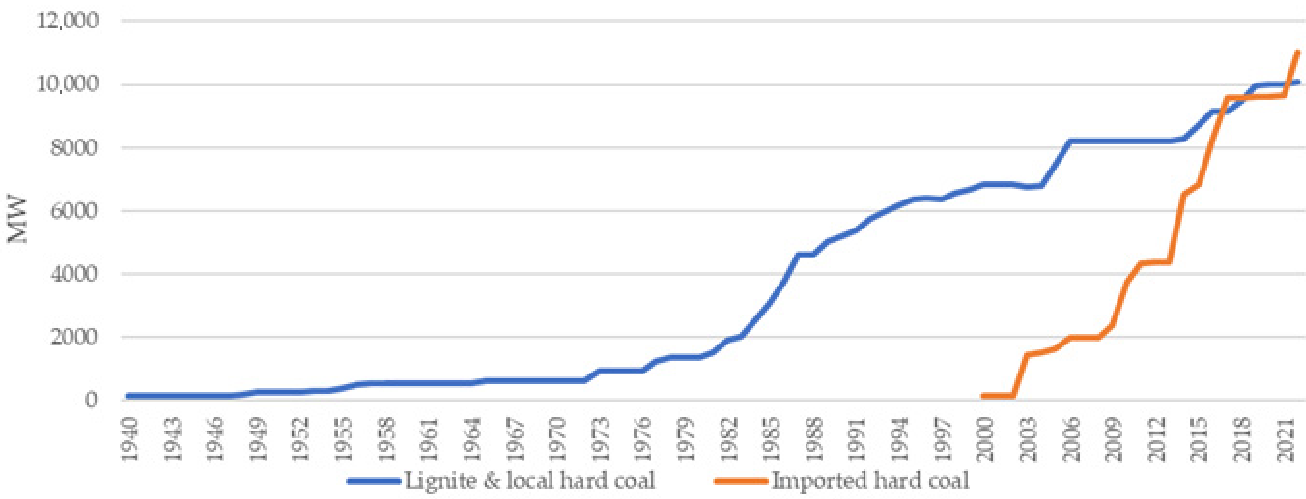

Figure 3. Development of Coal Fired Power Plant Capacity in Türkiye (1940 – 2022).

It is important to note at this point that, despite many new coal field explorations and government policy support, relatively few small and midsize (and all privately held) new domestic coal-based power plants (including Tufanbeyli and Soma-Kolin) with a capacity of 1900 MW have been installed in the last decade, with the last being in 2019 [26]. Some projects that aim to utilize large reserves have either been canceled or proven to be very difficult to develop so far (i.e., Çayırhan-B, Ilgın, Konya-Karapinar, Afsin-Elbistan-C, Afyon-Dinar, Eskisehir-Alpu, Amasra, etc.). Table 2 shows the summary of the current license status of domestic coal projects. Although the reported reserves increased more than 50% in the last decade, from 12 billion tons in 2013 [24] to 20 billion tons, the increase in domestic coal power capacity was only 20%, and the actual power generation increase was a mere 4 TWh (10%), from 41 TWh to 45 TWh. As a result, the expectation of the government and some analysts that domestic coal would decrease dependence on imported fuels has not been realized, as the increase in the power demand was much higher. The main reason for the recent very slow development of local capacity is because suitable models of project development have not been found in most cases. Some sites are deemed unfeasible due to coal quality or geology. Investors are unwilling in general despite buying guarantees from the government. The main reasons for that are financing difficulties, uncertainties in the economic environment, and high market volatility, as well as concerns of stranded asset status due to future carbon regulations [27].

Table 2. Local coal-based project stock status.

License Status	Project Status	Projects	Capacity (MW)
Prelicense	Under evaluation	3	38
	Canceled	16	3426
License	Operational	37	10,743
	Canceled	19	8275
Total Capacity of Local Coal Projects			22,532
Project Realization Ratio Operational Project Capacity/Total Project Capacity			48%

Personal study based on open data of EMRA sources [28].

In sum, in the last 50 years, coal has provided one-third of Türkiye's electricity on average. Nevertheless, the overall coal capacity is now barely 21 GW, and the usage ratio (34.5%) is still below the world average and fast-industrializing countries, like China, India, Poland, South Africa, and other South Asian countries.

2.1.2. Coal-Fired Power Generation and Energy Security Interaction

Two-thirds of coal production have been used for electricity generation worldwide. The energy crisis that emerged with the Ukrainian conflict made energy security more salient than climate change concerns. Coal consumption (in the EU and Türkiye) increased in 2021 and 2022 [23,29,30]. In 2022, coal power generation in Türkiye also rebounded to 113.6 TWh, with a 10% rise year-on-year [31,32].

The Russian–Ukrainian conflict has sharply altered the dynamics of global energy markets in 2022, making energy security a vital concern [1,29]. The EU is one of the regions hardest hit by the crisis and has undergone a significant fuel switch to coal [33]. Additionally, some issues with hydro and nuclear power output are due to weather conditions, which put more strain on the European electricity system. In response, some 26 coal plants that had previously shut down or been left in reserve have re-entered the market. Coal-based electricity generation rose by 6.7, from 419 TWh in 2021 to 447 TWh in 2022. This pushed coal's share in the electricity mix from 14.5% in 2021 to 16% in 2022 [34,35].

Coal can be said to have a multidimensional interaction with energy security. First, in terms of access to primary resources, as well as the availability and reliability of its supplies, it has a huge advantage over other resources, including gas and oil. It is not used as a strategic tool or political weapon. Therefore, the crisis surged the use of coal by 9% in 2021, and it is expected to remain high until 2024 [36–38]. In fact, in nearly all past crises, the share of coal increased exactly when a decline had been expected [39].

The second aspect regarding the coal and energy security interaction is the adequacy and reliability of power generation, including grid stability. The importance of this issue is frequently raised due to the variability and intermittency of renewable energy (RE).

It is often asserted that RE is able to meet all our power needs. However, experts have determined that integrating intermittent wind and solar, "VRE", into the power mix is not easy because VRE, unlike "base-load" (controllable) or "dispatchable" (ready-to-run) conventional power sources, like thermal and nuclear, varies over time and as per weather conditions [40]. Indeed, the rapid growth of VRE has paradoxically caused a rise in the need for back-up thermal capacity [41–43].

In short, as is evident from the foregoing account, amid shortages or the unavailability of other sources of energy for a variety of reasons, to enhance energy security, countries resort to using more coal.

2.2. The Challenges Facing the Coal-Fired Power Generation Phase-Out

We tried to review the role that coal has played in reliable electricity generation. As it is also one of the main culprits contributing to climate change, there are efforts to reduce and eventually end the use of coal. That is, however, proving no easy task. For the intended coal phase-out plans/targets to become reality and for the world to wean itself off the coal, there are certain challenges which need to be overcome. This part of the study aims to explain the most important technical and nontechnical challenges that affect a coal phase-out discussions.

2.2.1. Technical Challenges

As noted earlier, coal is the single most important fuel for electricity generation. "The possibility of safe long-term storage of coal on site of the power plant makes it the most reliable source for base-load electricity generation" [44]. Moreover, coal plants are given a back-up role to VRE. There is, on the other hand, the global promotion of the use RE instead of fossil fuels. RE will become the largest source of global power generation by 2025 [45]. However, as Vos and Sawin mentioned [46], faster RE deployment faces many issues, like the availability of material supplies and environmental concerns. Moreover, intermittency is the main technical reason that limits the level of RE which can be incorporated into a grid without compromising the overall reliability.

Geopolitics, as happened in the gas crisis with Russia, can also play a very adverse role for VRE deployment. For example, China now has a 90% share in the solar equipment supply chain and will remain dominant in the future [47]. In the event of an international crisis, so high a dependence rate of the world on China may likely trigger a serious setback to the expected solar boom [48]. Moreover, increasing geopolitical competition over critical materials for RE and battery technologies may cause supply-chain bottlenecks [49].

Grid connection unavailability is another major issue. Connection queues already have become an enormous challenge. For example, the UK's existing renewable capacity is about 50 GW, but 200 GW additional projects are awaiting grid connection. The average time to receive a grid connection right is about 4 years in the developed world [48]. Other challenges are the slow and cumbersome permit processes and growing local resistance. Some scholars draw attention to "the well-known paradox of public support for sustainable energy transition on the one hand and local resistance to the expansion of renewable energy technologies, on the other". Although it is assumed that energy transition is generally supported by public opinion, it is often overlooked because, in the end, "the implementation of RE at local level is not a technical but rather a political challenge characterized by trade-offs" [50]. Lawsuits, regulatory troubles, and inadequate energy infrastructure pose challenges which are key to RE deployment.

As will be discussed below, energy storage is an important tool for the utilization of RE. However, even if the abovementioned hurdles can be overcome, it is unclear whether storage technology would be deployed sufficiently.

2.2.2. Nontechnical Challenges

The energy transition process involves risks while creating new sectors, investment, and employment alternatives. It obviously causes the shrinkage in the coal sector, with jobs and income loss for sector employees [51]. Therefore, determining legal, financial, and structural policy measures suitable to support phasing-out and ensuring a fair transition by preserving the social and economic structure are of importance. Moreover, phasing-out should offer a plan to invest in and provide a transition to environmentally and socially sustainable jobs, sectors, and economies [52]. As discussed by Krawchenko and Gordon [53], the harmful impacts of industrial transitions on workers and communities should be minimized. During the process of just transition, it is important to construct a sustainable socioeconomic structure by effectively implementing mechanisms for social dialogue [54]. This entails generating sustainable employment opportunities, providing education for vulnerable groups, and establishing support mechanisms.

According to the IEA [55], the renewable energy sector has the potential to create 70% more jobs per million USD invested, on average, compared to fossil fuel energy. However, the ability to shift employment from high-emission sectors to RE, and to also compensate for the job losses, depends on various factors. These would include the compatibility of labor market flexibility and incentives for investing in low-carbon sectors [56]. Retiring coal plants without creating proper restructuring plans and compensating the affected parties may be economically and politically disastrous [57]. At this point, the financing of coal phase-out emerges as a major challenge.

Coal is a socioeconomically important mining sector in Türkiye and it makes a sizeable contribution to the national economy. The Mining Industry Development Report [58] revealed that, in 2019, the number of laborers working in the extraction of coal and lignite was 36,436. Compared to 2010, this figure had decreased by 27%. This does not include those in the economic value chain and coal power plant workers. In fact, the economies of some provinces or towns (Zonguldak, Soma, Elbistan, Çayırhan, etc.) heavily depend on coal mining activities or coal-fired power plant operations. For example, in Zonguldak, which has a long history with coal, although the numbers have been steadily declining, more than ten thousand people are employed in the sector in numerous coal mines and several power plants. This figure corresponds to around 10% of the total employment of the province [59,60]. In Soma, this ratio is estimated to be much higher, as approximately fifteen thousand are employed in coal-related industries in a town with a total population of one hundred and seven thousand [61]. There is no study or report in Türkiye addressing the need of a just transition or its related costs.

Türkiye has been a party to the United Nations Framework Convention on Climate Change (UNFCCC) since 2004 and the Kyoto Protocol since 2009. It had also belatedly signed the Paris Agreement. Türkiye has declared a net zero emission target by 2053 and updated its Nationally Determined Contribution (NDC), with the commitment to cut its emissions by 41% from the business-as-usual (BAU) case by 2030. Accordingly, it is expected that targets and policies will be updated more aggressively for the purpose of reducing carbon emissions. RE and energy efficiency are seen as the pioneer tools for tackling climate change. Simultaneously, however, the National Energy and Mining Policy prioritizes the usage of domestic coal in addition to RE. To reduce dependency on import fuels, especially natural gas in power generation, the Turkish government is trying to utilize domestic coal reserves.

2.2.3. Energy Storage as an Option

Energy storage systems (ESSs) are regarded as the most effective choice to ensure a proper balance between power generation and demand, avoiding insufficiencies or excess generation (causing system overload) at times [62]. Therefore, if RE can be stored and then used in a controlled manner at scale as needed, energy transition will accelerate to a great extent.

Currently, Li-ion batteries and pumped hydroelectricity bear the main responsibility for storage, and they are anticipated to maintain their dominance in the future, alongside the rise of hydrogen fuel cells. As our interest is power generation, we will examine battery energy storage systems (BESSs), or rather, long-duration energy storage (LDES) systems that are used for electricity storage and the regulation of the grid. Li-ion batteries are popular due to their quick charging and discharging capabilities, but they may not suffice for scaling storage needs. The pace of advancement is slow, but the cost has fallen to USD 150 from USD 1500 a decade ago. The system cost of grid-scale Li-ion application, however, is around EUR 350/kWh, and for home storage systems, it was roughly twice that [63]. Only very-short-term balancing and voltage regulation can be performed by batteries and, in some places, battery storage is feasible to replace the "peaker" gas plants previously used to deal with over-the-top demand [64]. However, Li-ion batteries are found economically uncompetitive when it comes to LDES applications, defined by periods longer than eight hours. In addition, Li-ion batteries have safety and sustainability issues. Extra measures are required to predict and prevent thermal runaways. There is a range of LDES technologies available, which include redox flow batteries, metal–air batteries, and thermal and mechanical energy storage. Each is at a different level of maturity and market readiness. Yet, while they are promising, efforts should be made to reduce the costs and enlarge the scale [65]. These new technologies are said to have the potential to provide greater storage capacities, longer lifespans, and cost-effectiveness, making them critical to achieving sustainable energy systems. In the meantime, the race to develop higher-volume, longer-duration, more flexible, more reliable, recyclable, and cheaper batteries is ongoing. But the challenge is also so formidable that, for example, according to the Sustainable Development Scenario (SDS) of the IEA [66], there is a great need for 10,000 GWh supercapacity batteries. This requires roughly 50 times as much of today's capacity to meet the demand by 2040.

Worldwide, 10 GW/22 GWh of battery storage was deployed in 2021. Global cumulative installments reached 27 GW/56 GWh in 2021. The European share is 4.6 GW/7.7 GWh (14%), with 2.2 GW/3.7 GWh. Nearly half of the global capacity is in China. By 2040, the EU is expected to reach 160 GWh/ 80GW, 15% of the global share [63]. From today's perspective, however, despite this fast increase, a massive deployment, which would solve the intermittent power problem, seems to be far into the future. In the case of Germany, for example, energy security is largely unaffected by the penetration (up to 45%) of VRE, but further expansion will necessitate a battery solution [67]. It could currently be handled only by fossil fuel power plant back-ups.

3. Projecting the Future of Coal Power Generation for Türkiye (Phase-Out or Business-as-Usual?)

3.1. Materials and Methods

To understand the limits of coal phase-out/exit in Türkiye within the framework of future power demand projections, two related studies are examined, namely: (a) First Step in the Pathway to a Carbon Neutral Turkey: Coal Phase out 2030 [12] and (b) Türkiye National Energy Plan [7]. Afterwards, we adopted an empirical approach and developed scenarios based on Supply and Demand Model.

3.1.1. APlus Report, 2021

This report reflects a nongovernmental organization's perspective and argues that coal exit by is possible by 2030 if the below conditions can be met:

1. Reaching a 101 GW solar and wind capacity (20% higher than official targets);
2. The elimination of incentives for coal plants and the introduction of a carbon price;
3. A 136 GWh battery capacity.

We believe that this study exaggerates the effect of coal incentives in the market. As long as a baseload demand exists, without the need for incentives, there would be coal-generation. In fact, the Turkish grid operator (TEIAS) capacity mechanism incentives are more geared towards gas plants than coal plants, and do not even exist for imported coal power plants. Moreover, today's available information (as explained above) indicates that the assumption of this model for battery capacity (136 GWh) is unfeasibly high. For these reasons, the timeline of this study is not realistic.

3.1.2. Türkiye National Energy Plan

The Türkiye National Energy Plan (the Plan) reflects the official view covering until 2035 (with projections up to 2053), released in 2023 [7]. While considering the supply security, the very first sentence of this Plan states that it was developed in accordance with a 2053 net-zero emission target. According to the Plan, the installed capacity would be nearly doubled to reach ~190 GW, with most of the additions coming from solar (52 GW) and wind (30 GW). This would bring the share of RE and VRE in the installed capacity to 65% and 44%, respectively. Due to the high share of intermittent power, and projecting the need for flexibility, the Plan predicts a battery capacity of 7.5 GW (2 h-15 GWh). It also includes a nuclear power target of 7.2 GW. For coal, the Plan foresees an addition of 1.7 GW domestic coal-fired capacity by 2030. For the question of gas, it assumes that "approximately 10 GW new Combined Cycled Power Plant (CCGP) may be put into operation by 2035" for the system needs of flexibility and reliability.

The Plan takes "energy security and reliable power concerns" into account. Therefore, although the share of coal-fired generation will gradually be diminished, coal plants will stay in the system through 2053, at least with reserve capacity. However, the Plan adds a note of caution by stating that "carbon prices will play a key role in the electricity generated by coal-fired plants". In case the investment costs decline, coal-fired plants with "integrated carbon capture and storage technology" might be in sight. It is also mentioned that "the capacity support mechanism applied to base/flexible load power plants (that includes coal) to ensure the security of electricity supply is expected to continue in the Planning Period". It is clear from the foregoing that coal plants will continue to run as baseload and/or remain as reserve capacity. There is no "coal exit" target. There can still be coal-fired plants running or kept as reserve capacity even in 2053. Nonetheless, as we do not estimate any new project coming online, this should be seen as a gradual phase-out from two aspects. Firstly, as there is no new addition, but power demand increasing, the share of coal-fired generation automatically declines and those completing their technical lifetime will be retired. Secondly, as the Plan reiterates, in the case of accelerated developments in market conditions (like high carbon prices), coal may be driven out of the market despite not completing the lifetime or no official policy of "coal exit".

There seems to be no contradiction between net-zero targets and continued coal generation. It is because the RE share in electricity production increases while the share of coal (and pro rata the emissions from coal) decreases. The real emission cuts will come from other (than electricity) sectors.

Considering the abovementioned difficulties and current international financing environment, any additional coal capacity seems unrealistic. We believe that any new gas plant addition will depend on the developments of the alternative sources, battery capacity, and several other factors.

Analyzing the Plan's targets for RE, we must first look at the previous official targets. The Electrical Energy Market and Security of Supply Strategy Paper [68] and the National Renewable Energy Action Plan (REAC) [69] set out the targets (for 2023) of 20 GW wind and 5 GW solar. In practice, solar capacity reached 9.5 GW and wind reached 11.4 GW, roughly 1 GW per annum each. In total, though, this is an underachievement.

According to the new Plan, Turkey needs to add a 3.1 GW solar (3 times higher than the last 3 years' average) and 1.4 GW wind capacity annually until 2035. We believe that these ambitious targets can be achievable despite the challenges mentioned above.

3.1.3. Approach of Our Study and Analysis

Beginning with the question of how long coal plants will continue to function, we have focused on two issues that are directly affecting the future of coal power generation in Türkiye. Firstly, we have thoroughly examined the existing coal-fired power plants as to their commercial start dates, current standing, past capacity usage factors and generation figures, and technical and economic lifetimes. Secondly, we have projected a natural–gradual phase-out process without market or policy intervention. In addition to using open and public sources, we have gathered current market information via contacting relevant sector companies, organizations, and professionals. The following hypothesis was tested: coal plants are needed and will stay in the system if they are economically viable and technically available. Any coal plant not having these two conditions will be retired. Although there is no policy-forced coal exit, it is assumed that a natural phase-out process takes place over time.

Coal-Fired Capacity in Türkiye: A Slow but Imminent Phase-Out?

Having identified the current situation with expected lifetimes, we made a timeline analysis of the retirement prospects, as it is pertinent to the phase-out process (Figure 4).

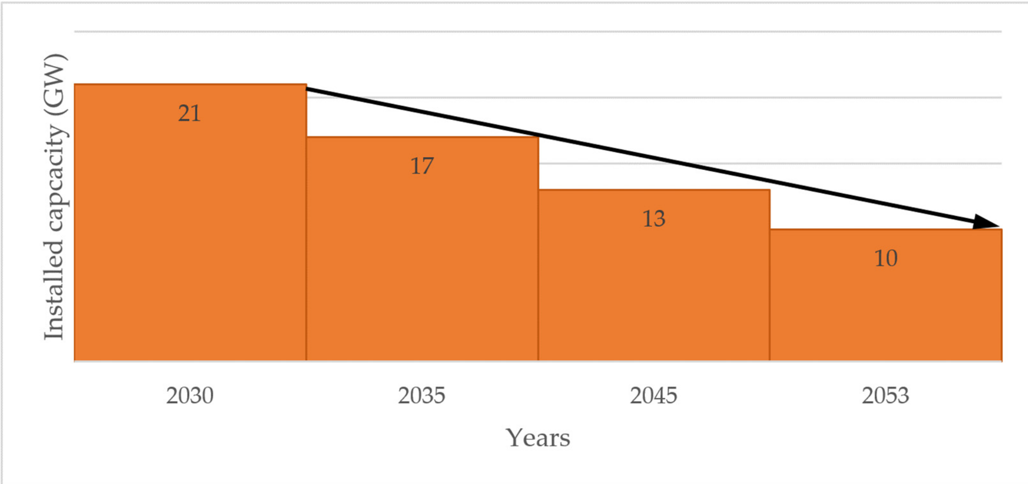

Figure 4. Expected technical lifetime analysis of the coal-fired generation fleet in Türkiye (source: Sırrı Uyanık, personal study).

The plants that are older, with low efficiency and without compatible environmental technology, are more susceptible to retirement. While accelerated retirement creates higher risks of asset stranding, potential continued coal expansion exacerbates the lock-in effect, which leads to a larger economic impact. Therefore, in our opinion, there would be no expansion to avoid both any lock-in effect and further conflict with climate policies. However, an accelerated phase-out or a sudden exit would create a stranded-asset problem and heighten energy security concerns for the policymakers and the industry. One other factor that would have an impact on the process of phase-out is gas prices, as gas is the marginal source for electricity.

Supply–Demand Model with Scenarios

Taking the above determinations and identifications regarding coal fleet into account, we ran a supply and demand model of the entire Turkish power system. The aim was to determine the point and time (if there is any) that coal plants would no longer be needed (by also forecasting the developments of other sources) without endangering energy security. Accordingly, the question of how much of a CO_2 emissions reduction is achievable in different scenarios is also answered.

We had the following assumptions in the supply–demand model:

1. The target year is 2035.
2. Hourly Consumption Profile: the rate of increase in the demand of electricity is taken from official MENR plan (as main scenario, 3.5% increase per annum), but we show low and high scenarios, too (see Figure 5).

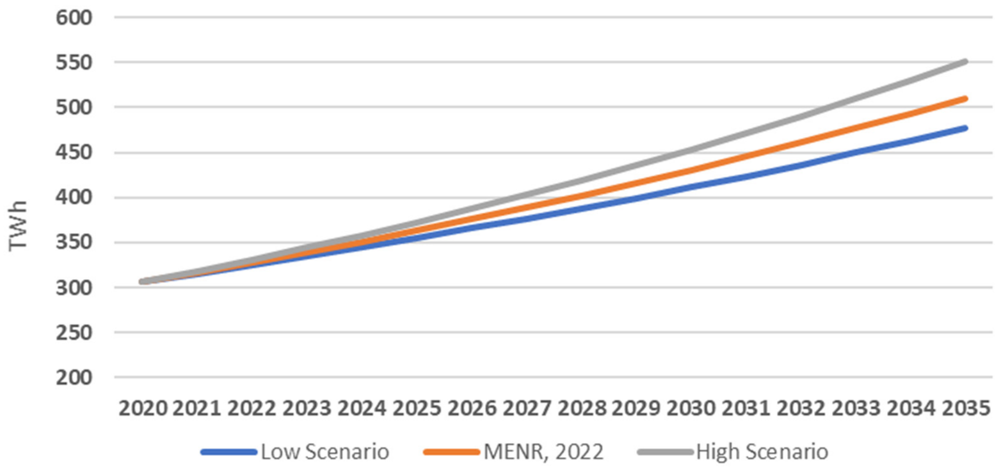

Figure 5. Power consumption forecast (source: prepared by the authors by using the data derived from the MENR).

3. Hourly demand and generation data from the past 5 years (2018–2022) have been taken and used for profiling the future demand and generation characteristics.
4. The "Hourly Dispatch" model applies the merit–order principle by taking marginal costs and the flexibilities of different generation sources into account. VRE generate their full potential with no curtailment. Nuclear capacity generates independent of its marginal cost. Other RE, CCGT, and coal share the rest of the demand. It is assumed that the increases in the other RE will be negligible due to near-complete utilization of these resources.
5. On the way to a decarbonized (and/or net-zero) economy, it is assumed that solar and wind capacity, VRE, would be massively deployed, especially to replace coal (and eventually gas, too). But, as they are intermittent, such an increase would require a sizable energy storage capacity. That is determined as the highest energy deficit across consecutive hours. The depth of discharge (DoD) is accepted as 80%.
6. Excess wind and solar generation beyond meeting the actual demand and beyond the storable capacity needs to be curtailed at a cost. For the ease of analysis, however, the need for additional battery capacity for the curtailment and the cost associated with it is omitted.
7. A balance of the Turkish power grid is highly sensitive to the generation of hydropower plants. Minor fluctuations in hydropower generation may have very impactful effects on the calculated battery storage capacities. This study does not consider the scenario of a dry year and assumes all hydro capacity (including run-of-river) dispatchable and has grid priority.
8. The carbon dioxide emission for a standard coal-fired power plant is assumed to be 0.85 tons/MWh, while a CCGT power plant is assumed to emit 0.45 tons/MWh.
9. In line with latest market expectations, we assume the cost of installing solar PV to be 480 USD/kW, wind to be 1450 USD/kW, and battery storage to be 400 (including installation and integration to grid costs) USD/KWh.

With these assumptions, we examined the feasibility of a more ambitious decarbonization policy and/or clean energy technology deployment scenarios forcing coal out. Thus, we tried to understand the possibility of a coal exit, and, if so, under which circumstances. For this purpose, we have developed three scenarios, respectively, as shown below:

BaU (Business-as-Usual) Scenario (official version): This scenario keeps the basic premises of the official Plan, only ruling out any coal capacity addition (see Figure 6). This, necessitates the increase in the storage capacity substantially (from the Plan's 15 GWh to 41 GWh). Under this scenario, although the coal capacity mostly stays, generation from coal will gradually decline due to the less-capacity-usage factor (more as a back-up function), and coal plant retirements will start, albeit at a slow pace. This can be considered a gradual but natural coal phase-out in the long run.

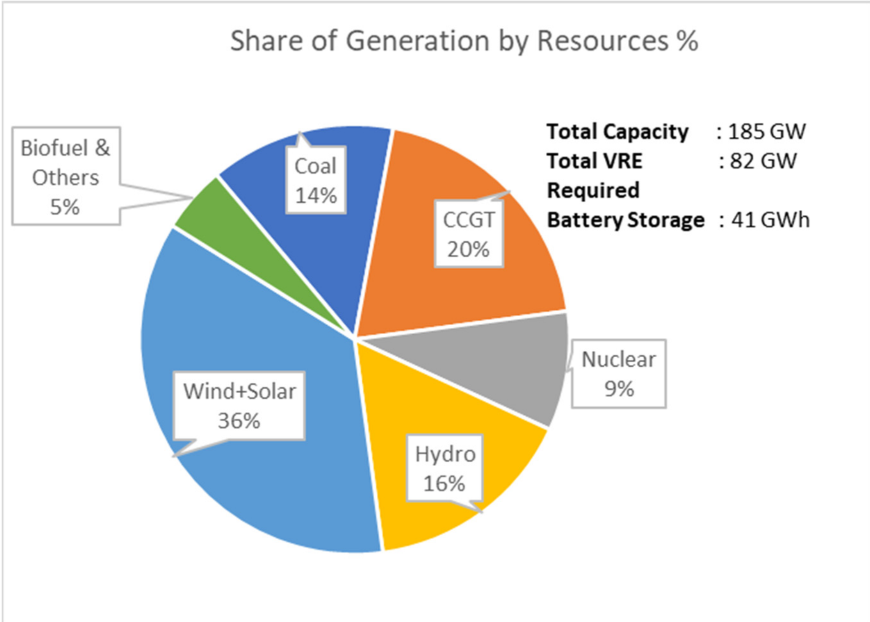

Figure 6. BaU Scenario 2035 (source: Sırrı Uyanık, personal study).

Coal-Exit Scenario 1: This scenario intends to demonstrate that, if the VRE additional capacity could be increased by close to 50% (24 GW of solar and 16 GW of wind, in total 40 GW, on top of the officially projected 82 GW, thus reaching to 122 GW in total) by 2035, and additionally a change in policy or due to market conditions (i.e., a coal-to-gas switch, high carbon price, etc.), coal exit seems possible (see Figure 7). To meet the demand for flexibility and to ensure security, the required capacity for battery storage is slightly raised to 46 GWh.

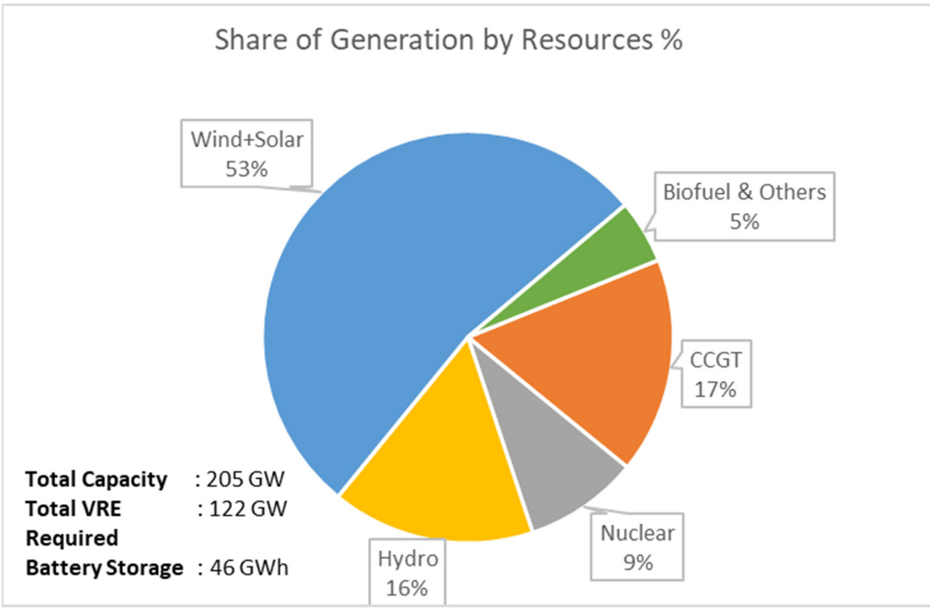

Figure 7. Coal-exit scenario 1 (source: Sırrı Uyanık, personal study).

Coal-Exit Scenario 2: This is another version of exiting coal. All assumptions of the second scenario hold, other than the gas capacity (instead of 10 GW, only 5 GW is installed due to the difficulties of new project development). In such a case, the required battery storage capacity (as the only preferred–viable alternative) is dramatically increased to 113 GWh. This is found to be totally unrealistic, considering that the whole EU target for 2035 is 160 GWh.

4. Results and Discussion

The results have revealed that coal-fired power plants have historically been key to the Turkish grid. They are the backbone of the system, supplying reliable baseload energy. From the energy security point of view, they are important. Figure 8 clearly demonstrates the current status of sources in the Turkish power market and the role of coal.

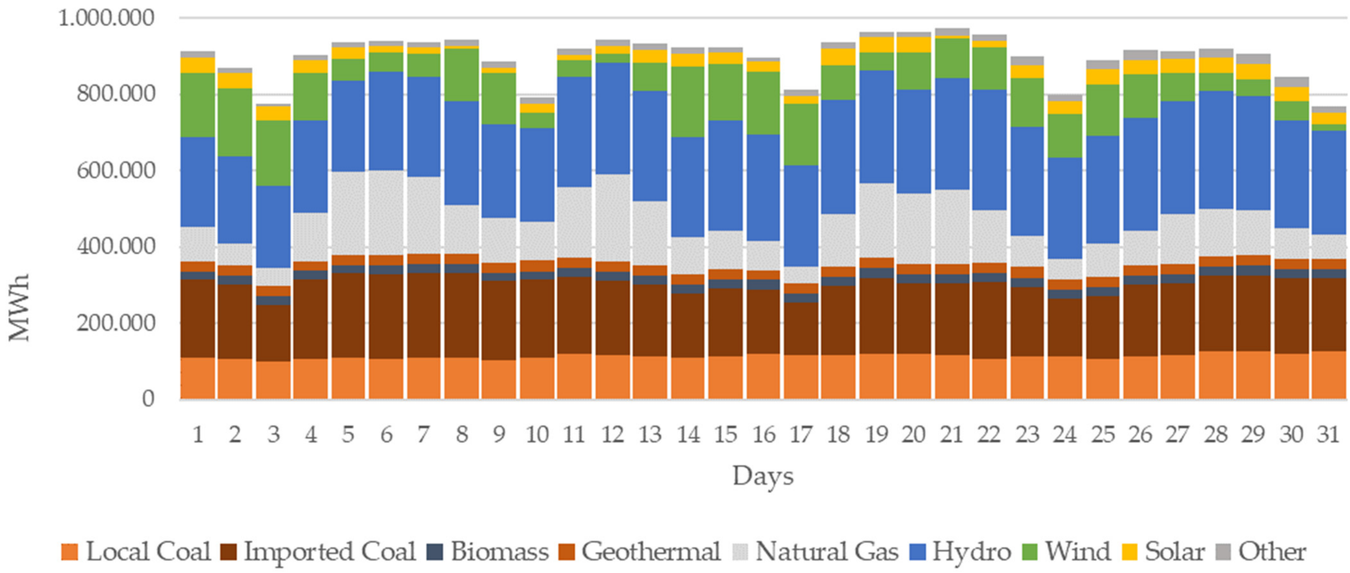

Figure 8. Power generation by sources, December 2023 (compiled from EPİAS data).

As a critical point, there is no official coal phase-out policy or target timeline; quite the contrary, the government appreciates the contribution of existing coal plants to supply security, and is actively promoting and encouraging the development of new projects, albeit to no avail so far.

Therefore, coal plants are needed for the foreseeable future and will stay in the power generation system as long as they are economically viable and technically available. If a coal plant is technically available but economically not viable in the market conditions, it would be kept in the system as reserve/stand-by, depending on the grid operator's system security evaluation at that time. As the fleet is relatively young and our technical lifetime analysis shows that technical retirement process will be slow, market conditions might actually be the determining factor on the capacity utilization rate of these plants most of the time. However, due to the increase in RE in the system, the utilization rate (capacity usage factor) will certainly decline over time. In any case, with the assumption that no new plant is installed, a natural phase-out process may start and accelerate after 2035 and will be in effect by 2053 (Figure 4).

However, if, by 2035, an additional (to the official target) 50% (40 GW) of the VRE capacity (which brings it to a VRE penetration rate of slightly above 50%) is deployed and an additional gas capacity, together with an ambitious 46 GWh of battery storage, is made available, a coal exit is theoretically possible (see Table 3). In such a case, although the actual generation from coal may not be needed, some plants can only be kept as a reserve capacity.

Table 3. Model results 2035 summary.

	BaU (Business-as-Usual)	Coal Exit 1	Coal Exit 2
Wind + solar installed capacity–VRE (GW)	82	122	122
Hydro + other RE installed capacity (GW)	40	40	40
Coal + CCGT installed capacity (GW)	56	36	30
Nuclear installed capacity (GW)	7	7	7
Total installed capacity (GW)	**185**	**205**	**200**
Battery capacity (GWh)	41	46	113
Share of sun + wind (VRE) in power generation (%)	36	53	53
Share of renewable energy in power generation (%)	55	74	74
Share of coal + CCGT in power generation (%)	35	17	17
CO_2 emissions from power generation (million tons)	108	40	40
Investment requirements (billion USD) excluding curtailment + transmission–grid	98	135	140

Source: supply and demand model results.

This is, however, a big "if" when considering:

1. The difficulties and challenges to be overcome. These include reviewing all the existing energy transition technologies and their deployment, procuring permits, and clearing land allocation hurdles. Other concerns are with the grid connection queues and the availability of critical minerals and supply-chain crunches [70]. For example, investments in new wind farms slumped to the lowest in more than a decade in Europe in 2022 [71]. Thus, the possibility of realizing the assumed rate of VRE deployment in Türkiye seems really low.
2. Even if the assumption looks achievable, the absence of an official commitment to a coal-exit policy, as well as a high possibility of new geopolitical tensions triggering energy security concerns, may necessitate a coal capacity retention approach by the government.
3. Involved costs: The latest observed trends and facts indicate that, after decades of declining technology prices, solar and wind project costs have now begun to increase [72]. Nevertheless, if a decrease should occur (at least for solar), the total estimated renewable transition CAPEX cost for the coal exit 1 scenario would amount to around USD 135 Bio (and for coal exit 2 to around USD 140 Bio). We must also emphasize that these sums do not include the relevant transmission and grid connection costs, as well as the VRE curtailment costs. Furthermore, no consideration is given to just transition issues and related costs. Thus, even if the technology is deployable and the challenges overcome (and policy approach changes towards coal, which looks unlikely), these costs are considerable and would increase the unit price of consumed electricity. That might be the last thing a country already under economic stress might want.
4. Coal will, anyway, undergo a slow natural phase-out process (even without policy force), and the speed and scope of this process will depend on the level of deployment of VRE together with battery back-ups, as well as the existence of the carbon price and other economic indicators. Phase-out may accelerate after 2035, probably aimed at a completion by 2053, which is the official net-zero target year of the Turkish government. This is a gradual and cautious transition away from coal (from a good one-third of generation today to around 14% in 2035), whereby coal will also function mostly in a back-up or reserve capacity, fulfilling energy security goals.
5. One reason that coal plants are needed in the system is that, even if a high storage capacity (calculated as 4% of global total target) is available and deployable at scale, the cost (as of today's calculations) of installing such a capacity involves enormous amounts. Until 2035, more than USD 11 billion CAPEX per annum for energy system decarbonization and transition is needed. This may indeed be beyond the means of the country, considering the last 20 years' trends and actual costs, which is about

USD 5 billion per annum, including not only the VRE but all generation facility installment costs.

6. As the main aim of decarbonization and energy transition is reducing carbon emissions, we also analyzed the results regarding this issue. In terms of coal generation-related emissions, there will be a ~45% reduction in the BaU scenario; that is, from ~118 million/t today to 62 million/t in 2035. This would be achieved through less utilization and the gradual retirement of coal plants. Total power emissions would amount to around 109 million/t, a reduction of 30% from today' figure. With the BaU scenario, the stranded-asset trap and associated costs, as well as employment and social issues (just energy transition concerns) in coal regions, can be avoided. In the coal-exit scenario, the reductions are higher than BaU by 63%, reduced to 40 G/tons, as there are only gas emissions left (see Table 4).

Table 4. Coal and gas emissions from electricity generation vs. electricity generation as per the scenarios.

	Generation in 2035 (TWh)		Equivalent CO_2 Emissions (Gton)	
	BaU	**Coal Exit 1**	**BaU**	**Coal Exit 2**
Coal	73	0	62,240	0
CCGT	103	89	46,402	40,225
Total	176	89	108,642	40,225
Delta				−63%

Emission factors: Coal: 0,85 tons CO_2/ MWh; CCGT: 0,45 tons CO_2/ MWh.

5. Conclusions

The coal phase-out/exit is not as simple as assumed, and timeline targets may not be realistic without considering the energy security aspect and numerous other challenges. Moreover, contrary to what has often been assumed, energy storage, in the short- and even the medium-term, will not be the solution for addressing the energy security concerns that coal has so easily provided.

Türkiye has a long and important history with coal in meeting its energy needs. Coal has provided at least a third of power generation for decades. Today, 20 domestic and 9 imported coal-fired power plants (with a total capacity of 21 GW) are operating and covering 34.5% of the demand. The industry is a very significant socioeconomic factor in some regions. Although the government has been promoting RE and emphasizing the decarbonization of energy, it has no intention of exiting coal, as it is quite aware of the role coal plays in energy supply security. Indeed, it even has plans to expand the coal capacity further. This might, however, prove to be very difficult. Nevertheless, our findings reveal that, as per our base case scenario (BaU), coal plants will continue to provide baseload power until 2035, but perhaps at a declining capacity usage factor over time. They will, thus, be subject to a gradual, natural phase-out process in the long run. Even in this scenario, there will be substantial emission reductions (by about 30%), which will help the country's climate commitments.

In our alternative scenarios, we have questioned a coal phase-out or exit by 2035. Although, under certain assumptions and conditions, it is possible but extremely ambitious. It involves overcoming all hurdles and incurring additional (to already high) CAPEX costs. It may also have negative energy security implications, depending on the geopolitics of that time. It is, therefore, considered relatively unrealistic.

To sum up, under coal phase-out discussions, the answer to the question of how long coal-based power plants in Türkiye will be running depends more on the power sector diversification structure, grid system requirements, market conditions, and official policy in line with net-zero targets. Nevertheless, it should be noted that economically nonviable and technically nonavailable coal-fired power plants in the generation system will retire naturally. In short, it seems that coal will be here to stay in Türkiye for some time to come, and the energy markets, along with policy considerations, will be determining the timing of the coal phase-out in the long run.

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Abbreviations

BAU	Business-as-Usual	LDES	Long-Duration Energy Storage
BESS	Battery Energy Storage System	MENR	Ministry of Energy and Natural Resources
CAPEX	Capital Expenditure	NDC	Nationally Determined Contribution
CCGP	Combined Cycle Gas Power Plant	OECD	Organization for Economic Co-operation and Development
CCGT	Combined Cycle Gas Turbine	PP	Power Plant
COP	Conference of the Parties	RE	Renewable Energy
DoD	Depth of Discharge	REAC	National Renewable Energy Action Plan
EMRA	Energy Market Regulatory Authority	SDGs	Sustainable Development Goals
EPIAS	Energy Market Operator	SDS	Sustainable Development Scenario
ESS	Energy Storage System	TEIAS	Turkish Electricity Transmission Corporation
EUAS	National Electricity Generation Corporation	TKI	Turkish Coal Enterprises
GHG	Greenhouse Gas	UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency	VRE	Variable Renewable Energy

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