A Low Carbon Pathway for the Turkish Electricity Generation Sector

Izzet Ari, Associate Professor, Social Sciences University of Ankara,
izzet.ari@asbu.edu.tr
Hukumet Meydani No:2 06050
Ulus, Altındag, ANKARA, Türkiye

Abstract

The aim of this article is to analyze the decarbonization options of Türkiye's electricity generation sector. Türkiye is an emerging economy, so its population, economic activities and overall welfare have been increasing. However, economic and social development result in rising greenhouse gases, particularly CO_2 emissions. Türkiye's emissions are required to be mitigated. Firstly, the main drivers (GDP, population, energy, and carbon intensity of primary energy sources, etc.) CO_2 emissions of electricity are investigated between 2008 and 2020. The method of this query is based on Logarithmic Mean Divisia Index (LMDI). Secondly, Türkiye's climate policy on the decarbonization of the electricity sector is analyzed. To that, supply and demand projections of electricity are conducted. After these projections are completed, decarbonization policy options are assessed in the LEAP Model (Low Emissions Analysis Platform). The reduction potential for CO_2 emissions and the costs will be calculated according to the policy options. The projections will be extended by 2053 because Türkiye has declared to net zero emissions target by 2053. The electricity sector will have a significant emissions reduction and decarbonization potential, so its contribution to the overall net zero emissions target is crucial for Türkiye's long-term low emissions development strategy.

Keywords: Decarbonization, Electricity emissions, Low emissions development

Introduction

The United FrameworkConvention on Climate Change (UNFCCC) was adopted in 1992 to stabilization of greenhouse gas (GHG) concentrations in the atmosphere (UNFCCC 1992). Countries have been trying to mitigate climate change by reducing greenhouse gas (GHG) emissions, conservation of emissions sink area and controlling land use change. In 1997, the Kyoto Protocol was adopted in order to reduce GHG emissions from 2008 to 2012 according to a reference year which was 1990 commonly (UNFCCC 1998). Since only Annex I of the UNFCCC led to quantified GHG emissions reduction, efforts were observed as inadequate without the participation of all countries. Finally, the Paris Agreement was adopted in 2015 (UNFCCC 2015). While the Paris Agreement demands GHG emissions reductions from countries, it also expects fundamental changes in countries' economic sectors towards low-carbon development. In this context, Article 4.19 of the Paris Agreement requests countries to prepare their long-term low emissions development strategies. Türkiye, a party to the Paris Agreement, is subject to this, so Turkey is expected to reveal its GHG emissions reduction potential.

The transition towards the low carbon development model is not only the agenda of the UNFCCC and the Paris Agreement. It is also supported by the Organization for Economic Cooperation and Development (OECD), the International Energy Agency (IEA), and multilateral development banks such as the World Bank (Fay et al., 2015; OECD, 2013; OECD, 2015; UNFCCC, 2015). The main motivation of this model is tackling global climate change without compromising on achieving sustainable development. Particularly alleviating poverty and unemployment by reducing the pressure on natural resources, put forward policy bundles that will contribute to economic growth and employment within sustainable production and consumption patterns. Since each country has unique conditions, there are no uniform policy bundles and scenarios. While low-carbon development allows countries to reduce GHG emissions, the cost of this should be estimated and the realization of the model for the energy system should be investigated. The aim of this paper is to analyze the drivers of emissions increases in electricity generation and to estimate the reduction potential and cost of the sector to a low-carbon development model.

Literature Review

The low-carbon development model has emerged frequently in recent years (Broek, Berghout, and Rubin 2015; Gu et al. 2015; IDDRI 2017; Blumberga et al. 2014; OECD, IEA, NEA 2015). This model aims to reduce GHG emissions in production and consumption chains in many sectors, especially in the electricity generation sector (Yao, Feng, and Hubacek 2015; Fragkos et al. 2017; Pearson and Foxon 2012). Within the model's scope, the transition from higher carbon-intensive sources and technologies to lower carbon and zero emissions intensities are the main objectives (Rüdinger et al. 2018; Foxon 2011; Bodnar et al. 2018). Using renewable energy sources and nuclear energy, the preference for natural gas with a lower carbon intensity instead of coal and lignite are the primary measures in the initial steps (IPCC 2011; OECD 2015). The second step for the model is to ensure energy efficiency at every stage, from energy production to consumption. For example, in the electricity sector, technology changes in production plants, increasing efficiency by adding additional processes, improving the transmission and distribution lines of electricity, renewal of high voltage and low voltage transformers, optimizing the use of minimum lines in the distribution network, preferring efficient goods and tools by users in the final consumption of electricity can be shown as measures to increase energy efficiency (Edenhofer et al. 2011; Bruckner T., I. A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij, B. Fungtammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H. B. Nimir, K. Riahi, N. Strachan, R. Wiser 2014). The third and final stage is using the carbon capture and storage (CCS) option in the cement, iron, steel and chemical sectors, which is not technically possible to reduce the carbon intensity to zero with the existing technology and innovation opportunities. Although the CCS method has not completed its technology readiness level, it is being applied by countries at pilot scales. Scientific research is ongoing on this method to increase the risks in storage, the high cost and the fact that it has not yet reached the level of technological maturity. On the other hand, the first and second priorities for low-carbon development, such as fuel and technology change and the handling of energy efficiency in the life cycle, are widely used (Bruckner T., I. A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij, B. Fungtammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H. B. Nimir, K. Riahi, N. Strachan, R. Wiser 2014).

Material and Method

Within the scope of the article, driving factors affecting the emission structure of the Turkish electricity sector will be investigated between 2008-2020. The reason for selecting 2009 as a starting year is that Türkiye’s ratification process of the Kyoto Protocol. The decomposition analysis method has been selected since it is widely used in determining the factors affecting CO_2 emissions. This method is most often used to decompose electricity and other energy sectors. Under the decomposition analysis, *Index Decomposition Analysis* (Ang 2004; Hoekstra and van den Bergh 2003) which has been widely performed to detect CO_2 emissions from electricity generation (Huang et al. 2019), provides a sub-method, namely Logarithmic Mean Divisia Index (LMDI).

In the LMDI method to be used for Türkiye, the change in the control year and target year will be examined (Equation 1).

$$\Delta C_{tot} = C^T - C^0 \tag{1}$$

In Equation 1, C^T indicates CO_2 emissions in the target year, and C^0 indicates emissions in the control year. Then five main factors are identified that can effectively change CO_2 emissions. These are:$\Delta C_g,\ \Delta C_p,\ \Delta C_m, \Delta C_u, \Delta C_e$ (Ang 2004; 2015; Wang and Wang 2019; Hoekstra and van den Bergh 2003). These factors are expressed as additive decomposition. Emissions for one year are based on the change of factor five by representation in equations 2 and 3.

$$\Delta C_{tot} = C^T - C^0 = \Delta C_g + \Delta C_p + \Delta C_m + \Delta C_u + \Delta C_e \tag{2}$$

In the LMDI, variables $(G, p, m_i, u_i\ and\ e_i)$ are:

- C: CO_2 emissions from the combustion of fossil fuels
- G: Total electricity generation
- Q: Electricity generated by fossil fuel-using thermal power plants
- F: Fuel consumption
- p (Q/G): proportion of electricity generated from fossil fuels
- m_i (Q_i/G): ratio of electricity generated from fossil fuel (i) to total electricity production
- u_i (F_i/Q_i): electricity generation (i) based on fossil fuel (i)
- e_i (C_i/Q_i): the emission factor of fossil fuel (i)

$$C = \sum_i G\frac{Q}{G} \times \frac{Q_i}{Q} \times \frac{F_i}{Q_i} \times \frac{C_i}{F_i} = \sum_i Gpm_i\, u_i e_i \tag{3}$$

$$\Delta C_G = \sum_i \frac{(C_i^T - C_i^0)}{(lnC_i^T - lnC_i^0)} ln\left(\frac{G^T}{G^0}\right)$$

(4) *Change in total electricity generation*

$$\Delta C_p = \sum_i \frac{(C_i^T - C_i^0)}{(lnC_i^T - lnC_i^0)} ln\left(\frac{p^T}{p^0}\right)$$

(5) *Change in the share of fossil fuels in electricity generation*

$$\Delta C_m = \sum_i \frac{(C_i^T - C_i^0)}{(lnC_i^T - lnC_i^0)} ln\left(\frac{m_i^T}{m_0^T}\right)$$

(6) *Change in the share of fossil fuel (i) in electricity generation from fossil fuels*

$$\Delta C_u = \sum_i \frac{(C_i^T - C_i^0)}{(lnC_i^T - lnC_i^0)} ln\left(\frac{u_i^T}{u_0^T}\right)$$

(7) *Input/output share for fossil fuel (i)*

$$\Delta C_e = \sum_i \frac{(C_i^T - C_i^0)}{(lnC_i^T - lnC_i^0)} ln\left(\frac{e_i^T}{e_0^T}\right)$$

(8) *Emission factor c(i)/f(i)*

The second objective of this study is to explore emissions mitigation in the electricity sector between baseline, in other words, business as usual (BaU) and low-carbon development policies. According to the policy options, the reduction potential and cost for CO_2 emissions will be calculated. Low Emissions Analysis Platform *(LEAP)* will be used to achieve this goal. LEAP is an integrated, scenario-based modeling tool that can monitor energy consumption, production, and resource extraction across all sectors of an economy. Both the energy sector and the non-energy sector are used to account for GHG emissions sources and sink areas. The LEAP program was chosen because it allows the use of a comprehensive database and provides the opportunity to analyze energy supply and demand projections in terms of cost, environmental impact and GHG emissions. The LEAP program is widely used worldwide for electricity demand and supply projections. Such as projecting the GHG emissions generated by different policy options of the Japanese energy sector (Takase & Suzuki, 2011), analysis of China's energy-based low-carbon development scenarios (Zhou et al. 2014) and modeling the reduction of CO_2 emissions in the electricity sector(Cai et al. 2007), modeling Lebanon's electricity sector with alternative scenarios (Dagher and Ruble 2011), making long-term supply-demand forecasts for Pakistan's electricity generation (Mirjat et al. 2018), evaluation of long-term alternative scenarios of the Panamanian electricity sector (McPherson and Karney 2014) and development and evaluation of renewable energy policies of Bulgaria (Nikolaev and Konidari 2017).

For data collection, energy-related data such as final energy consumption, electricity installed capacity and generation, electricity prices, the calorific value of coal, lignite, natural gas, oil; socio-economic data (GDP and population) are gathered from TURKSTAT and Turkish official databases located in line ministries. Technical coefficient and variables are obtained from the LEAP databases, and capacity credit, capacity factor, and merit order for power plants are discussed with energy experts of public and private institutions.

Results and Discussions

Electricity generation of Türkiye increased from 194,736 GWh to 306,703 GWh between 2008 and 2020 (Figure 1). The CO_2 emissions from electricity generation fluctuated for the same period, but the overall trend increased. For example, it was more than 115 million ton (mt) in 2008, 144 mt in 2018 (as a maximum level) and 123 mt in 2020.

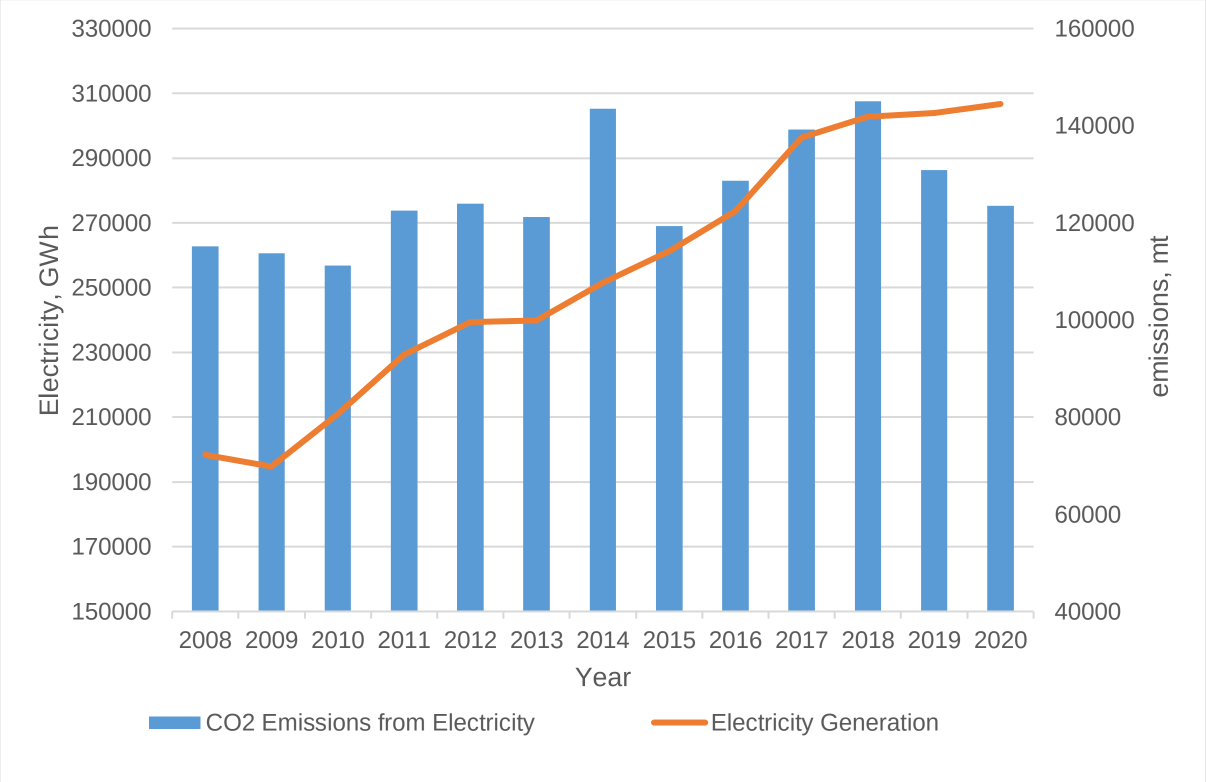
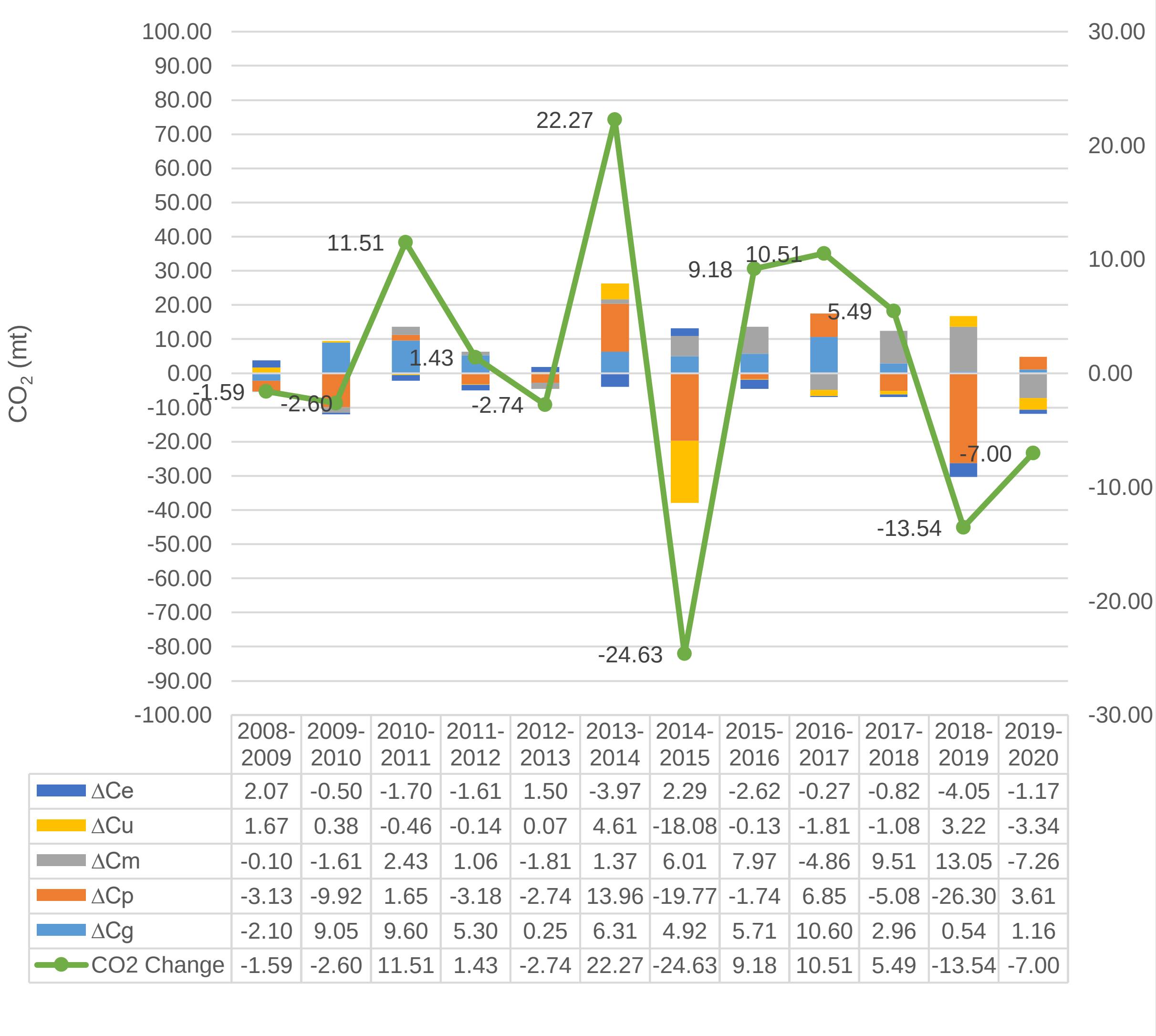


Figure 1. Electricity generation and its related CO_2 emissions between 2008 and 2020.

The reason behind this fluctuation is explained in Figure 2. Five decompositions of drivers $(\Delta C_g,\ \Delta C_p,\ \Delta C_m, \Delta C_u, \Delta C_e)$ on CO_2 emissions have different impact and magnitude. For ΔC_G, except for 2009, the global financial crisis year, electricity generation continuously raised and has an increasing effect on emissions. ΔC_p has increasing and decreasing effects on emissions because of the changing share of fossil fuel inputs into electricity generation. ΔC_p has a mitigation effect of 45.79 mt emissions between 2008 and 2020. Similarly, ΔC_m has a fluctuating role in emissions. Still, it has an increasing effect of more than 25 mt for the same period because the share of primary energy sources among fossil fuels came from more carbon-intensive (i.e., imported coal and lignite) than before. On the other hand, there has been energy efficiency improvement in fossil fuel-based power plants ΔC_u. Even though there has been a lack of efficiency improvements in some years, the efficiency improvement has contributed to more than 15 mt emissions reduction. Last but not least, changes in emission factors (ΔC_e) have positive and negative effects on emissions reduction. For this driver, reduction of emissions factors contributed to almost 11 mt. Emissions from electricity generation increased by only 8.3 mt between 2008 and 2020.



	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
ΔCe	2.07	-0.50	-1.70	-1.61	1.50	-3.97	2.29	-2.62	-0.27	-0.82	-4.05	-1.17
ΔCu	1.67	0.38	-0.46	-0.14	0.07	4.61	-18.08	-0.13	-1.81	-1.08	3.22	-3.34
ΔCm	-0.10	-1.61	2.43	1.06	-1.81	1.37	6.01	7.97	-4.86	9.51	13.05	-7.26
ΔCp	-3.13	-9.92	1.65	-3.18	-2.74	13.96	-19.77	-1.74	6.85	-5.08	-26.30	3.61
ΔCg	-2.10	9.05	9.60	5.30	0.25	6.31	4.92	5.71	10.60	2.96	0.54	1.16
CO2 Change	-1.59	-2.60	11.51	1.43	-2.74	22.27	-24.63	9.18	10.51	5.49	-13.54	-7.00

Figure 2. Decomposition of CO_2 emissions in electricity generation between 2008 and 2020

301,100 GWh electricity generated in Türkiye in 2019. According to the Ministry of Energy and Natural Resources projection, Türkiye's electricity demand will be 591 thousand GWh in 2040 (MENR 2022). The projected electricity generation is extrapolated by 2053 to obtain demand for the final year. Two scenarios (Baseline and Net Zero Electricity) are conducted in the LEAP. Assumptions of Baseline, in other words, Business as Usual scenario, are based on reducing electricity transmission and distribution losses by 10% by 2053. Besides, using primary energy sources (both renewable and non-renewable) by 2053 is accepted as the 2019 ratio. Assumptions of the Net Zero Electricity scenario focus on further reduction in electricity transmission and distribution losses (5%), and utilization of economically feasible renewable energy sources in Türkiye. In that regard, hydro (50,000 MW), biogas and waste (20,000 MW), wind (30,000 MW), solar (50,000 MW), and geothermal (10,000 MW) will be utilized for generating electricity. The remaining demand will be supplied by fossil and nuclear energy sources. Figure 3 presents the emission difference between Baseline and Net Zero scenarios. Baseline and Net Zero's Emissions are estimated to be 424,6 and 84,3 mt by 2053. Therefore, 340.3 mt of emissions can be mitigated in 2053.

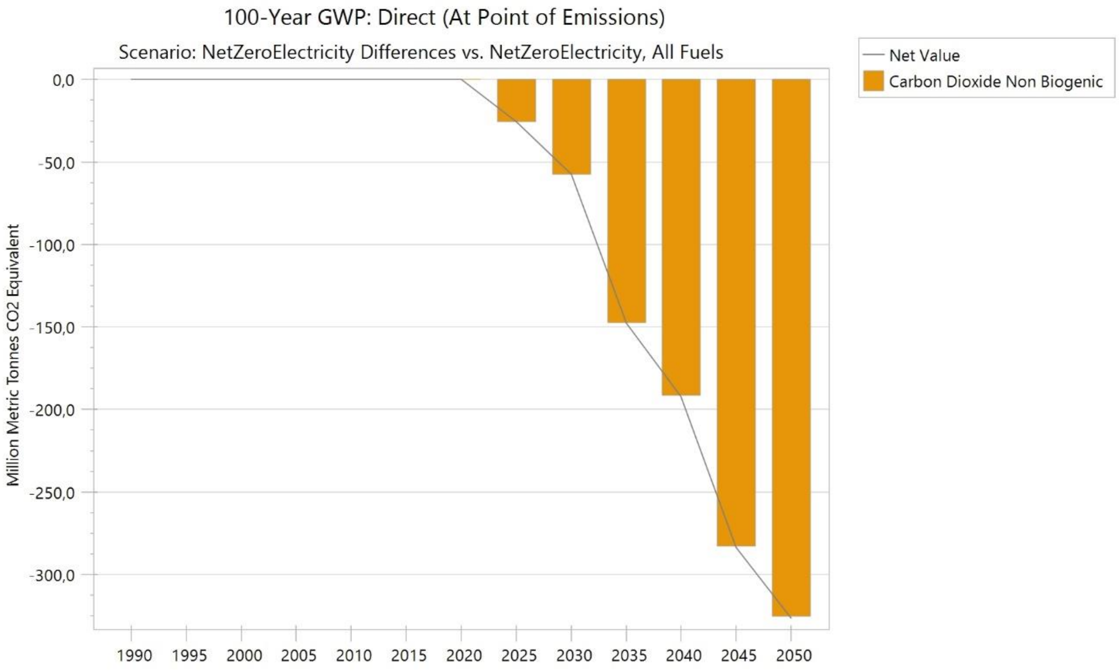


Figure 3. CO_2 emissions mitigation potential of Net Zero Scenario

The additional cost of the Net Zero scenario is shown in Figure 4. Cost parameters in LEAP are feedstock and auxiliary fuel costs, capital, fixed and variable operating and maintenance costs, module costs and any stranded costs associated with pre-existing processes. Baseline and Net Zero scenarios cost USD 23.961 billion and USD 27.993 billion in 2053. Therefore additional cost in 2053 will be USD 4.031 billion. When additional cost is considered with mitigated emissions amount, it can be inferred that cost per ton of carbon reduction will be 11.84 USD.

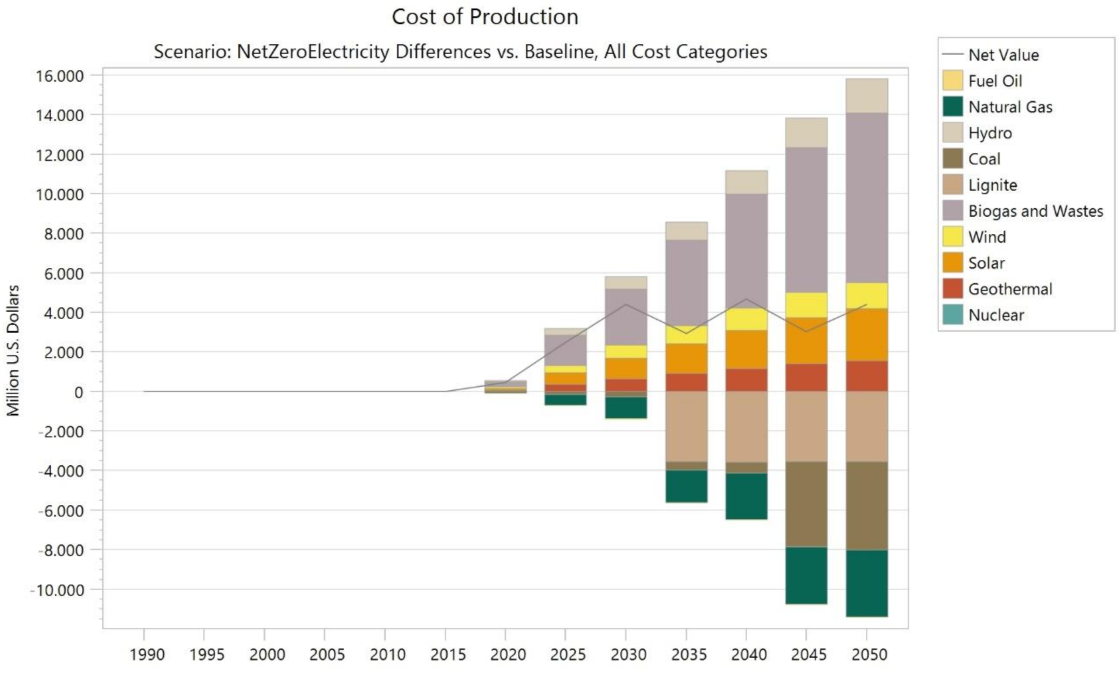


Figure 4. Additional cost of production of Net Zero Scenario

Conclusion

Effective combatting climate change requires international efforts. The UNFCCC, the Kyoto Protocol and the Paris Agreement are multilateral climate agreements for this objective. GHG emissions mitigation is the utmost priority and main goal of these treaties. In 2015, the Paris Agreement successfully introduced the long-term low emissions development strategies in Article 4.19. Several key policies exist for all in the transition towards low emissions development strategies. Utilization of renewable energy sources, increasing energy efficiency, reduction of demand without compromising welfare, and introducing new and innovative emissions mitigation technologies. In that regard, the electricity generation sector still has room for energy efficiency and renewable energy measures for emissions mitigation. In this study, energy efficiency measures in the electricity sector reduce electricity transmission and distribution losses. For renewable energy sources, economically feasible potential sources are replaced with fossil fuels by 2053. When drivers of electricity originated emissions are decomposed by the LMDI method, the main contribution to emission mitigation (45.79 mt) between 2008 and 2020 comes from replacing fossil fuels with renewable energy sources. Besides, for the same period, total energy efficiency improvement contributes to around 15 mt. Both renewable energy and energy efficiency are considered as main measures in the Net Zero Scenario, 340.3 mt of emissions can be reduced in the electricity sector in 2053. The annual cost of this reduction is estimated at 4,031 million USD for the same year. This implies that the cost of per ton of emission mitigation can be 11.84 USD. When carbon price instruments such as tax or trade are higher than 11.84 USD, it is rational to mitigate emissions rather than purchase carbon credit/allowances or pay a carbon tax.

In conclusion, Türkiye has significant potential to reduce emissions in the electricity sector via using renewable energy sources and technologies and improving energy efficiency in transmission and distribution lines.

Acknowledge

I would like to acknowledge the support of the Social Sciences University Scientific Research Fund under Scientific Research Project SBE-2020-193.

Bibliography

Ang, B. W. 2004. “Decomposition Analysis for Policymaking in Energy: Which Is the Preferred Method?” *Energy Policy* 32 (9): 1131–39. https://doi.org/10.1016/S0301-4215(03)00076-4.

———. 2015. “LMDI Decomposition Approach: A Guide for Implementation.” *Energy Policy*. https://doi.org/10.1016/j.enpol.2015.07.007.

Blumberga, Dagnija, Andra Blumberga, Aiga Barisa, and Marika Rosa. 2014. “System Dynamic Modeling of Low Carbon Strategy in Latvia.” *Energy Procedia* 61 (November 2015): 2164–67. https://doi.org/10.1016/j.egypro.2014.12.100.

Bodnar, Paul, Caroline Ott, Rupert Edwards, Stephan Hoch, Emily F. McGlynn, and Gernot Wagner. 2018. “Underwriting 1.5°C: Competitive Approaches to Financing Accelerated Climate Change Mitigation.” *Climate Policy* 18 (3): 368–82. https://doi.org/10.1080/14693062.2017.1389687.

Broek, Machteld Van Den, Niels Berghout, and Edward S Rubin. 2015. “The Potential of Renewables versus Natural Gas with CO 2 Capture and Storage for Power Generation under CO2 Constraints.” *Renewable and Sustainable Energy Reviews* 49: 1296–1322. https://doi.org/10.1016/j.rser.2015.04.089.

Bruckner T., I. A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij, B. Fungtammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H. B. Nimir, K. Riahi, N. Strachan, R. Wiser, and X. Zhang. 2014. “Energy Systems.” In *Climate Change 2014: Mitigation of Climate Change. Contribution* *of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 5-1-5–30.

Cai, Wenjia, Can Wang, Ke Wang, Ying Zhang, and Jining Chen. 2007. “Scenario Analysis on CO2 Emissions Reduction Potential in China’s Electricity Sector.” *Energy Policy* 35 (12): 6445–56. https://doi.org/10.1016/j.enpol.2007.08.026.

Dagher, Leila, and Isabella Ruble. 2011. “Modeling Lebanon’s Electricity Sector: Alternative Scenarios and Their Implications.” *Energy* 36 (7): 4315–26. https://doi.org/10.1016/j.energy.2011.04.010.

Edenhofer, Ottmar, Ramón Pichs Madruga, Youba Sokona, Kristin Seyboth, Patrick Matschoss, Susanne Kadner, Timm Zwickel, et al. 2011. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1017/CBO9781139151153.

Fay, Marianne, Stephane Hallegatte, Adrien Vogt-Schilb, Julie Rozenberg, Ulf Narloch, and Tom Kerr. 2015. *Decarbonizing Development*. https://doi.org/10.1596/978-1-4648-0479-3.

Foxon, TJ. 2011. “A Coevolutionary Framework for Analysing a Transition to a Sustainable Low Carbon Economy.” *Ecological Economics* 70 (12): 2258–67. https://doi.org/10.1016/j.ecolecon.2011.07.014.

Fragkos, Panagiotis, Nikos Tasios, Leonidas Paroussos, Pantelis Capros, and Stella Tsani. 2017. “Nationally Determined Contribution and Low-Carbon Pathway to 2050.” *Energy Policy* 100 (October 2016): 216–26. https://doi.org/10.1016/j.enpol.2016.10.023.

Gu, Baihe, Xianchun Tan, Yuan Zeng, and Zekun Mu. 2015. “CO2 Emission Reduction Potential in China’s Electricity Sector: Scenario Analysis Based on LMDI Decomposition.” *Energy Procedia* 75: 2436–47. https://doi.org/10.1016/j.egypro.2015.07.210.

Hoekstra, Rutger, and Jeroen C.J.M. van den Bergh. 2003. “Comparing Structural Decomposition Analysis and Index.” *Energy Economics* 25 (1): 39–64. https://doi.org/10.1016/S0140-9883(02)00059-2.

Huang, Fei, Dequn Zhou, Qunwei Wang, and Ye Hang. 2019. “Decomposition and Attribution Analysis of the Transport Sector’s Carbon Dioxide Intensity Change in China.” *Transportation Research Part A: Policy and Practice*. https://doi.org/10.1016/j.tra.2018.12.001.

IDDRI. 2017. “Modelling and Informing Low Emission Strategies.”

IPCC. 2011. “IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.” *Choice Reviews Online*. Vol. 49. Cambridge: The Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.5860/CHOICE.49-6309.

McPherson, Madeleine, and Bryan Karney. 2014. “Long-Term Scenario Alternatives and Their Implications: LEAP Model Application of Panama’s Electricity Sector.” *Energy Policy* 68: 146–57. https://doi.org/10.1016/j.enpol.2014.01.028.

MENR. 2022. “Electricity Demand Projection of Türkiye (2020-2040).” 2022.

Mirjat, Nayyar Hussain, Muhammad Aslam Uqaili, Khanji Harijan, Gordhan Das Walasai, Md Alam Hossain Mondal, and Hasret Sahin. 2018. “Long-Term Electricity Demand Forecast and Supply Side Scenarios for Pakistan (2015–2050): A LEAP Model Application for Policy Analysis.” *Energy* 165: 512–26. https://doi.org/10.1016/j.energy.2018.10.012.

Nikolaev, Angel, and Popi Konidari. 2017. “Development and Assessment of Renewable Energy Policy Scenarios by 2030 for Bulgaria.” *Renewable Energy* 111 (2017): 792–802. https://doi.org/10.1016/j.renene.2017.05.007.

OECD, IEA, NEA, ITF. 2015. “Aligning Policies for a Low-Carbon Economy.” OECD Publishing. https://doi.org/10.1787/9789264233294-en.

OECD. 2013. “Climate and Carbon: Aligning Prices and Policies.” https://doi.org/10.1787/5k3z11hjg6r7-en.

———. 2015. “Aligning Policies for a Low-Carbon Economy.” *Aligning Policies for a Low-*

Carbon Economy, no. June: 205–38. https://doi.org/10.1787/9789264233294-en.

Pearson, Peter J.G., and Timothy J. Foxon. 2012. “A Low Carbon Industrial Revolution? Insights and Challenges from Past Technological and Economic Transformations.” *Energy Policy* 50: 117–27. https://doi.org/10.1016/j.enpol.2012.07.061.

Rüdinger, A, J Voss-Stemping, O Sartor, M Duwe, and A Averchenkova. 2018. “Towards Paris-Compatible Climate Governance Frameworks.”

UNFCCC. 1992. “UNFCCC.” 1992. http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf.

———. 1998. “Kyoto Protocol.” 1998. https://unfccc.int/process/the-kyoto-protocol.

———. 2015. *Paris Agreement*. *Adoption of the Paris Agreement. Proposal by the President.* Vol. 21932. https://doi.org/FCCC/CP/2015/L.9/Rev.1.

Wang, Qiang, and Shasha Wang. 2019. “A Comparison of Decomposition the Decoupling Carbon Emissions from Economic Growth in Transport Sector of Selected Provinces in Eastern, Central and Western China.” *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.04.375.

Yao, Congrong, Kuishuang Feng, and Klaus Hubacek. 2015. “Driving Forces of CO2emissions in the G20 Countries: An Index Decomposition Analysis from 1971 to 2010.” *Ecological Informatics* 26 (P1): 93–100. https://doi.org/10.1016/j.ecoinf.2014.02.003.

Zhou, Yun, Fanghua Hao, Wei Meng, and Jiafeng Fu. 2014. “Scenario Analysis of Energy-Based Low-Carbon Development in China.” *Journal of Environmental Sciences (China)* 26 (8): 1631–40. https://doi.org/10.1016/j.jes.2014.06.003.