ANALYZING THE EFFECTS OF SOLAR PHOTOVOLTAIC SYSTEMS IN TÜRKİYE BY A COMPUTABLE GENERAL EQUILIBRIUM MODEL

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

EZGİ İPEK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF ECONOMICS

SEPTEMBER 2023

Approval of the thesis:

ANALYZING THE EFFECTS OF SOLAR PHOTOVOLTAIC SYSTEMS IN TÜRKİYE BY A COMPUTABLE GENERAL EQUILIBRIUM MODEL

submitted by **EZGİ İPEK** in partial fulfillment of the requirements for the degree of **Master of Science in Economics, the Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Sadettin KİRAZCI
Dean
Graduate School of Social Sciences ____________________

Prof. Dr. Dürdane Şirin SARAÇOĞLU
Head of Department
Department of Economics ____________________

Assoc. Prof. Dr. Pınar DERİN GÜRE
Supervisor
Department of Economics ____________________

Examining Committee Members:

Prof. Dr. Ebru VOYVODA (Head of the Examining Committee)
Middle East Technical University
Department of Economics ____________________

Assoc. Prof. Dr. Pınar DERİN GÜRE (Supervisor)
Middle East Technical University
Department of Economics ____________________

Assoc. Prof. Dr. Ahmet Atıl AŞICI
İstanbul Technical University
Department of Management Engineering ____________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Ezgi İPEK

Signature:

ABSTRACT

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İPEK, Ezgi
M.S., The Department of Economics
Supervisor: Assoc. Prof. Dr. Pınar DERİN GÜRE

September 2023, 106 pages

Due to its geographical and climatic conditions, Türkiye has a high potential for solar photovoltaic energy. The crucial aspect of this potential is analyzing whether it can turn into domestically produced energy, as the energy supply is already highly dependent on imports, especially fossil fuels. Türkiye Photovoltaic Technology Platform (TFTP) aims to promote high-efficiency solar PV cells and panels, and it is expected that the increased share of domestic production from solar PV energy will have positive macroeconomic and economic effects. This thesis aims to analyze whether the expected outcomes of TFTP can be achieved using a Computable General Equilibrium Model (CGE) for Türkiye. No other study for Türkiye uses CGE to focus on sole impacts of solar PV energy. An electricity sector detailed social accounting matrix for Türkiye is constructed for 2021 for the model. It is the most detailed and recent SAM for Türkiye. For the scenario, it is assumed that the productivity of solar PV electricity production will increase due to the actions taken by TFTP. The environmental impacts of the shock are calculated based on the avoided carbon emissions. The results indicate that the output, domestic production, and exports of solar PV electricity increased, along with the other electricity sectors. Other affected sectors are the ones that are highly related to solar PV and have high energy intensity.

Moreover, the macroeconomic effects of the shock coincide with the expected results. Also, high levels of carbon emission can be avoided if solar PV electricity replaces fossil fuels.

Keywords: Computable General Equilibrium Models, Social Accounting Matrix, Solar Photovoltaic Energy, Carbon Emissions, Türkiye

ÖZ

TÜRKİYE'DEKİ GÜNEŞ FOTOVOLTAİK SİSTEMLERİNİN ETKİLERİNİN HESAPLANABİLİR GENEL DENGE MODELİ İLE ANALİZİ

İPEK, Ezgi
Yüksek Lisans, İktisat Bölümü
Tez Yöneticisi: Doç. Dr. Pınar Derin Güre

Eylül 2023, 106 sayfa

Türkiye coğrafi ve iklim koşulları nedeniyle güneş enerjisi açısından yüksek bir potansiyele sahiptir. Güneş enerjisi ile ilgili en önemli tartışmalardan biri, bu potansiyelin yerli enerjiye dönüştürülüp, zaten büyük ölçüde fosil yakıtlara bağımlı olan enerji arzına katkı sağlayıp sağlayamayının analiz edilmesidir. Türkiye Fotovoltaik Teknoloji Platformu (TFTP), yüksek verimli fotovoltaik güneş hücre ve panellerinin yerli üretimini arttırmayı amaçlamaktadır ve fotovoltaik güneş enerjisinden yerli üretimin payının artmasının olumlu makroekonomik ve ekonomik etkilere sahip olması beklenmektedir. Bu tez, Türkiye için Hesaplanabilir Genel Denge (HGD) Modeli, CGESOLAR, kullanarak TFTP'den beklenen sonuçlara ulaşılıp ulaşılamayacağını analiz etmeyi amaçlamaktadır. Türkiye için yapılan başka hiçbir çalışmada HGD modeli kullanılarak yalnızca güneş enerjisinin etkilerine odaklanılmamıştır. CGESOLAR için 2021 yılı için Türkiye elektrik sektörü detaylı sosyal muhasebe matrisi oluşturulmuştur. Oluşturulan matris Türkiye için en detaylı ve güncel olandır. Senaryo için TFTP'nin aldığı aksiyonlar sayesinde fotovoltaik güneş elektrik üretiminin verimliliğinin artacağı varsayılmaktadır. Şokun çevresel etkileri, kaçınılan karbon emisyonlarına göre hesaplanmaktadır. Sonuçlar, fotovoltaik güneş elektrik üretimiyle beraber diğer elektrik sektörlerindeki üretiminin, yerli üretiminin ve ihracatının arttığını göstermektedir. Etkilenen diğer sektörler ise güneş enerjisiyle

yüksek oranda ilişkili olan ve yüksek enerji yoğunluğuna sahip olan sektörlerdir. Üstelik şokun makroekonomik etkileri de beklenen sonuçlarla örtüşmektedir. Ayrıca, fotovoltaik güneş ten elde edilen elektrik fosil yakıtların yerini alırsa yüksek düzeyde karbon emisyonun önlenebileceği hesaplanmıştır.

Anahtar Kelimeler: Hesaplanabilir Genel Denge Modeli, Sosyal Muhasebe Matrisi, Fotovoltaik Güneş Enerjisi, Karbon Salınımı, Türkiye

To my beloved family

ACKNOWLEDGMENTS

First, I would like to express my gratitude to my advisor, Assoc. Prof. Dr. Pınar Derin Güre for her guidance, advice, and contributions. Without her, I would not be able to experience learning and researching a field I enjoy. Also, I would like to thank my examining committee members, Prof. Dr. Ebru Voyvoda and Assoc. Prof. Dr. Ahmet Atıl Aşıcı for their valuable comments and suggestions.

I would like to thank the SOLARSOS project team; it has been a privilege to be part of this project and to be able to work with them.

Most importantly, I would like to express my gratitude to my dear family, Adnan, Feride, and Aslan İpek, for their continuous support and encouragement throughout my long years of education.

Finally, I would like to thank Fırat Koçlu, my best companion and biggest supporter during my academic journey. Without him, this thesis would not have been completed.

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LIST OF ABBREVIATIONS

CES Constant elasticity of substitution
CET Constant elasticity of transformation
CGE Computable General Equilibrium
CS Concentrated Solar
EPDK Republic of Türkiye Energy Market
ETS Emission Trading System
GAINS Greenhouse Gas and Air Pollution Interactions and Synergies
GAMS General Algebraic Modeling System
GDP Gross domestic product
IEA International Energy Agency
IO Input-Output
kWh Kilowatt Hours
MENR Ministry of Energy and Natural Resources
MTCO2 Metric Tons of Carbon Dioxide
OLS Ordinary Least Squares
PV Photovoltaic
PVOUT Photovoltaic Power Potential
SAM Social Accounting Matrix
TEİAŞ Turkish Electricity Transmission Corporation
TFTP Türkiye Photovoltaic Technology Platform
TURKSTAT Turkish Statistical Institute
VAR Vector Autoregression
YEKA Renewable Energy Resource Areas
YEKDEM Renewable Energy Support Mechanism

CHAPTER 1

INTRODUCTION

The energy demand in Türkiye has been increasing rapidly due to economic improvements and population growth. However, the demand increase also brings import dependency as Türkiye meets a high portion of its energy supply from imports, especially fossil fuels. Almost all-natural gas is imported, domestic oil production is %7 of total demand, and although coal has a higher share of domestic production, Türkiye still imports 58% of its coal (IEA, 2021). High reliance on imports for energy supply weakens the country's energy security and threatens the production processes, leading Türkiye to prioritize protecting and improving its energy supply and sustainability. Also, the domestic and global events force Türkiye to focus on sustainable energy systems. Starting from the COVID-19 pandemic, problems related to energy supplies emerged, and they were accelerated due to increasing prices, mainly due to Russia's Ukraine invasion.

Moreover, ratifying the Paris Climate Agreement in October 2021 and the commitments related to zero emissions requires Türkiye to pace the energy transition, as the current energy mix relying heavily on fossil fuels will not help Türkiye to achieve its goal. In addition, the Kahramanmaraş-centered earthquake on February 6, 2023, followed by the flood disasters in the region, led to significant loss of life and property and showed the energy supply's vitality after a natural disaster (SHURA, 2022). Therefore, renewable energy resources are the most prominent solution for the country to overcome these problems and the energy transition.

The share of renewable energy resources has increased enormously in Türkiye in the last decade, led by government policies favorable resource endowment; especially electricity from renewables almost tripled (IEA, 2021). The most affected sectors are solar, wind, and geothermal. Solar energy is focused highly on the Türkiye's potential due to its climatic and geographical conditions. Electricity production is the leading indicator for the discussion of energy sources. The share of renewable energy resources in electricity production is expected to reach 54.7% by 2035, and the installed capacity of solar energy is the highest contributor to this share (MENR, 2022). One of the most prominent discussions about installing solar systems is whether they are domestically produced. Unfortunately, the share of domestic production in solar electricity is not high enough for Türkiye to meet its potential, as it is not the leader in the sector and depends on the import of technology, production processes, infrastructure, and raw materials (IEA, 2021). Therefore, although the share of renewable electricity increases, the import dependency of the sector remains, which is an issue that has to be overcome.

Türkiye Photovoltaic Technology Platform (TFTP) was formed to contribute to the domestic production of solar photovoltaic (PV) technologies in Türkiye by bringing together companies, R&D organizations, small and medium enterprises, and researchers in the area. It aims to promote domestic production and development of high-efficiency solar cell types and related technologies at all levels. The improvements in solar PV technologies led by TFTP are expected to contribute to countries' economic growth, decrease import dependency in the energy sector and current account deficit, create employment, and have a positive environmental impact. This thesis aims to analyze whether the improvements in the solar PV electricity sector resulting from the actions of TFTP bring the expected results in the leading economic indicators and environment. A static computable general equilibrium model (CGE), CGESOLAR, will be used to analyze whether the desired results can be achieved. No other study focuses on the pure impact of the solar photovoltaic electricity sector for Türkiye.

CGE models are suitable for such analysis as they can show how the selected variables react to an introduced shock or a policy change in the economy. CGE models unite all economic actors, producers, households, firms, and government and present their behavior via the equations. Based on their optimal behavior and assumptions, the economy reaches an equilibrium. After that, a distortion is introduced, and one can observe how the variables form to get a new equilibrium. CGE models are based on the Social Accounting Matrixes (SAM), a balanced square matrix showing the relationships between the economic agents. A SAM for Türkiye will be formed for CGESOLAR. The formation of the SAM includes several steps, starting from the Input-Output (IO) table of Türkiye, the latest format published in 2012. Using the sectoral information from the 2012 IO table, 2021 SAM will be obtained by collecting the necessary data. There are no separate sectors for solar electricity in the IO table. Therefore, the electricity sector will be disaggregated to get the solar industry, and the primary discussion will be formed around electricity production. There is no other information related to further disaggregation of the solar sector; therefore, it is assumed that the PV systems produce all solar electricity.

To our knowledge, the 2021 SAM for Türkiye is the latest and most detailed one; no other SAM for Türkiye presents the electricity sector as detailed as this one. After the disaggregated and detailed 2021 SAM is formed, it will be calibrated to the CGESOLAR to obtain the baseline results. The shock presenting the implications of TFTP will be based on the National Energy Plan (MENR, 2022). According to the Plan, the share of solar PV electricity production is expected to reach %16.5. This share is %2.54 for 2021, based on the electricity production data published by TEİAŞ. It will be assumed that this increase will occur due to TFTP and will be expressed as an efficiency improvement. After this shock is introduced to CGESOLAR, the new results will be compared with the baseline, and whether TFTP achieves the promised goals will be analyzed. For the formation of the CGESOLAR and the introduction of the shock, GAMS will be used.

Also, improving domestic production from solar PV electricity will have environmental implications, as it is a form of clean energy, as opposed to fossil fuels, which are dominant in the electricity sector of Türkiye. The environmental effects will be based on the carbon emissions. The need for fossil fuels will decrease once the electricity production from solar PV improves. It will be assumed that the new electricity production from solar PV will replace the electricity production from fossil fuels. The avoided carbon emissions will be calculated based on these replaced production values.

The result of CGESOLAR indicates that the efficiency improvements in the sector led to output growth, increased domestic production and exports, and decreased import levels. The most affected sector due to the shocks is the ones most related to solar PV, the other electricity production sectors, from renewables and non-renewables, Iron & Steel, Electronics, and Mining. These sectors are energy-intensive and used in the different solar PV electricity production processes. Moreover, the shock led to improvements in the GDP, current account deficit, and a decrease in unemployment for Türkiye. In addition, replacing domestic solar PV electricity with fossil fuels decreases carbon emission levels.

The rest of the study is organized as follows. In Chapter 2, the literature on the subject is reviewed. In Chapter 3, the solar PV energy in Türkiye will be presented. Chapter 4 explains the construction of the SAM used in CGESOLAR. In Chapter 5, the details of the CGESOLAR are given. Chapter 6 introduces the scenario and gives the model results, and Chapter 7 presents the conclusion.

CHAPTER 2

LITERATURE REVIEW

CGE models combine the abstract equilibrium structure with real economic data to solve and simulate the supply, demand, and price that support equilibrium (Wing, 2009). They bring about the agents and structure representing the economy and show how the reaction to a change in one of the variables channeled through the economy. The CGE models are helpful for policy analysis for any subject, and they are appealing because they are flexible and can be extended according to the research needs. One can shape the production structure as desired, disaggregate the sectors, and choose the model's scope as needed, as long as the necessary data is available. The theoretical design of CGE models allows one to interpret the changes in terms of the agents in the model and track flows of factors of production and goods in the economy (Cai & Arora, 2015).

CGE models can analyze various energy-related aspects and the possible problems in the energy structure, such as climate change, energy efficiency, energy subsidies and taxes, renewable integration, and energy security. A bibliometric analysis is conducted to see how the energy issues are investigated in the CGE models. Combining the selected energy and CGE modeling subjects, bibliometric research shows the relationship between publications, authors, journals, and related information. The analysis uses the keywords "CGE" and "Energy" from 1990-2020. The data is retrieved from the Web of Science, and Vos Viewer is used for illustrations. There are 715 publications on the subject. Figure 1 shows the number of studies on CGE models and energy based on years. The number of studies has an increasing trend with minor fluctuations.

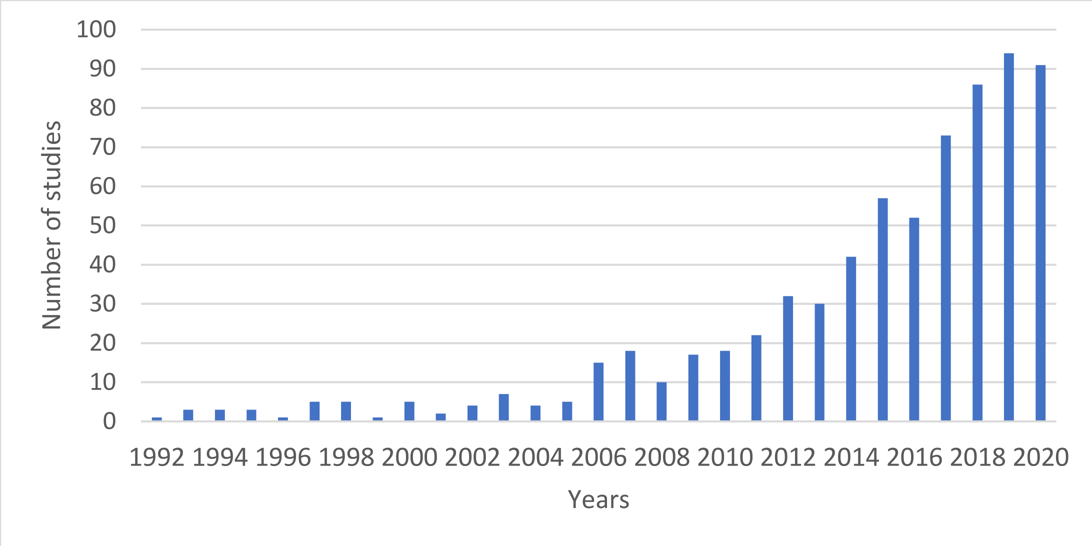
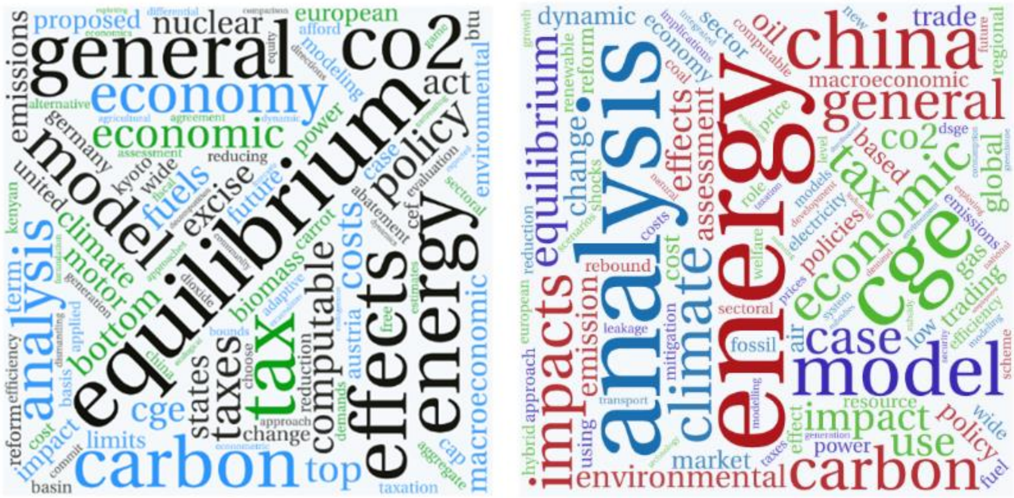


Figure 1: Number of studies per year

These recent energy issues caused countries to take measures and act together, and there is an international effort to overcome the problems. The number increased primarily after 2005, which was the year that the Kyoto Protocol entered into force. Therefore, the implications of the Kyoto Protocol can explain the increase after 2005, as the Kyoto Protocol presented the concerns related to climate change and binds developed countries to follow emission targets (Böhringer, 2003). The number of publications increased even more after 2015, with a slight decrease in 2016. The adaptation of the Paris Agreement in 2015 may explain this trend since the focus on energy analysis gains pace as the parties in the Paris Agreement are obliged to make and pursue pledges for nationally determined contributions related to emission reduction, both for developed and developing countries (Horowitz, 2016). The number of studies reached its peak in 2019, with 96 publications. Similar to the Kyoto Protocol and the Paris Agreement, the formation of the European Green Deal in 2019 may explain the peak. These energy-related discussions bring about different research areas for all the countries as their structures require them to react differently to similar concerns. Therefore, as these subjects are focused more, CGE models have become more dominant for the analysis because they can address such issues at the national, regional, and global levels. Moreover, the CGE models for energy-economic-environmental analysis can cover central economic indicators (Böhringer & Löschel, 2006).



1990-2004

2005-2020

Figure 2: World Clouds

The data used for bibliometric analysis is divided into two periods: 1990-2004 and 2005-2020, and Figure 2 shows the world clouds for these two periods. The division is from 2005 because the number of publications increased, especially after this year. The aim is to see whether there is a new focus on the second period. As seen, there are no significant word differences between the two periods. Equilibrium, energy, carbon, analysis, policy, tax, and economy dominate both periods. The main difference between the two periods is that "China" became a dominant word for the second period because many articles focus on analyzing energy in China in this period.

Table 1 shows the top 15 journals in the field based on the records in the dataset. The local citation score shows the total citations of a paper within the searched group. In contrast, the global citation score presents the total number of citations in the Web of Science collection. Energy Economics and Energy Policy have the highest record compared to the other journals. Journal of Cleaner Production, Applied Energy, and Energy followed the two top journals with similar publications. The citation scores are consistent with the publication records of the journals.

Table 1: Top 15 Journals

	Journal	Records	Percent	Local Citation Score	Global Citation Score
1	ENERGY ECONOMICS	97	13,6	522	2872
2	ENERGY POLICY	91	12,7	418	2172
3	JOURNAL OF CLEANER PRODUCTION	31	4,3	78	394
4	APPLIED ENERGY	29	4,1	258	1294
5	ENERGY	29	4,1	175	722
6	ENERGIES	18	2,5	25	175
7	SUSTAINABILITY	16	2,2	8	62
8	ECOLOGICAL ECONOMICS	15	2,1	103	524
9	ENVIRONMENTAL & RESOURCE ECONOMICS	14	2	28	409
10	ECONOMIC MODELLING	13	1,8	26	158
11	CLIMATE POLICY	12	1,7	20	122
12	APPLIED ECONOMICS	10	1,4	14	61
13	CLIMATE CHANGE ECONOMICS	10	1,4	0	30
14	ENERGY JOURNAL	9	1,3	15	110
15	JOURNAL OF POLICY MODELING	9	1,3	66	262

Figure 3 shows the network of citations and documents in the field based on the bibliometric analysis. There are 26 clusters in the network. The authors in the network are close to the central nodes; the data has no outliers. The most crowded cluster is the red one, with 43 documents. It includes the different authors' work, and the main focus of this cluster's publications is China's policies on climate change, focusing on carbon emissions. There are 38 documents in the second cluster, the green one, and the main focus of these documents is climate change, mitigation, and targets.

In addition, in the purple cluster, energy efficiency issues are considered. The light blue cluster is about the implications of the Kyoto Protocol. Different from the others, some groups focus on the different types of CGE models. For instance, the brown cluster consists of articles using dynamic stochastic general equilibrium models. The orange cluster presents how the hybrid CGE models can be constituted by combining top-down and bottom-up approaches. Therefore, based on the most crowded clusters, the leading areas in the literature utilizing CGE models are carbon emissions, pollution, deployment of renewable energy sources, carbon tax, energy efficiency, energy policy, and climate policies.

The global energy-related CO2 emission grew by 0.9% in 2022 and reached a new peak (IEA, 2023). Therefore, carbon emission analysis has become more crucial for countries, and CGE models are one of the most used tools. For example, Vandyck et al. (2016) used a global CGE model covering 38 regions with a technology-rich bottom-up energy system model to assess the Paris Agreement and its mitigation policies. Similarly, McFarland et al. (2004) used a dynamic multi-regional CGE model of the world economy for analyzing the low-carbon emitting technologies.

Related to the literature on carbon emission, the emission trading system (ETS), relocation effects, and carbon leakage are also discussed widely by the CGE models. In an ETS, the entity responsible for emissions must hold allowances to match their emissions over a given time frame (IEA, 2010). However, it is acknowledged that unilateral regulation of carbon emissions may induce industries to relocate to other countries with less stringent environmental targets, which is the main channel of carbon leakage (Schmidt & Heitzig, 2014). Therefore, relocation can weaken the effectiveness of climate change mitigation policies (Antoci et al., 2021). Babiker (2005) used a multi-regional CGE model to investigate the possible relocation effects. The question is whether the carbon emission obligations imposed by the Kyoto Protocol caused relocation in energy production for developed countries.

Thanks to its oligopolistic structure and increasing returns to scale, the model can present strategic interactions among the firms, showing that the relocation effects may cause more carbon emissions than intended. Thepkhun et al. (2013) constructed a CGE model to analyze mitigation measures under ETS in Thailand. Similarly, Kuik & Hofkes (2010) focused on the implications of border adjustment measures in the European Union ETS for sectors subject to carbon leakage and their competitiveness using a multi-region CGE model. The focus on ETS is exceptionally high for countries with relatively high carbon emission rates.

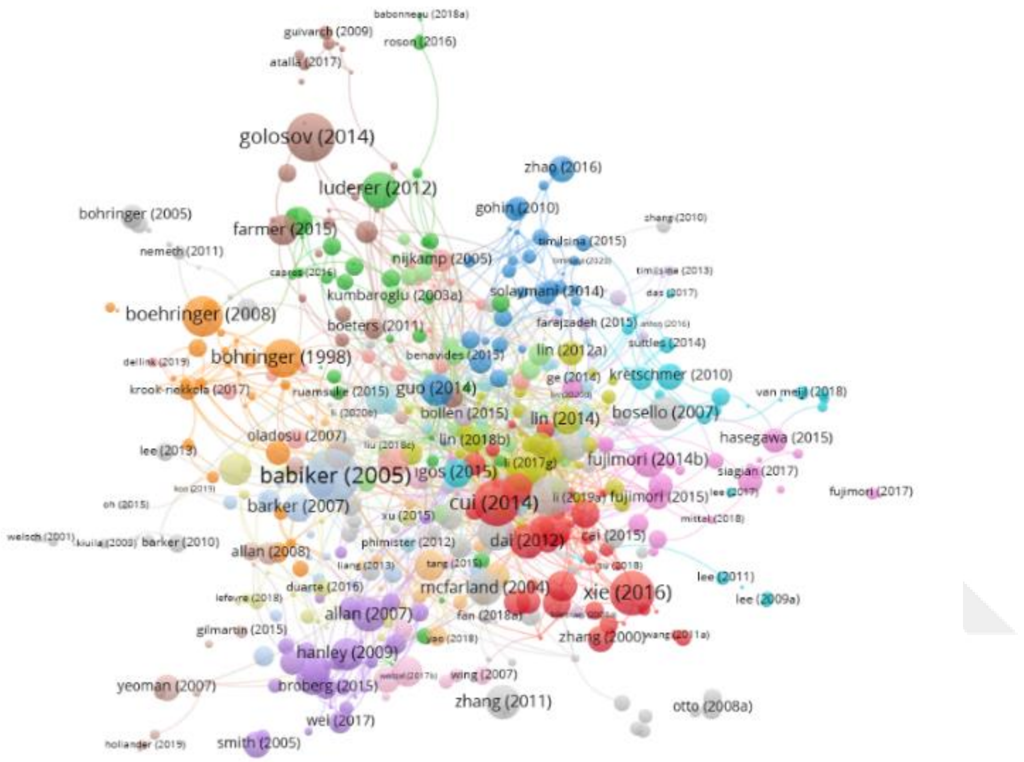


Figure 3: Document Citation Network

Figure 4 shows the distribution of publications across countries based on the bibliometric analysis. China has the highest records since the top institutions are in these countries. There is research on China as it strongly relies on energy-intensive industries for economic development, making China the world's largest energy consumer in 2009, and its reliance on coal has made it the biggest emitter of energy-related CO2 since 2005 (IEA, 2021). At the same time, there is an effort to reorientate these trends and adopt a more environmentally friendly energy structure. Therefore, there are a lot of studies focused on China. For example, Li & Jia (2016) used a dynamic-recursive CGE to simulate scenarios related to ETS and its effects on China's economy and environment.

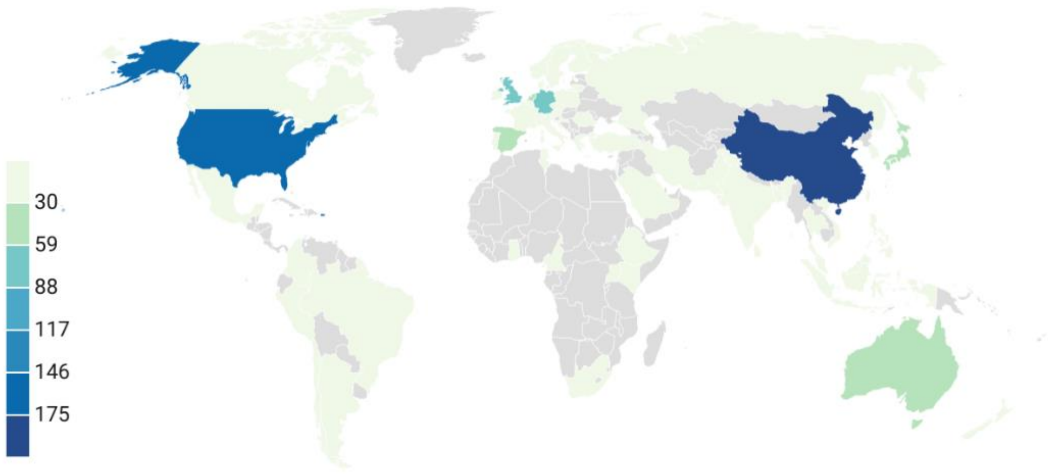


Figure 4: Distribution of publications across countries

In addition, Hübler et al. (2014) used a multi-sectoral CGE model to analyze the economic impacts of the ETS scheme in China. The CGE models do not have to be country-specific; the model can be regional or provincial. For example, Liu et al. (2017) used a multi-regional CGE to investigate ETS's economic and environmental effects in Hubei province, China. Wang et al. (2015) used a dynamic CGE model with two regions of China (Guangdong & Rest of China) to analyze the impacts of the carbon ETS policy on the energy-intensive sectors. Similarly, Wu et al. (2016) evaluated the economic implications of ETS policy by a static CGE model for Shanghai, China.

The CGE model can also analyze another crucial aspect of the all-energy-related subjects and pollution. Xie et al. (2016) used a CGE model and the exposure-response functions to analyze PM2.5 pollution-related health impacts both on the national and provincial economy of China and evaluated how the health issues caused by the pollution affect macroeconomy and what the costs and benefits once the pollution improves. Dong et al. (2015) combined a CGE model with the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) to project future CO2 and air pollution emissions in China and what will be the reduction costs and co-benefit effects.

In addition, Nam et al. (2010) used a CGE model to estimate the socioeconomic impacts and costs of air pollution for 18 European countries, as the CGE models can describe savings and investments, and resource re-allocation implications of lost labor, leisure, and demands on the health sector.

Another area covered by CGE models is the energy-related tax and subsidies, which are the essential ingredients of macroeconomic policy, especially for developing countries on the road to reaching energy and environmental targets (Lin & Jiang, 2011). For instance, Liu & Lu (2015) utilized a dynamic CGE to investigate the impacts of carbon tax and tax revenue recycling schemes on China's economy. There are 137 sectors in this model and three input factors (labor, capital, land), showing that the CGE models can be extended as needed. In a similar study, Guo et al. (2014) analyzed the effects of a carbon tax on China's economy and carbon emissions with a disaggregated energy sector based on energy use characteristics. Lin & Jiang (2011) used a CGE model to analyze the economic impacts of the energy subsidy reforms in China. Beck et al. (2015) CGE with disaggregated households based on annual income to focus on the distributional implications of Canada's revenue-neutral carbon tax policy. Again, Liu et al. (2018) CGE model for Canada to examine and analyze the direct and indirect impacts of a carbon tax. Allan et al. (2014) used an energy-economy-environment CGE model for Scotland to study the effects of carbon tax. In addition, Freire-González & (2019) utilized a dynamic CGE model with a high level of industry details for Spain to assess the economic and environmental effects of a carbon tax, with the primary goal of reducing CO2 emissions. Unlike the discussed work, Van Heerden et al. (2006) used a CGE model for Africa with a detailed labor structure to determine if the revenues raised from an energy-related environmental tax are recycled into households and industries by lowering existing taxes. This model has seven labor categories: legislators, professional workers, technicians, clerks, service industry workers, skilled agricultural workers, and craftsmen.

Energy efficiency and the rebound effects are another emerging topic in the CGE model literature. The rebound effect determines how behavioral changes offset energy efficiency improvements (Böhringer & Rivers, 2021). Allan et al. (2007) utilized an economy-energy-environment CGE model for the UK to measure the impact of the advancements in the efficiency of energy use in all production sectors and the rebound effects. Similarly, Turner (2009) used a CGE model to focus on how energy efficiency may cause rebound effects in the UK. Hanley et al. (2009) focused on the same question as others for Scotland's economy, AND Koesler et al. (2016) for Germany. Any other energy-related issue can also be analyzed using a CGE model. For example, O'Neill et al. (2012) investigated the implications of urbanization with the consequences of energy use and carbon emissions in India and China.

In addition, Malliet et al. (2020) used a CGE model to assess the environmental and energy policy's impact of the lockdowns in France during COVID-19. Similarly, Lahcen et al. (2020) evaluated the macroeconomic implications of the COVID-19 crisis for Belgium based on the CO2 emission scenarios using a CGE model. Cabalu et al. (2015) used a CGE model of the Philippine economy to analyze the effects of climate change policy options such as future emission growth, carbon tax, and energy efficiency.

Other than these issues, the most prominent energy subject studies using CGE models are the deployment and implications of renewable energy resources, which is also the main research area of this work. Various studies focus on how promoting more renewable energy resources affects countries' economic and environmental indicators. For example, Dai et al. (2016) analyzed the economic and ecological impacts of large-scale renewable energy development in China toward 2050, using a dynamic CGE model with distinguished improvements in the power sectors. Qi et al. (2014) used a CGE model to evaluate the energy and CO2 emission impacts of China's renewable energy development. In addition, Chatri et al. (2018) also employed a CGE model to assess and compare the effects of two methods of providing funds for encouraging the development of renewable energy production. O'Ryan et al. (2020) investigated the economy-wide impacts of renewable energy expansion in Chile's energy mix based on a CGE model, examining different CO2 baseline scenarios.

Also, there is research on renewable energy resources separately. For instance, Taheripour et al. (2010) examined how policies encouraging bioenergy production affect the economy and the environment.

Hoefnagels et al. (2013) analyzed the economic implications for value-added, employment shares, and the trade balance of substituting fossil resources with biomass for energy in the Netherlands.

On the other hand, Dai et al. (2016) assessed the key factors affecting global onshore wind energy penetration by 2050 by combining a wind resource model and a CGE. Graziano et al. (2017) evaluated the macroeconomic effects of an expansion in the UK offshore wind sector by the CGE model. Similarly, Qu et al. (2021) assessed the impacts of expanding the scale of offshore wind farms from a macroeconomic perspective by using a CGE for Scotland.

There are also studies for analyzing the impact of nuclear energy. For example, Almutairi et al. (2018) assessed the economic, social, and environmental effects of renewable and nuclear energy targets for global electricity generation by 2030 by using a CGE model. The analysis is for different regions: Saudi Arabia, the US, China, India, Europe, and ROW.

Although solar energy deployment is also discussed with the help of the CGE modeling in the literature, its analysis is usually combined with other renewable energy resources. For example, Bachner et al. (2019) quantified the macroeconomic effects of improvements in wind and PV in Europe by a global, multi-regional, multi-sectoral CGE. A few studies are analyzing solely the implications of solar energy for the economy and the environment. The most prominent work is Cansino et al. (2014). This study investigates the socioeconomic effects of increasing the production capacity of photovoltaic solar energy in Andalusia, Spain, using a CGE model.

Following Cansino et al. (2014), this study aims to constitute a static CGE model for Türkiye, CGESOLAR, analyzing the effects of promoting domestic photovoltaic solar energy production. The model will be based on the electricity sector detailed 2021 SAM, which is constituted based on the 2012 IO table for Türkiye. There is no other work that solely focuses on photovoltaic solar energy. In addition, the 2021 SAM for Türkiye is the latest compared to the rest of the literature.

The following discussion provides the framework for how CGE models are used to discuss Türkiye's energy issues and how these models are similar or different from the CGESOLAR that will be formed for this research.

The literature for Türkiye also includes research on the subjects mentioned earlier. For instance, Karapınar et al. (2019) used a CGE model to analyze how the macroeconomic indicators of Türkiye are affected by a carbon tax and ETS. The scenarios are introduced based on the Intended Nationally Determined Contribution (INDC) and different government options to follow by 2030. et al. Telli et al. (2008) utilized a CGE model to focus on the economic implications of the policy scenarios that complied with the Kyoto Protocol. They focused mainly on CO2 emissions as the key indicator of environmental pollution. In addition, Olçum & Yeldan (2013) studied the mechanisms of adjustment and economic welfare consequences of various ETS regimes that Türkiye considers to apply by using a multi-region, multi-sectoral CGE. In addition, Kat et al. (2018) assessed the implications of the Paris Agreement by using a CGE model for Türkiye, with a detailed representation of the power sector. CGESOLAR will not focus directly on these introduced subjects as it does not include differentiated CO2 emissions based on production levels, as in Telli et al. (2008). There is no regional differentiation in the model like Olçum & Yeldan (2013), and it is a static model as opposed to the recursive dynamic structure introduced by Kat et al. (2018). However, there are also similarities. Karapınar et al. (2019) added unemployment in the model and disaggregation of the energy sectors based on their resource. Also, the shock is based on productivity improvements in the renewable energy sectors. CGESOLAR will follow similar approaches in these aspects.

Studies primarily focus on the implications of other policy instruments and alternatives. The discussion usually concerns whether the different policies bring up economic growth and employment and affect Türkiye's carbon emissions levels. For example, Kumbaroğlu (2003) studied the implications of environmental policy decisions on adopting energy technologies and socioeconomic indicators using an energy-economy-environment CGE model. The model aggregated the energy sectors into three main sectors: electricity, oil and gas, and soils, which indicates less sectoral details than CGESOLAR. In addition, Akkemik & Oğuz (2011) examined the potential

impacts of full liberalization on efficiency and competition in the electricity market, using a CGE model, and analyzed the effects of the deregulation on the economy. Although the electricity sector is disaggregated, as intended for CGESOLAR, the disaggregation levels differ. Here, the disaggregation includes electricity generation, transmission, and distribution. However, CGESOLAR will disaggregate electricity production based on energy resources. Bouzaher et al. (2015) developed a CGE model to examine the impact of green policy instruments and public policy intervention mechanisms to accelerate technology adoption and sustainable growth. Also, Kolsuz & Yeldan (2017) implemented a CGE model to study the synergies between environmental abatement instruments and policies toward sustaining green jobs. These models are different from CGESOLAR because they are dynamic and include greenhouse gases and pollution into the models. Yeldan et al. (2015) assessed the impacts of climate policy instruments and public policy intervention mechanisms, and they focused on the carbon emissions from both firms and households and the relevant market instruments of abatement. The electricity sectors are distinguished based on renewable energy sources, especially solar and wind.
Moreover, Sahin (2004) used a CGE model to analyze the interactions between Türkiye's environmental and economic policies. The model is regionally disaggregated based on the industrialization levels of the regions of Türkiye.

Unlike these subjects, Aydın & Acar (2011) analyzed how the oil price shocks affect the Turkish economy using a dynamic multi-sectoral CGE model. Economic impacts include GDP, consumer price inflation, indirect tax revenues, trade balance, and carbon emissions. On the other hand, Aydın & Acar (2010) used a CGE model to measure the economic and environmental implications of Türkiye's possible accession to the European Union. As a different approach than the others and CGESOLAR, there is migration in this model. That is, labor can shift sectors in foreign firms across borders. Moreover, Acar & Yeldan (2016) analyzed the impacts of the energy policy instruments, particularly coal subsidies and their removal implications, on macro-indicators and environmental outcomes in Türkiye, using a regionally differentiated CGE model. The regional differentiation is based on income: High Income vs. Low-Income Regions.

There are other methods to analyze these similar issues, such as IO Analysis, SAM analysis, or econometric models. These methods do not entirely differ; they have similarities and can be used in the same context. For instance, in IO tables, the economy is divided into sectors where each produces an output and goes to other industries or consumption. IO tables allow transparent analysis, rely only on a few assumptions, are quickly built on national accounts, and are easily used for energy analysis. For example, Garrett-Peltier (2017) used IO tables to present clean energy industries and estimated their employment multipliers. In addition, Liu et al. (2010) used IO analysis to evaluate the energy changes embodied in China's exports as the IO framework allows the exploration of power flows into, out of, and within the economy.

On the other hand, SAM gives a picture of the economy for a given period. It can be considered as the extension of the IO tables. While IO tables explain the relationship between the final demand and production, SAM shows the effects of productive processes on demand (Cansino et al., 2014). For instance, Hartono & Resosudarmo (2008) used a SAM for Indonesia to analyze the implications of the energy policies controlling energy use because the multiplier coefficients in SAM can illustrate the policy impact on the household's income distribution. In addition, Cardenete et al. (2012) used SAM for Andalusia to calculate energy intensity and emissions based on different scenarios as SAM completes the information of an IO table and the income distribution and spending in the economy.

Also, econometrics methods such as time series applications, VAR models, and forecasting are highly preferable and expand the study of the interconnected energy markets by providing quantitative arguments related to all actors in the sector, like companies, consumers, governments, and international organizations (Chevalier, 2007). For instance, Leitão (2014) used time series analysis for Portugal to investigate the correlation between growth, emission, renewable energy, and globalization. In addition, Wu et al. (2020) used panel data from the Chinese provinces for 16 years and obtained a stochastic frontier model to measure agricultural energy efficiency at the provincial level. Moreover, Balta-Ozkan et al. (2021) used OLS and geographically weighted regression to investigate the spatial relationship between photovoltaic adoption and socioeconomic explanatory variables. It can be said that the econometric methods are more suitable for forecasting than the policy analysis, as they do not provide an optimization.

These models present a prominent framework to discuss energy issues in the world and Türkiye. However, CGE models offer the macroeconomic analysis for the whole economy and allow one to follow how the changes in one factor are channeled through the rest of the economy. Therefore, it is the most prominent model for this paper as it enables behavioral action and scenario analysis, unlike the static representation of the economy as in the IO tables and SAM. In addition, the CGE models can present the character and magnitude of the economic impacts of different energy and environmental policies (Wing, 2009). Also, CGE models in energy-related subjects show the interaction of energy supply and demand in various sectors or regions in an economy-wide context (Faehn et al.,2019).

CHAPTER 3

SOLAR PHOTOVOLTAIC ENERGY IN TÜRKİYE

This chapter will provide insight into solar photovoltaic energy and how it has evolved in Türkiye throughout the years before leading up to the model and scenario discussion. There are various processes to convert solar energy into usable format, such as heat, kinetic, electricity, and chemical energy (Tyagi et al., 2013). These methods can be summarized in two main types of solar energy technologies: photovoltaic (PV) technology, photo-emissive solar technologies, and concentrated solar power (CSP). While solar PV systems convert sunlight into electricity without requiring a heat engine or interference (Parida et al., 2011), CSP obtains heat, which can be utilized directly or for electricity production. Therefore, solar PV is the primary indicator for electricity production embedded in the CGE model.

In a solar PV system, solar cells consist of materials that receive sunlight and convert sunlight into electrical energy. Batteries are placed into the cells to store the electrons formed, and electrical energy is generated with the voltage here (SHURA, 2020). Solar PV systems can be employed as electricity resources for household and industrial use; moreover, they are clean and sustainable. The benefits of the solar PV systems accelerated the related technology and efficiency improvements. As a result, solar PV energy has become one of the leading renewable energy resources, and the use of solar PV energy has been increasing worldwide over the years. According to the forecast of IEA (2022), the solar PV capacity will expand to the point where it exceeds natural gas by 2026 and coal by 2027, and it is the cheapest option for electricity production for most countries in the world. The solar PV market has improved significantly, especially in Asia, using highly automated production lines, and China is the current global leader in solar PV production and installation (Kost et al., 2013).

The levelized cost of electricity (LCOE) presents the lifetime cost of a plant, considering its construction, operation, and maintenance costs, and it can be used to compare different generation technologies. The global weighted average LCOE for solar PV energy declined by 88% from 2010 to 2021, with the significant role of the developments led by China, followed by India, the United States, Brazil, and Germany (IRENA, 2022). The advancements in cell technologies and increased efficiency lead to cost improvements and reduced costs (PwC, 2021). The decrease in the cost of solar PV energy drives the competition in the sector, and other countries than the leaders achieved critical LCOE reductions: LCOE in Türkiye halved between 2016 and 2021 (IRENA, 2022).

The potential for solar PV energy in Türkiye is high due to its location. There is a high intensity of solar radiation, and large unused areas can be utilized for solar PV (Seker & Kahraman, 2021). The solar energy potential of Türkiye is 380 billion kWh, the average annual sunshine duration is 2766.5 hours per year, and the average yearly radiation intensity is 1527.1 kWh per m2 per year; moreover, the solar energy can be utilized efficiently for up to 110 days in a year (MENR, 2023).

Figure 5 shows the photovoltaic power potential (PVOUT) of Türkiye, based on the Global Solar Atlas (GSA). (World Bank, 2019). The GSA summarized the estimated solar PV power potential based on the average daily and yearly electricity production. It takes solar radiation, air temperature, and terrain into account to analyze the conversion and losses of the solar PV plants. According to Figure 5, the Southeast Anatolia Region has the most significant potential, followed by the Mediterranean Region. These regions' climatic and geographical conditions increase their solar PV energy potential. Conversely, the Black Sea Region has the least potential due to its humid climate and high latitude. The potential of the rest of the regions is similar but not as low as the Black Sea, indicating that overall, Türkiye has a promising potential for solar PV energy production based on its geographical conditions.

However, the solar PV production in Türkiye does not match its high potential. Figure 6 shows the annual development of Türkiye's solar and total electricity production.

TEİAŞ does not provide electricity production from solar PV energy separately; therefore, it is assumed that all solar electricity production is from PV energy.

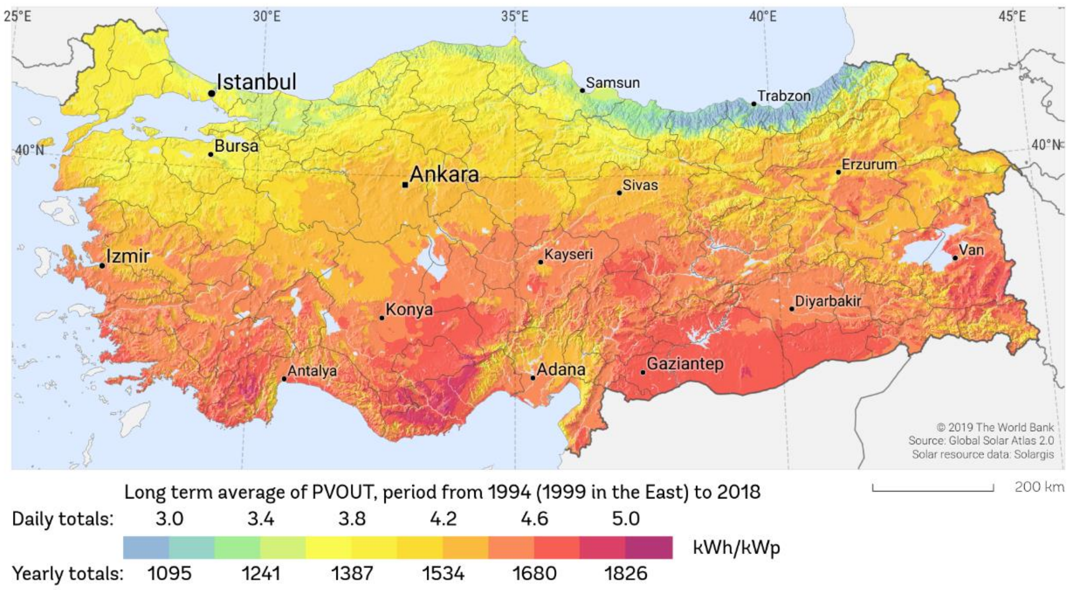


Figure 5: Photovoltaic solar potential of Türkiye based on the Global Solar Atlas by the World Bank (2019)

It shows that the total electricity production in Türkiye has been increasing with minor fluctuations since 2000. Solar electricity production in Türkiye started in 2014 and accelerated rapidly ever since. The increase in electricity production by solar energy was faster during the previous years; it got closer after 2018. However, it increased again in 2021. Compared with the rest of the world and other developing countries, the electricity production from solar PV energy is left behind in Türkiye, although the potential is higher (PwC, 2021).

One of the main results of this is the import dependency of solar PV cells. Considering the increasing trends of the exchange rates in Türkiye, importing the parts of solar PV systems decelerates production. Import dependency is already an issue for Türkiye due to its high levels of imports of fossil fuels. Shifting the production to renewable energy resources, especially solar PV, is a way to overcome import dependency. Therefore, the domestic production of solar PV cells gains importance for the sector to increase energy security for the country.

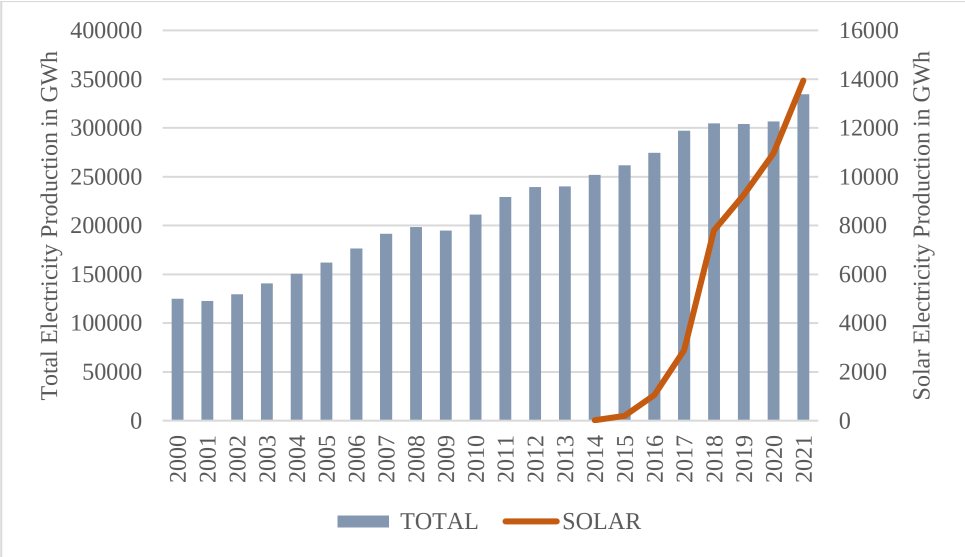


Figure 6: Annual Development of Türkiye's Solar Electricity Production based on TEİAŞ

Besides the import dependency, Türkiye has to deal with its carbon emissions after ratifying the Paris Climate Agreement in 2021. It has to complete its energy transition to meet its net zero greenhouse gas emissions and obtain more sustainable energy systems. Solar PV energy is a vital tool for this aim.

The government has followed various policies to promote Solar PV systems in Türkiye. For example, under the Renewable Energy Support Mechanism (YEKDEM), Türkiye offered feed-in tariffs for renewable power resources, including solar energy. The number of power plants benefiting from the YEKDEM reached 1036, and the operating power of these participants was 22982.1 MW in 2022 (EPDK, 2023).

In addition, the Renewable Energy Resource Areas (YEKA) are implemented as a new investment model to reduce the cost of electricity from renewable energy plants and promote domestic production (MENR, 2023). By focusing on the promotion of the domestic output in solar PV energy and other renewable energy resources, Türkiye aims to achieve self-sufficiency in the energy sector.

As a result, there are various actions to improve R&D, innovation, and technology, especially the domestic production of machinery and equipment used for renewables (IEA, 2021).

CHAPTER 4

CONSTRUCTION OF SOCIAL ACCOUNTING MATRIX FOR TÜRKİYE

4.1 Introduction

CGE models are simulation tools describing the economy through macroeconomic equations and constraints. They answer different questions based on various scenarios and allow measurements of the changes in the economy. Their strength lies in the fact that CGE models take interrelations between the industries and agents into account, and by doing so, they can capture the complexities in the economy. They provide a consistent framework of analysis that incorporates economic actors that can be solved numerically (Bhattacharyya, 1990). CGE models are based on some conditions, such as market clearance, zero profit, and income balance. These conditions allow a model to be solved based on the relative prices and allocate goods and factors supporting the equilibrium.

Every CGE model needs a database to run; in most cases, this database is the SAM. SAM is a square matrix that presents economic transactions and income transfers between the agents and the institutions of the economy. It records the detailed economic interdependencies, from individual production to all institutions (Reinert & Roland-Holst, 1997). While the rows in the SAM present the incomes of the corresponding agent, sector, or institution, the columns show the expenditures. A SAM has to be balanced; that is, the total income of each factor is equal to the total expenditure. SAMs are usually yearly and give the economy's snapshot for the chosen year, referred to as the base year, and CGE models explain the behavior of each flow in the SAM. SAM is a framework to explore macroeconomic and multi-sectoral problems and provides a starting point for detailed models like CGE (Robinson, 1989). After constructing a SAM for the base year, it is assumed that the SAM presents a solution for the CGE model, and parameters are calibrated accordingly. That is, the calibration refers to calculating the intercept and share parameters of the functions of the CGE model to give the base year values, given the exogenous elasticities. Elasticities in the CGE model present the responsiveness of the producers and consumers to changes in the parameters (Burfisher, 2021). The elasticity parameters are usually chosen based on the existing literature and assumptions. After the calibration process is completed, the model has to give the base year SAM without statistical corrections (Acar et al., 2018).

For the CGESOLAR, the base year for the SAM is 2021, which is the most recent SAM for Türkiye, to our knowledge. There are several steps to construct the SAM, summarized in Figure 7. At first, an aggregated 2021 SAM is built based on the necessary data given by the national accounts. However, SAM has to have sectoral details to meet the aims of the CGESOLAR. As the most recent sectoral details for Türkiye are presented in the 2012 IO table, the aggregated 2021 SAM is distributed according to the shares of the 2012 IO table. In the following step, the electricity sector is disaggregated based on the electricity production and the rest of the electricity sector. For this disaggregation, the production values are used. As a final step, the electricity production is further disaggregated based on the primary energy resources used in the production, based on the electricity production. After the detailed 2021 SAM is obtained, CGESOLAR can be run. Further details related to the creation of the SAM will be given in the following section.

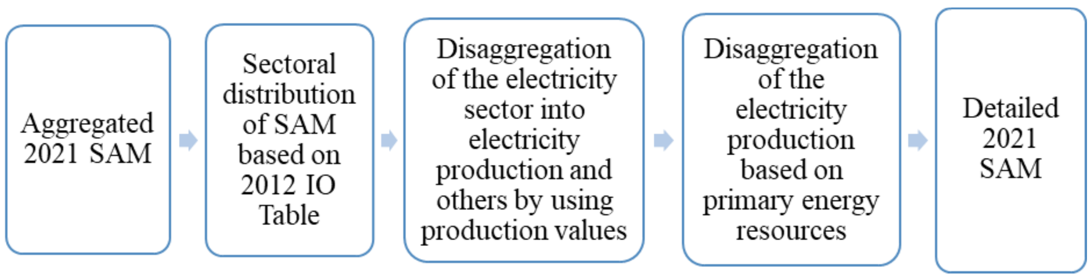


Figure 7: Construction of Detailed 2021 SAM for Türkiye

4.2 Aggregated 2021 SAM

The last available IO Table for Tukiye was published by TURKSTAT in 2012. The table presents inter-sectoral data between the actors: intermediate inputs, household consumption, government consumption, investment, imports, and exports. One can form a 2012 SAM starting from this IO table by adding all the necessary data that complies with the aim of the research. These sectoral details are not available for any year later than 2012. However, more recent aggregated SAM can be formed based on the data. Table 2 shows the data required for any aggregated SAM. The aggregated SAM will be for 2021 because of the officially published data's availability. The 2012 IO table will be combined with this table to create a more detailed SAM for 2021. The entries in the SAM are based on different resources, which will be explained below.

4.2.1 Activities & Commodities

Both activities and commodities are based on the sectors of the economy. Productive activities represent domestic production and how it is channeled into the economy. They use intermediate inputs and factors of production (labor, capital) for production in return for factor payments, which will combine with imports to create the total output. The output is distributed among the domestic sales and exports. On the other hand, goods and services represent domestic sales with indirect taxes other than production tax in the economy. Intermediate inputs are based on the "Institutional Sector Accounts, current prices." Labor income, capital income, and production tax are based on the "Gross Domestic Product by income method. TURKSTAT publishes both. Imports and exports are based on the "General Balance of the Economy," published by the Presidential Strategy and Budget Department. Domestic goods are calculated by extracting exports from the total output. Other indirect taxes consist of import, export, and sales taxes. Export and import taxes are obtained from the "Central Government Consolidated Budget Table," published by the Republic of Türkiye Ministry of Treasury and Finance, Directorate General of Public Institutions. The value that complements the total indirect tax (available at the Public Sector General Balance table) is assumed to be equal to sales tax.

Table 2: Aggregated SAM entries

	Activities	Commodities	Labor	Capital	Firms	Households	Government	Accumulation	Rest of the World	TOTAL
Activities		Domestic good							Exports	**Production**
Commodities	Intermediate Inputs					Household Consumption	Government Consumption	Investment		**Demand**
Labor	Labor income									**Labor income**
Capital	Capital income									**Capital income**
Firms				Capital income			Subsidies		Currency income	**Firm income**
Households			Labor income		Profit transfers		Transfers		Foreign remittances	**Household income**
Government	Production tax	Other Indirect taxes			Corporate tax	Income tax			Net unrequited transfers	**Government income**
Accumulation						Household Saving	Government Saving		Foreign savings	**Total savings**
Rest of the World		Imports			Transfers to row		Transfers to row			**Payments to ROW**
TOTAL	**Output**	**Supply**	**Labor income**	**Capital income**	**Firm Expenditure**	**HH Expenditure**	**GOV Expenditure**	**Investment**	**Income from ROW**	

4.2.2 Government

The majority of the government's income comes from indirect and direct taxes. The indirect tax details are explained in the previous section. Direct taxes include income and corporate tax. While the households pay the income tax, the firms pay the corporate tax. The details for the direct tax are available on the consolidated budget tables, which complete the tax revenue for the government.

In addition, the non-tax revenue is paid by the households, based on the Public Sector General Balance table. The firms make factor payments to the government, whose data is based on the Public Sector General Balance Table. Finally, the government gets net unrequited transfers from the rest of the world.
The data for the unrequited transfers is published by the Central Bank's Balance of Payments Statistics in a million US dollars, converted into Turkish liras using the average exchange rate of 2021.

The government divides its income between transfers, subsidies, and debt interest payments. The TURKSTAT publishes the production subsidies to firms in the GDP table by the income approach. Also, it is assumed that the government makes its domestic debt interest payments to the firms by following Erten (2009). Similarly, the government makes foreign domestic debt payments to the rest of the world. The transfer to the households is assumed to complete the total current transfer payments published by the Public Sector General Balance after excluding the other payments made by the government. The subsidies to firms, domestic debt interest payments, and foreign debt interest payments are excluded from the total current transfer payments to find the transfer to the households based on Erten (2009). The difference between total income and payments to the other economic agents gives the disposable income. The government spends its disposable income on consumption, investment, and savings based on the "General Balance of the Economy."

4.2.3 Firms

Firms' income can be explained as follows. They earn capital income; the government provides production subsidies and pays domestic debt interest payments to the firms. They earn foreign currency income from the rest of the world. The capital income and subsidies are explained in the previous section. The foreign currency income is calculated based on the assumption that the total external resources are equal to the Turkish Lira value of the current account deficit. (Erten, 2009)

The firms make the corporate tax and factor income payments to the government, as explained above. Also, the firms pay foreign debt interest payments, profit transfers abroad, and net profit transfers to households, all based on Erten (2009). The private sector foreign debt interest payments are based on the Balance of Payments Statistics, and it is assumed to be equal to the summation of the Central Bank and the private sector's short-, medium-, and long-term debt interest payments. Net direct investment expenses from the Balance of Payments Statistics are assumed to equal the profit transfers abroad. These values are available as dollars; the average exchange rate in 2021 is used to convert these values to Turkish Liras for the SAM. The complementary value of the total income and the firms' expenses is assumed to be transferred to the households as a net profit share.

4.2.4 Households

The households earn income from their compensation for labor, net profit transfers from the firms, transfers from the government, and workers' foreign remittances. The labor income, net profit transfers, and government transfers are explained in the previous section. The foreign remittances are obtained from the Balance of Payments Statistics and converted into Turkish Lira using the average exchange rate in 2021. The households pay income tax and non-tax revenue to the government. After deducting these payments from the income, disposable income is obtained. The disposable income is divided between consumption, investments, and savings based on the "General Balance of the Economy."

4.2.5 Rest of the World

The income from the rest of the world consists of exports, workers' foreign remittances, currency income of the firms, and net unrequited transfers. In contrast, expenses include imports, private-sector foreign debt interest payments, profit transfers to the firms, and public-sector foreign debt interest payments. The previous sections explain all the listed income and expense data except for the exports and imports. Exports and imports data are obtained from the "General Balance of the Economy" table. The difference between income and expenditure will give foreign savings inputs to the economy equal to the current account deficit. The current account deficit equals the difference between the exports and imports, net factor income, and net unrequited transfers.

4.2.6 Capital Account

Capital account in the SAM represents the investment and savings of the households and the government. In addition, the capital account includes foreign savings.
As explained, indirect taxes will be paid to the government, presented in the SAM under the goods and services. These taxes are income for the government. However, there is no counterpart for this income in the existing data. Therefore, this value should be net for SAM. Otherwise, there is an unused income in the table, distorting SAM's balance principle. Following Erten (2009), this tax income is distributed among the end uses of household consumption, imports, and exports to ensure the SAM's balance. Completing all necessary data, the following aggregated SAM for Türkiye is obtained. Table 3 shows the aggregated SAM for Türkiye in million Turkish Liras (TL).

4.3 Distribution of Sectoral Data

As the most recent IO table for Turkiye is from 2012, to distribute aggregated 2021 SAM into sectors, one should benefit from this table. The sectoral classification of the IO table is based on the Statistical Classification of Economic Activities in the European Community NACE Rev.2. (TURKSTAT, 2013) and the IO table includes 64 production sectors.

Table 3: Aggregated 2021 SAM for Türkiye in Million TL

2021	Activities	Commodities	Labor	Capital	Firms	Households	Government	Accumulation	Rest of the World	TOTAL
Activities		12444.656							2264.153	**14708.809**
Commodities	8082.051					3882.677	664.498	2897.691		**15526.917**
Labor	1947.929									**1947.929**
Capital	4640.475									**4640.475**
Firms				4640.475			283.037		193.622	**5117.134**
Households			1947.929		4760.432		280.819		1.777	**6990.957**
Government	38.354	704.981			309.526	337.296			3.821	**1393.978**
Accumulation						2770.984	122.757		3.949	**2897.691**
Rest of the World		2377.280			47.175		42.867			**2467.322**
TOTAL	**14708.809**	**15526.917**	**1947.929**	**4640.475**	**5117.134**	**6990.957**	**1393.978**	**2897.691**	**2467.322**	

These sectors in the IO table are aggregated into 16 sectors, presenting the leading industries in the economy: Agriculture, Mining, Refined Petroleum, Chemicals, Cement, Iron & Steel, Paper & Print, Food processing, Textiles & Clothing, Machinery, Electronics, Electricity, Construction, Transportation, Other Economy. The sectors of the 2012 IO table are gathered together as follows:

Table 4: Aggregation of the sectors

Abbreviations	**Aggregated Sectors**	**Nace Rev.2. Product Code**
AGR	Agriculture	A-01,02,03
MINI	Mining	B-05,06,07,08
PE	Refined Petroleum	C-19
CH	Chemicals	C-20,21,22
CE	Cement	C-23
IS	Iron & Steel	C-24
PA	Paper & Print	C-17,18
FD	Food processing	C-10,11,12
TE	Textiles & Clothing	C-13,14,15
MW	Machinery	C-25,28
ET	Electronics	C-26,27
AU	Automotive	C-29
EL	Electricity	D-35
CN	Construction	F
TR	Transportation	H-49,50,51,53
OE	Other Economy	The rest

Most entries from the 2021 SAM have to be disaggregated to present the introduced sectors. These entries are intermediate inputs, capital income, labor income, indirect taxes, household consumption, government consumption, investment, exports, and imports. For the disaggregation of these values, Kılınç (2022) will be followed; in this study, she used the 2012 In IO table with the other necessary additional data to create a 2012 SAM and updated SAM for 2019 by taking the share among sectors in the 2012 SAM as the basis for disaggregation of 2019 values. That is, the share of each sectoral value to its total is assumed to be constant for the 2021 SAM. For example, the share of the automotive sector in the total imports for 2012 is kept constant for 2021, too. This procedure is repeated for each sector and each entry in the SAM.

A disaggregated SAM for 2021 is obtained after each sectoral data is distributed based on their calculated shares. Since the sectoral share is based on the explained assumption, the balance of each sector is distorted. Although the aggregated 2021 SAM is in balance, disaggregation causes disturbances in the sectoral aggregates. For example, the total demand for the construction sector does not match its total supply. Therefore, the balance of this SAM has to be ensured.

Different methods to balance SAM exist, such as RAS[1], cross-entropy, and maximum-likelihood estimation methods. For example, for Turkish SAM, Şenerdem (2013) benefited from the RAS method in 2010, whereas Akkemik (2011) used the cross-entropy method to obtain a balanced SAM for 2002. The cross-entropy method is flexible and can incorporate errors in variables, inequality constraints, and prior knowledge about the SAM, not just the rows and columns sum in the case of the RAS method (Robinson et al., 2001). Therefore, the SAM for 2021 will be balanced using the cross-entropy method in GAMS. The cross-entropy method is an estimation technique where sums and macro aggregates present control totals that may be measured with error (Robinson & El-Said, 2000). The estimation adjusts a matrix to its totals to minimize the divergence of the adjusted matrix from the unadjusted matrix (Lemelin et al.,2013). To use the cross-entropy method in GAMS, the unbalanced 2021 SAM based on the sectoral shares 2012 are introduced with the optimization criterion and balance constraints. Most of the values for the non-sectoral entries, such as subsidies, government transfers to households, firms' profit transfers to the households, and the rest of the world, government's foreign debt interest payments are fixed. Choosing the number of fixed variables carefully is vital to avoid non-optimal solutions. Table 6 shows the sectoral detailed 2021 SAM in thousand TL, balanced using the cross-entropy method. As seen, some of the entries in the matrix are empty. These empty entries show that there is no interaction between the sectors or agents in the economy. In addition, when an entry is 0, it means that there is interaction through the years, but it is 0 for the year.

[1] RAS method takes its name from the economist Richard Stone.

4.4 Distribution of the electricity sector

Once the sectoral 2021 SAM is obtained, one can disaggregate the sectors, as desired, to present the best picture of the economy that will comply with the research question. In this case, the primary focus of the SAM is the electricity sector and how increasing the share of photovoltaic solar energy in electricity production will affect the rest of the economy. Therefore, the electricity sector in the SAM can be disaggregated based on the different production resources.

The electricity sector in the SAM represents electricity, gas, steam, and air conditioning supply, and it has three sub-groups based on Nace Rev. 2 distribution: Electric power generation, transmission, and distribution, manufacture of gas, distribution of gaseous fuels through mains, and steam, and air conditioning supply. Table 5 shows the details of the electricity sector.

Table 5: Production values of the sub-sectors of the electricity sector in TLs

Electricity, gas, steam, and air conditioning supply	Production values for 2021
Electric power generation, transmission and distribution	*581710880552*
Production of electricity	229505173565
Transmission of electricity	87574606410
Distribution of electricity	0[2]
Trade of electricity	264631100577
Manufacture of gas, distribution of gaseous fuels through mains	*85871080916*
Manufacture of gas	87039287
Distribution of gaseous fuels through mains	68963291718
Trade of gas through mains	16820749911
Steam and air conditioning supply	*498666566*
Steam and air conditioning supply	498666566

Table 6: Sectoral 2021 SAM in Million TL

[2] Distribution of electricity is 0 based on the production values data published by the TURKSTAT.

	2021.0	Activites (1)																Commodities (2)																3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
		AGR	MIN	PE	CH	CE	IS	PA	FD	TE	MW	ET	AU	EL	CN	TR	OE	AGR	MIN	PE	CH	CE	IS	PA	FD	TE	MW	ET	AU	EL	CN	TR	OE	Labor	Capital	Firms	HH	GOV	ACC	ROW	TOTAL
	AGR																	855.6																						80.7	**936.3**
	MIN																		130.2																					46.1	**176.3**
	PE																			116.2																				110.5	**226.7**
	CH																				312.7																			207.3	**520.0**
	CE																					225.0																		59.3	**284.3**
	IS																						204.9																	366.3	**571.2**
1	PA																							124.9																26.4	**151.3**
	FD																								678.9															176.3	**855.2**
	TE																									381.3														453.8	**835.1**
	MW																										240.3													223.3	**463.6**
	ET																											72.8												191.4	**264.1**
	AU																												59.2											236.0	**295.1**
	EL																													641.3										19.8	**661.0**
	CN																														1562.4									42.4	**1604.8**
	TR																															1053.4								289.4	**1342.8**
	OE																																5508.2							382.6	**5890.8**
	AGR	165.6	0.8	0.0	3.8	0.2	0.0	1.9	286.7	35.3	0.0	0.0	0.0	0.0	0.7	0.1	35.9																				316.3	0.0	84.5		**931.9**
	MIN	2.3	10.9	186.1	13.7	47.1	57.8	1.5	3.9	5.9	1.1	0.7	0.8	160.1	26.8	2.4	17.8																				56.3	0.0	15.4		**610.8**
	PE	22.3	10.3	5.0	4.7	10.0	2.3	0.5	3.0	2.1	2.1	2.3	0.6	2.2	26.4	155.1	69.9																				77.8	0.0	0.6		**397.2**
	CH	47.1	3.8	0.2	224.6	12.5	13.2	16.6	26.8	66.3	11.9	22.0	14.2	0.4	50.2	14.7	92.7																				123.8	5.2	1.4		**747.8**
	CE	0.7	1.1	0.0	3.5	38.8	2.3	0.0	2.5	0.2	2.7	2.1	2.7	0.7	141.4	4.9	29.3																				23.1	0.0	3.8		**259.9**
	IS	0.0	2.0	0.1	3.3	2.2	124.2	0.7	0.5	0.2	125.3	47.9	38.8	0.4	131.0	1.2	31.1																				31.7	0.0	11.7		**552.2**
2	PA	0.6	0.1	0.2	5.7	3.2	1.4	43.2	12.0	6.4	2.2	2.4	0.5	0.4	0.9	2.9	61.1																				30.7	0.0	-3.1		**170.8**
	FD	39.8	0.3	0.1	1.1	0.2	0.1	0.8	134.1	3.5	0.4	0.1	0.1	0.1	0.7	1.3	127.4																				432.6	0.0	4.0		**746.8**
	TE	0.6	0.6	0.0	3.8	1.1	0.4	2.5	1.5	308.8	1.1	0.6	2.1	0.0	0.9	1.3	31.4																				160.6	0.0	-15.9		**501.3**
	MW	1.0	2.1	0.2	4.1	1.1	4.2	0.3	3.3	2.2	48.0	13.8	24.1	0.1	80.8	6.0	38.9																				22.6	0.0	286.8		**539.7**
	ET	0.4	0.5	0.0	0.7	0.8	0.2	0.2	0.6	1.4	8.1	49.4	13.1	3.1	31.5	1.4	46.4																				60.4	0.0	111.3		**329.5**
	AU	1.4	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	5.2	0.2	79.7	0.0	0.2	6.4	14.1																				42.8	0.0	109.0		**259.1**
	EL	4.6	5.5	0.2	11.1	14.5	25.6	2.8	8.5	16.7	6.5	2.2	2.6	340.1	2.3	2.5	87.4																				154.6	0.0	0.0		**687.7**
	CN	1.9	0.5	0.0	1.3	0.5	1.5	0.3	1.7	1.1	1.5	0.3	0.2	2.4	265.8	2.5	81.2																				47.5	0.0	1212.6		**1622.9**
	TR	13.0	9.6	4.9	17.5	10.5	26.1	5.7	31.8	16.3	18.8	8.9	10.7	2.9	30.6	227.4	154.4																				571.9	0.3	32.0		**1193.3**
	OE	46.2	25.7	11.7	78.4	41.5	222.4	28.0	111.7	106.7	65.5	50.5	49.9	32.2	232.5	267.1	1448.1																				2604.9	96.2	467.8		**5986.8**
	3.0	15.5	27.8	2.7	48.7	32.3	26.9	14.7	58.4	100.2	62.6	28.6	26.6	18.5	145.6	97.1	1332.6																								**2038.9**
	4.0	573.1	74.1	13.0	92.1	66.6	60.4	31.1	167.5	160.6	99.3	31.2	27.5	94.7	433.5	540.9	2179.0																								**4644.6**
	5.0																																		4644.6			283.0		193.6	**5121.2**
	6.0																																	2038.9		4713.4		280.8		1.8	**7034.9**
	7.0	0.0	0.6	2.4	1.9	0.9	2.0	0.4	0.7	1.2	1.1	0.9	1.1	2.5	3.2	7.6	12.0	-3.7	11.4	44.1	34.7	16.0	37.5	8.2	12.1	21.2	21.1	17.4	19.7	45.8	59.7	139.3	220.3			309.5	337.3			3.8	**1393.9**
	8.0																																				1940.1	722.6		-341.0	**2321.8**
	9.0																	79.9	469.2	236.9	400.4	18.9	309.7	37.7	55.8	98.8	278.3	239.3	180.2	0.6	0.8	0.6	258.3			98.3		5.8			**2769.9**
	10.0	**936.3**	**176.3**	**226.7**	**520.0**	**284.3**	**571.2**	**151.3**	**855.2**	**835.1**	**463.6**	**264.1**	**295.1**	**661.0**	**1604.8**	**1342.8**	**5890.8**	**931.9**	**610.8**	**397.2**	**747.8**	**259.9**	**552.2**	**170.8**	**746.8**	**501.3**	**539.7**	**329.5**	**259.1**	**687.7**	**1622.9**	**1193.3**	**5986.8**	**2038.9**	**4644.6**	**5121.2**	**7034.9**	**1393.9**	**2321.8**	**2769.9**	

As the electricity sector includes all detailed sub-sectors, first, the electricity sector should be disaggregated. Akkemik (2011) disaggregated the electricity sector into five sectors: generation, transmission, distribution, water supply, and gas supply while analyzing the effects of changing electricity prices using a SAM price modeling.

For 2021 SAM, the focus will be on electricity production, as explained. Therefore, the electricity sector will first be disaggregated as electricity production and others. Thus, only electricity production can be observed and disaggregated even more. Kılınç (2022) used the production values by economic activities (published by TURKSTAT) to identify groups and classes of cement and iron-steel sectors. Using the production values, the shares of detailed sectors within the division are calculated, and the SAM is divided. The same approach will be followed. Table 5 shows the production values by economic activities for 2021. Based on these values, the share of electricity production is %34.35, whereas the share of others is %65.65. Once the electricity sector is divided, production from different resources can be considered.

Electricity production in Türkiye is based on various primary resources: coal, liquid fuels, natural gas, thermal, hydro, geothermal, wind, and solar. There is no data for photovoltaic solar electricity production; therefore, it is assumed that the solar presents the production from photovoltaic. The non-renewable energy resources are grouped: coal, liquid fuels, and natural gas. Therefore, 2021 SAM will include the following electricity sectors: electricity production from thermal, hydro, geothermal, wind, solar, non-renewable resources, and other electricity sectors. To disaggregate the electricity production into the introduced sectors, the distribution of electricity generation by primary resources, published by TEİAŞ, will be used. Table 7 shows the shares of energy resources in electricity production for 2021.

Based on these shares for the electricity production, the electricity production is disaggregated. As the 2021 detailed SAM is balanced, the distribution of the shares does not distort this balance. Table 8 shows the final details of SAM for 2021, which will be used for the model. The sectoral details for the electricity sectors allow the precise analysis of the increasing solar electricity production.

Table 7: Shares of energy resources in the electricity production in GwH.

Energy Resources	**Production**	**Share (%)**
Coal	103382.0793	18.81
Liquid Fuels	281.4881803	0.05
Natural Gas	111180.755	20.23
Thermal	222623.4644	40.51
HYDRO	55926.80938	10.18
Geothermal	10793.22753	1.96
Wind	31436.74982	5.72
Solar	13942.8608	2.54

Table 8: Detailed 2021 SAM in Million TL

	2021	Activites (1)																					
		AGR	MINI	PE	CH	CE	IS	PA	FD	TE	MW	ET	AU	ELTHER	ELHYDRO	ELGEO	ELWIND	ELSOLAR	ELNONREN	ELOT	CN	TR	OE
	AGR																						
	MIN																						
	PE																						
	CH																						
	CE																						
	IS																						
	PA																						
	FD																						
	TE																						
1	MW																						
	ET																						
	AU																						
	ELTHER																						
	ELHYDRO																						
	ELGEO																						
	ELWIND																						
	ELSOLAR																						
	ELNONREN																						
	ELOT																						
	CN																						
	TR																						
	OE																						
	AGR	165.619	0.814	0.002	3.767	0.184	0.010	1.947	286.740	35.275	0.042	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.679	0.092	35.909
	MIN	2.342	10.950	186.066	13.676	47.129	57.808	1.459	3.911	5.930	1.134	0.731	0.828	22.284	5.598	1.080	3.147	1.396	21.505	105.123	26.835	2.414	17.817
	PE	22.338	10.307	5.045	4.707	10.015	2.309	0.542	2.952	2.072	2.150	2.293	0.557	0.308	0.077	0.015	0.043	0.019	0.297	1.452	26.362	155.076	69.939
	CH	47.140	3.823	0.203	224.646	12.490	13.249	16.644	26.803	66.334	11.897	22.020	14.153	0.060	0.015	0.003	0.009	0.004	0.058	0.285	50.189	14.707	92.733
	CE	0.666	1.140	0.005	3.459	38.816	2.341	0.023	2.518	0.186	2.704	2.118	2.699	0.101	0.025	0.005	0.014	0.006	0.098	0.477	141.373	4.940	29.285
	IS	0.031	1.962	0.086	3.309	2.200	124.209	0.664	0.488	0.185	125.317	47.863	38.777	0.054	0.014	0.003	0.008	0.003	0.052	0.256	130.959	1.176	31.078
	PA	0.603	0.052	0.201	5.733	3.167	1.448	43.160	12.029	6.421	2.204	2.352	0.524	0.062	0.016	0.003	0.009	0.004	0.060	0.294	0.898	2.949	61.071
	FD	39.835	0.253	0.059	1.092	0.245	0.111	0.794	134.108	3.505	0.363	0.147	0.062	0.020	0.005	0.001	0.003	0.001	0.019	0.094	0.744	1.343	127.383
	TE	0.584	0.616	0.022	3.774	1.138	0.370	2.474	1.493	308.753	1.139	0.601	2.054	0.004	0.001	0.000	0.001	0.000	0.004	0.018	0.853	1.271	31.399
2	MW	0.985	2.134	0.162	4.121	1.150	4.234	0.298	3.293	2.225	48.012	13.798	24.107	0.011	0.003	0.001	0.002	0.001	0.011	0.052	80.785	5.977	38.948
	ET	0.384	0.502	0.049	0.744	0.812	0.203	0.242	0.560	1.400	8.074	49.449	13.130	0.427	0.107	0.021	0.060	0.027	0.412	2.015	31.453	1.383	46.355
	AU	1.404	0.057	0.000	0.006	0.103	0.000	0.008	0.003	0.000	5.249	0.179	79.679	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.151	6.351	14.149
	ELTHER	0.644	0.759	0.022	1.548	2.019	3.569	0.396	1.177	2.327	0.898	0.301	0.359	6.587	1.655	0.319	0.930	0.413	6.357	31.074	0.323	0.350	12.164
	ELHYDRO	0.162	0.191	0.005	0.389	0.507	0.897	0.099	0.296	0.585	0.226	0.076	0.090	1.655	0.416	0.080	0.234	0.104	1.597	7.806	0.081	0.088	3.056
	ELGEO	0.031	0.037	0.001	0.075	0.098	0.173	0.019	0.057	0.113	0.044	0.015	0.017	0.319	0.080	0.015	0.045	0.020	0.308	1.507	0.016	0.017	0.590
	ELWIND	0.091	0.107	0.003	0.219	0.285	0.504	0.056	0.166	0.329	0.127	0.043	0.051	0.930	0.234	0.045	0.131	0.058	0.898	4.388	0.046	0.049	1.718
	ELSOLAR	0.040	0.048	0.001	0.097	0.126	0.224	0.025	0.074	0.146	0.056	0.019	0.022	0.413	0.104	0.020	0.058	0.026	0.398	1.946	0.020	0.022	0.762
	ELNONREN	0.621	0.732	0.021	1.494	1.948	3.444	0.382	1.136	2.246	0.867	0.290	0.347	6.357	1.597	0.308	0.898	0.398	6.135	29.988	0.311	0.338	11.739
	ELOT	3.036	3.580	0.102	7.305	9.523	16.836	1.866	5.552	10.977	4.237	1.420	1.694	31.074	7.806	1.507	4.388	1.946	29.988	146.587	1.522	1.653	57.382
	CN	1.938	0.539	0.012	1.286	0.502	1.546	0.250	1.678	1.073	1.526	0.346	0.242	0.333	0.084	0.016	0.047	0.021	0.321	1.572	265.785	2.510	81.217
	TR	13.023	9.569	4.899	17.533	10.540	26.059	5.686	31.816	16.316	18.817	8.890	10.693	0.401	0.101	0.019	0.057	0.025	0.387	1.892	30.623	227.395	154.422
	OE	46.178	25.659	11.689	78.356	41.512	222.380	28.036	111.726	106.745	65.488	50.479	49.853	4.480	1.125	0.217	0.633	0.281	4.323	21.132	232.511	267.075	1448.100
	3	15.5	27.8	2.7	48.7	32.3	26.9	14.7	58.4	100.2	62.6	28.6	26.6	2.6	0.6	0.1	0.4	0.2	2.5	12.2	145.6	97.1	1332.6
	4	573.1	74.1	13.0	92.1	66.6	60.4	31.1	167.5	160.6	99.3	31.2	27.5	13.2	3.3	0.6	1.9	0.8	12.7	62.2	433.5	540.9	2179.0
	5																						
	6																						
	7	0.0	0.6	2.4	1.9	0.9	2.0	0.4	0.7	1.2	1.1	0.9	1.1	0.3	0.1	0.0	0.0	0.0	0.3	1.6	3.2	7.6	12.0
	8																						
	9																						
	10	936.3	176.3	226.7	520.0	284.3	571.2	151.3	855.2	835.1	463.6	264.1	295.1	92.0	23.1	4.5	13.0	5.8	88.8	434.0	1604.8	1342.8	5890.8

	2021	Commodities (2)																					
		AGR	MIN	PE	CH	CE	IS	PA	FD	TE	MW	ET	AU	ELTHER	ELHYDRO	ELGEO	ELWIND	ELSOLAR	ELNONREN	ELOT	CN	TR	OE
	AGR	855.6																					
	MIN		130.2																				
	PE			116.2																			
	CH				312.7																		
	CE					225.0																	
	IS						204.9																
	PA							124.9															
	FD								678.9														
	TE									381.3													
1	MW										240.3												
	ET											72.8											
	AU												59.2										
	ELTHER													89.2									
	ELHYDRO														22.4								
	ELGEO															4.3							
	ELWIND																12.6						
	ELSOLAR																	5.6					
	ELNONREN																		86.1				
	ELOT																			421.0			
	CN																				1562.4		
	TR																					1053.4	
	OE																						5508.2
	AGR																						
	MIN																						
	PE																						
	CH																						
	CE																						
	IS																						
	PA																						
	FD																						
	TE																						
2	MW																						
	ET																						
	AU																						
	ELTHER																						
	ELHYDRO																						
	ELGEO																						
	ELWIND																						
	ELSOLAR																						
	ELNONREN																						
	ELOT																						
	CN																						
	TR																						
	OE																						
	3																						
	4																						
	5																						
	6																						
	7	-3.7	11.4	44.1	34.7	16.0	37.5	8.2	12.1	21.2	21.1	17.4	19.7	6.4	1.6	0.3	0.9	0.4	6.1	30.0	59.7	139.3	220.3
	8																						
	9	79.9	469.2	236.9	400.4	18.9	309.7	37.7	55.8	98.8	278.3	239.3	180.2	0.1	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.6	258.3
	10	931.9	610.8	397.2	747.8	259.9	552.2	170.8	746.8	501.3	539.7	329.5	259.1	95.7	24.0	4.6	13.5	6.0	92.4	451.4	1622.9	1193.3	5986.8

	2021	3	4	5	6	7	8	9	10
		Labor	Capital	Firms	HH	GOV	ACC	ROW	TOTAL
	AGR							80.7	936.3
	MIN							46.1	176.3
	PE							110.5	226.7
	CH							207.3	520.0
	CE							59.3	284.3
	IS							366.3	571.2
	PA							26.4	151.3
	FD							176.3	855.2
	TE							453.8	835.1
1	MW							223.3	463.6
	ET							191.4	264.1
	AU							236.0	295.1
	ELTHER							2.8	92.0
	ELHYDRO							0.7	23.1
	ELGEO							0.1	4.5
	ELWIND							0.4	13.0
	ELSOLAR							0.2	5.8
	ELNONREN							2.7	88.8
	ELOT							13.0	434.0
	CN							42.4	1604.8
	TR							289.4	1342.8
	OE							382.6	5890.8
	AGR				316.3	0.0	84.5		931.9
	MIN				56.3	0.0	15.4		610.8
	PE				77.8	0.0	0.6		397.2
	CH				123.8	5.2	1.4		747.8
	CE				23.1	0.0	3.8		259.9
	IS				31.7	0.0	11.7		552.2
	PA				30.7	0.0	-3.1		170.8
	FD				432.6	0.0	4.0		746.8
	TE				160.6	0.0	-15.9		501.3
2	MW				22.6	0.0	286.8		539.7
	ET				60.4	0.0	111.3		329.5
	AU				42.8	0.0	109.0		259.1
	ELTHER				21.5	0.0	0.0		95.7
	ELHYDRO				5.4	0.0	0.0		24.0
	ELGEO				1.0	0.0	0.0		4.6
	ELWIND				3.0	0.0	0.0		13.5
	ELSOLAR				1.3	0.0	0.0		6.0
	ELNONREN				20.8	0.0	0.0		92.4
	ELOT				101.5	0.0	0.0		451.4
	CN				47.5	0.0	1212.6		1622.9
	TR				571.9	0.3	32.0		1193.3
	OE				2604.9	96.2	467.8		5986.8
	3								2038.9
	4								4644.6
	5		4644.6			283.0		193.6	5121.2
	6	2038.9		4713.4		280.8		1.8	7034.9
	7			309.5	337.3			3.8	1393.9
	8				1940.1	722.6		-341.0	2321.8
	9			98.3		5.8			2769.9
	10	2038.9	4644.6	5121.2	7034.9	1393.9	2321.8	2769.9	

CHAPTER 5

MODEL

CGESOLAR is a static CGE model and aims to analyze the effects of increasing the domestic production of photovoltaic solar energy in Türkiye. There are no separate sectoral details for photovoltaic solar energy in the national accounts, so the analysis is based on the electricity sector and production. The main agents in the economy are the households, firms, government, and the rest of the world. Also, there is an accumulation account. CGESOLAR follows a Cobb-Douglas production function, transforming the total output into exports of domestic goods. Also, it follows the Armington assumption, and there is unemployment. Households' utility maximization is used to solve the model. Moreover, there is a discussion related to carbon emissions. GAMS (General Algebraic Modeling System) is used to solve the model. GAMS is user-friendly and allows one to focus on the model quickly, as it can overcome the complexities of optimization problems. In addition, an extensive library exists to build a code for the CGE models in GAMS. For CGESOLAR, the starting point for the GAMS code and the equations is Yeldan (2014).

In the model, there are 22 productive sectors, and labor and capital are the factors of production. In the SAM, the firms are aggregated as one, and it is assumed that they carry out the production activities. The representative firm constitutes the total output with the Cobb-Douglas production function for each sector. The following equation shows the production structure.

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$$XS_i = A_i * \left(K_i^{\alpha_i} * LD_i^{1-\alpha_i}\right) \quad (1)$$

In this equation, XS_i presents the total output, K_i is the capital demand, and LD_i is the labor demand. A_i shows the shift parameter, the technology parameter for the production function. α_i is the share parameter. The capital and labor demand are solved based on the firm's profit maximization problem, presented below.

$$maximize_{XS_i, LD_i, K_i}\, \pi_i = PVA_i * XS_i - (W * WDIST_i LDi + RK * RKDIST_i K_i) \quad (2)$$

The capital and labor demand are calculated based on their share in the production and the value-added price (PVA_i). The second part of the equation presents the amount the firms spend on labor and capital for production. The firms make these payments based on the wage rate (W), sectoral wage distribution ($WDIST_i$), capital return (RK), and sectoral distribution ($RKDIST_i$). For the sake of the model, these values are assumed to be constant and equal to 1, and the wage rate is chosen as the numeraire. Numeraire is chosen for CGE models to express all prices in relative terms. Solving this maximization problem gives the labor and capital demand, presented by the following equations.

$$W * WDIST_i * LD_i = (1 - \alpha_i) * PVA_i * XS_i \quad (3)$$

$$RK * RKDIST_i * K_i = \alpha_i * PVA_i * XS_i \quad (4)$$

On the other hand, the price of value added is calculated as follows.

$$PVA_i = (1 - PROTAX_i) * PX_i - \sum_J PC_j * IO_{i,j} \quad (5)$$

In this equation, $PROTAX_i$ is the production tax rate. PX_i is the gross output price, PC_i is the composite good price, and $IO_{i,j}$ is the input-output flows. That is each sector's intermediate demand from the other sectors. The input-output flows of the sectors constitute the total intermediate demand as a constant share of the total output.

$$INT_i = \sum_j IO_{i,j} * XS_j \quad (6)$$

The capital and labor supply in the model is assumed to be constant. While the capital is fully utilized in the model, and the labor is not, unemployment can exist. Employment is defined in the model as follows:

$$UNEMP = LSUP - \sum_{i} LD_i \tag{7}$$

In this equation, UNEMP is the unemployment for Türkiye in 2021, and LSUP is the total labor supply.

The economy's total output is sold in the international or domestic markets. The total output is transformed into exports and domestic goods following a constant elasticity of transformation (CET) production function. CET structure allows imperfect substitution between exports and domestic goods.

$$XS_i = At_i * \left(\left(\beta_i * E_i{}^{\psi_i} + (1-\beta_i) * DC_i{}^{\psi_i}\right)\right)^{\frac{1}{\psi_i - 1}} \tag{8}$$

Here, E_i presents the exports, and DC_i presents the domestic goods in the economy. At_i is the productivity parameter for the production function, and βi is the share parameter for exports in the total output. Ψ_i is the parameter calculated based on the elasticity of transformation. ($\psi_i=(1/\phi_i)$ +1, ϕ_i is the elasticity of transformation). The demand functions for export and domestic goods are obtained by solving the maximization problem based on the transformation function.

$$\frac{E_i}{DC_i} = \left(\frac{PE_i}{PD_i} * \frac{1-\beta_i}{\beta_i}\right)^{\frac{1}{\psi_i - 1}} \tag{9}$$

In addition, the Armington composite good is introduced in the model. The Armington structure assumes that the imports and domestic goods are imperfect substitutes, similar to CET. The Armington assumption introduces a composite good based on the constant elasticity of substitution (CES) production function. Imperfect substitution constitutes a more realistic approach for the representation of the economy, as there are choices of both imported and domestic goods for consumers.

$$CC_i = Ac_i * \left((\beta c_i * M_i{}^{-\Theta_i} + (1-\beta c_i) * DC(I)^{-\Theta_i})\right)^{-\frac{1}{\Theta_i}} \tag{10}$$

CC_i is the Armington composite good, and M_i is the import. Ac_i is the coefficient for productivity, and Θ_i is the parameter calculated by the elasticity of substitution. ($\Theta_i = (1/\rho_i)-1$), ρ_i is the elasticity of substitution) Based on the Armington assumption, the demand functions for the imports and the domestic goods are calculated as follows.

$$\frac{M_i}{DC_i} = \left(\frac{PD_i}{PM_i} * \frac{\beta c_i}{1-\beta c_i}\right)^{-\frac{1}{\Theta_i}} \tag{11}$$

All parameters will be calibrated according to SAM to obtain a baseline scenario. The elasticity parameters must be determined exogenously to calibrate the above variables related to production, as there are not enough equations in the model to calculate them. For CGESOLAR, the elasticity of transformation (ϕ_i) and the elasticity of substitution (ρ_i) must be assigned. These values are chosen based on Erten (2009), assuming that the elasticity of transformation is high because of the increased foreign trade volumes in recent years and the elasticity of substitution is lower because of the low substitution levels of some imported products with domestic products. Table 9 shows the elasticity and calculated parameters used in these equations.

Table 9: Elasticity parameters based on Erten (2009)

Transformation Function	ϕ_i=4	ψ_i=1.25
Armington Function	ρ_i=3	Θ_i=-0.67

The households are aggregated in the SAM, and it is assumed that there is a representative household for the model. The income of the household is presented below.

$$Y = \sum_i W\ WDIST_i LD_i + GOVTRANS + PROFTRAN + REMIT \tag{12}$$

Y is the household income. The first part of the equation shows the return for the labor coming from the production activities. In addition, the household obtains transfers from the government (GOVTRANS), profit transfers from the firms (PROFTRAN), and foreign remittances (REMIT) from the rest of the world. For the model, the profit transfers and foreign remittances are assumed to be constant. In contrast, government transfers are calculated as a constant share of the GDP. In the following equation, GVTR is the share of the government transfers in the GDP.

$$GOVTRANS = GVTR * \ GDP \tag{13}$$

Equation 7 shows the GDP. In this equation, CD_i is the household consumption, GD_i is the government consumption, GID_i is the government investment, and ID_i is the household investment. PWE_i is the world export price, and PWM_i is the world import price.

$$GDP = \sum_i PC_i * (CD_i + GD_i + GID_i + ID_i) + PWE_i * E_i - PWM_i \ * M_i \tag{14}$$

Household consumption is based on disposable income, income after deducting the savings, and tax payments to the government from the total income.

$$PC_i \, CD_i = CLES_i * \ (1 - MPS) * \ Y * (1 - HTAX) \tag{15}$$

In this equation, CD_i is the household consumption. $CLES_i$ is the share of consumption for each sector. MPS is the marginal propensity to save, and HTAX is the household tax rate. MPS is assumed to be constant as a rule of macro closure and to ensure savings-investment balance.

The household's savings (HHSAV) is calculated based on the marginal propensity to savings after the household tax paid to the government is deducted from the income.

$$HHSAV = MPS * Y * (1 - HTAX) \tag{16}$$

The government's sectoral consumption is based on constant sectoral shares (GLESi) of the total government consumption (GOVCON).

The total government consumption is assumed to be a constant share (GCR) of the GDP. Government savings (GSAV) are calculated as a constant share (GSR) of the government revenue.

$$PC_i * GD_i = GLES_i * GOVCON \tag{17}$$

$$GOVCON = GCR * \ GDP \tag{18}$$

$$GSAV = GSR * GREV \tag{19}$$

The government revenue (GREV) is presented in Equation 18. The government revenue is calculated based on the tax revenues, net unrequited transfers from the rest of the world (NURT), and the firms' public factor income (PFI). The net unrequited transfers are assumed to be constant for the model.

$$\begin{aligned} GREV = \sum_i PROTAX_i * \ PX_i * \ XS_i + \sum_i SALTAX_i * (PD_i * \ DC_i + PM_i * \ M_i) \\ + \sum_i TM_i * \ PWM_i * \ M_i + \sum_i CORPTAX * RK * RKDIST_i * K_i \\ + HTAX * \ Y + \sum_i TE_i * \ PWE_i * \ E_i \ + NURT + PFI \end{aligned} \tag{20}$$

In this equation, SALTAXi, TMi, TEi, and CORPTAX are the sales, import, export, and corporate tax rates. PDi is the domestic good price. Public factor income is the constant share (RATEPFI) of the firm's profit (PROF).

$$PFI = RATEPFI * \ PROF \tag{21}$$

Equation 22 shows the firm's profit. Here, SUBS are subsidies from the government. DBIP is the domestic debt interest payment from the government. CURINC is the currency income of firms from the rest of the world. The profit is calculated after the corporate tax is paid to the government.

$$\begin{aligned} PROF = \big((1 - CORPTAX)\big) \\ * \left(\sum_i RK * \ RKDIST_i * \ K_i + SUBS + DBIP + CURINC\right) \end{aligned} \tag{22}$$

Currency income and domestic debt interest payments are assumed to be constant. Subsidies from the government are calculated as a constant share (subsrate) of the government revenue.

$$SUBS = subsrate * GREV \tag{23}$$

The last part of the equations presents the equilibrium conditions for the model. It is given that the capital supply (KSUP) is assumed to be constant.

$$KSUP = \sum_i K_i \tag{24}$$

Equation 25 presents the equilibrium in the goods market. The total intermediate demand, household consumption, government consumption, household investment, and government investment equal the composite goods in each sector.

$$CC_i = INT_i + CD_i + GD_i + ID_i + GID_i \tag{25}$$

Equation 26 shows the investment-savings balance. The household, government, and foreign savings must match the total investment. The household investment (HHINV) and the government investment (GINV) constitute the total investment.

$$HHSAV + GSAV + FSAV = HHINV + GINV \tag{26}$$

Considering the balance of payments, the current account deficit (CAD) is calculated as follows.

$$\begin{aligned} CAD = &\left(\sum_i PWM_i * Mi + RPT + PROFTRAN + G\ FINT\right) \\ &-\left(\sum_i PWE_i * E_i + REMIT + NURT + CURINC)\right) \end{aligned} \tag{27}$$

In this equation, RPT is the firm's transfer to the rest of the world, and GFINT is the government's foreign interest debt payments to the rest of the world. Both are assumed to be fixed throughout the model.

The following equation shows the model's main maximization problem: consumer's utility maximization (UU), based on the total consumption of the households.

$$UU = \prod_{i} CDi^{cles_i} \tag{28}$$

CHAPTER 6

SCENARIO AND RESULTS

6.1 Scenario

The main scenario for the CGESOLAR is based on the TFTP (Türkiye Photovoltaic Technology Platform) and its focus on the domestic production of solar PV electricity. The main aim of the TFTP is to promote domestic production and development of high-efficiency solar cell types and related technologies at all levels. The targeted improvements include high-efficiency k-Si-based solar cell technologies, advanced material technologies used in cell and panel production, and photovoltaic panel technologies produced using crystalline si. When the targeted levels of domestic production and use of domestic energy are achieved, the import dependency in the energy sectors and the current account deficit are expected to improve. In addition, more employment will be created. These improvements, if achieved, can contribute to economic growth and sustainable development, considering the high potential of solar power in Türkiye. In addition, there can be positive environmental effects.

The introduced CGE model aims to measure these possible outcomes that TFTP targets to bring. The model focuses on how the activities of the different parameters of the economy will react to these outcomes, such as production, growth, employment, and current account deficit. Moreover, a discussion on CO2 emissions will also be included to measure the environmental effects. Following Cansino et al. (2014), the amount of avoided carbon emission will be calculated. These calculations are based on the assumption that the electricity production from photovoltaic solar energy will replace the electricity production of non-renewable energy resources, coal, natural gas, and liquid fuels. In addition, it can also replace the production from the combined cycle plants, which use liquid fuel and natural gas together. The data for carbon emission caused by the electricity production by each energy resource is needed to complete the calculations. However, the carbon emission data published by the TURKSTAT does not have sectoral information as detailed as in the model. The sectoral disaggregation is limited and only includes energy, industrial processes and product use, agriculture, and waste. Although carbon emission data from the energy sector may provide insightful information, it is not enough to focus on electricity production. Therefore, the emission factors are based on the electricity generation and consumption points published by the Republic of Türkiye Ministry of Energy and Natural Resources (MENR). The emission factors present the greenhouse gas emissions in terms of CO2 and CO2 equivalents emitted per unit of net electricity production from fossil fuel power plants. (MENR, 2022). The latest data was published in August 2022. The emission factors are given based on the type of fuels used in the plants. The sectors are lignite, hard coal, asphaltite, imported coal, natural gas, fuel oil, and diesel. These sectors are aggregated to present the same sectors introduced in the SAM. Lignite, hard coal, asphaltite, and imported coal are aggregated as coal, and fuel oil and diesel are aggregated as liquid fuels. The emission factors in tonnes of CO2 and CO2 equivalent per unit of electricity production in MWh for these sectors are presented in the following table. Photovoltaic solar energy is a type of clean energy and does not cause any carbon emissions. Therefore, its emission factor is 0. There is no other study for Türkiye to focus on these effects using a CGE model.

Table 10: Emission factors

Emission Factors	**tCO2/MWh**	**tCO2-eq/MWh**
Coal	4.408	4.428
Liquid Fuels	1.287	1.289
Natural Gas	0.371	0.376

The scenario that will present the changes in the production structure can be explained as follows. As described while constructing 2021 SAM, the published data does not include detailed information on solar energy as a sector. Therefore, the scenario focuses on the electricity that photovoltaic solar energy produces. According to the latest National Energy Plan, published by the Ministry of Energy and Natural Resources, it is expected that the share of solar energy in electricity production will increase to %16.5. Similar to the SAM data, it is assumed that this solar electricity is solely from the photovoltaic panels.

For the scenario, it is assumed that the TFTP will ensure the solar electricity share of %16.5 will be reached following the National Energy Plan for Türkiye. For 2021, the same percentage is %2.537. Therefore, the solar share in electricity production has to be increased by 6.5 times. There are different ways to introduce this shock to the model, such as introducing new subsidies for the solar electricity sector, adding new taxes that will be transferred into the solar electricity sector, and benefiting from the platform's budget. However, there are no sectoral details for the subsidies provided by the government and no channels that can transfer taxes across the model. In addition, the platform's budget is tentative as it can change due to the current needs for research and development or domestic and international inflation pressures.

On the other hand, an augmented budget does not fully reflect the platform's possible outcomes. It solely introduces an overall increase in the economic parameters without channeling through them. Therefore, the scenario depends on the production function for the CGE model. An increase in productivity allows the analysis of the targeted outcomes.

In equation (1), the Cobb-Douglas production function is introduced. In this equation, A_i is the technology parameter and will be used for the scenario. It is assumed that the $A_{ELSOLAR}$ increases by 6.5 times as the shock. That is, the productivity of electricity production by solar photovoltaic energy increases as a result of the activities of the TFTP. This shock will cause changes in the following parameters introduced by the model. Appendix A gives the model's formation, the shock's introduction, and the results in GAMS.

6.2 Results

Table 11 shows how the total output, XS_i, changes once the productivity in the ELSOLAR increases. In total, the output increases by % 0.032. The sectoral details will give more information about the changes. It is observed that the output rises most for the ELSOLAR by %4.582, as the productivity increase in this sector is introduced as a shock.

Table 11: Changes in the total output in Million TLs

Output (XS)	**Base**	**Scenario**	**% Change**
AGR	936.288	936.202	-0.009
MINI	176.342	176.465	0.070
PE	226.706	226.716	0.004
CH	520.015	520.225	0.040
CE	284.251	284.348	0.034
IS	571.236	572.263	0.180
PA	151.330	151.361	0.020
FD	855.214	855.160	-0.006
TE	835.089	835.459	0.044
MW	463.622	463.807	0.040
ET	264.145	264.282	0.052
AU	295.137	295.401	0.089
ELTHER	91.991	92.114	0.133
ELHYDRO	23.110	23.141	0.133
ELGEO	4.460	4.466	0.133
ELWIND	12.990	13.007	0.133
ELSOLAR	5.761	6.025	4.582
ELNONREN	88.777	88.895	0.133
ELOT	433.959	434.538	0.133
CN	1604.848	1605.083	0.015
TR	1342.788	1342.823	0.003
OE	5890.821	5891.911	0.019
TOTAL	**15078.880**	**15083.690**	**0.032**

Following ELSOLAR, the output improves most for the Iron-Steel sector by %0.180. Improvements in the solar PV sector increase the production of the Iron-Steel sector, which is energy-intensive. In addition, steel is one of the primary raw materials used in producing solar PV panels in their structural and electric components (Carrara et al., 2020). Therefore, as the output increased in solar PV, the iron-steel sector's output improved as well, driven by the need for steel. The other electricity production sectors follow the increase of Iron-Steel with increases of around %0.133. These sectors interacted more with the ELSOLAR based on the introduced SAM. Therefore, an improvement in this sector affects them positively as well. The output of the Automotive sector increased by %0.089, as solar PV is highly used in the production and usage processes of electric cars, which presents exponential growth and is expected to accelerate even more (IEA, 2023). Solar PV can be used for charging stations or battery storage. For instance, Ford's production plant in South Africa implemented a Solar PV carports project, which can generate %35 of the plant's electricity (FORD Media Center, 2022). These sectors' interdependence is similar for CGESOLAR; the automotive industry improved due to the more efficient solar PV production. Also, the Mining sector increased by %0.070, for the same reason as in the Iron-Steel. There is a need for raw materials obtained by mining. Increases in the Electronics is %0.052, and in the Textile & Clothing is %0.044. Both industries are energy intensive, so having a more efficient energy source improved their production. Moreover, the manufacturing different types of batteries used in solar PV panels belongs to the Electronics sector based on the Nace-Rev 2 division. The Chemical sector includes the production of silicon, one of the leading materials used in solar PV cells, increased by %0.040, followed by Machinery, Cement, and Paper & Printing. Once again, the improvements in solar PV production positively affect the production of energy-intensive industries. Moreover, there is an increase by %0.034 in the Cement sector, which includes concrete, whose material intensity is the second highest after steel in the components of the solar PV plants. (Jean et al., 2015). The total output decreased the most for the Agriculture sector. Although the change rate is not high, -%0.009, it is not an expected result as Solar PV systems can be applied in the farms as a form of AgroPV, and increasing the efficiency in the Solar PV sector can benefit Agriculture as well. However, this is not the case for the CGESOLAR, which may be due to the structure of agriculture in Türkiye.

Table 12 shows the changes in the domestic goods, one of the most critical parameters for the model. The main motive of the TFTP is to promote the domestic production of photovoltaic energy and all of the following technologies. In line with this goal, the total domestic goods increased by %0.027.

Table 12: Changes in the domestic goods in Million TLs

Domestic good (DC)	**Base**	**Scenario**	**% Change**
AGR	854.344	854.305	-0.005
MINI	134.467	134.562	0.070
PE	132.663	132.674	0.008
CH	325.628	325.742	0.035
CE	230.942	230.999	0.025
IS	218.949	219.199	0.114
PA	127.964	127.990	0.020
FD	683.408	683.414	0.001
TE	389.213	389.352	0.036
MW	248.149	248.229	0.032
ET	79.254	79.284	0.038
AU	66.514	66.554	0.060
ELTHER	91.617	91.737	0.131
ELHYDRO	23.016	23.046	0.131
ELGEO	4.442	4.448	0.131
ELWIND	12.937	12.954	0.131
ELSOLAR	5.738	5.977	4.167
ELNONREN	88.416	88.531	0.131
ELOT	432.193	432.760	0.131
CN	1584.665	1584.900	0.015
TR	1105.337	1105.453	0.010
OE	5590.403	5591.485	0.019
TOTAL	**12430.260**	**12433.590**	**0.027**

Looking at the sectors, the most increased sector is ELSOLAR by %4.167, followed by the other electricity production sectors, both renewables and non-renewables. These results signal that more productivity increases in the renewable energy sectors, as in the case of solar, have the potential to affect other energy sectors positively, as well.

There are also increases in the Iron&Steel sector, followed by Mining, Automotive, Electronics, Textiles&Clothing, Machinery, and Chemicals. Domestic production increases in these sectors contribute to the domestic production of Solar PV electricity, as the materials used in these sectors are used in the Solar PV systems, and they are the most related sectors with Solar PV, as explained.

Table 13 shows the changes in the imports, another crucial parameter. Increasing the share of domestic production in the energy sector aims to decrease the import dependency in the energy sector in Türkiye, which is one of the most critical problems in the country.

Table 13: Changes in the imports in Million TLs

Import (M)	**Base**	**Scenario**	**% Change**
AGR	79.738	79.757	0.023
MINI	469.779	470.116	0.072
PE	239.064	239.100	0.015
CH	402.124	402.222	0.024
CE	19.730	19.728	-0.011
IS	311.530	311.637	0.034
PA	38.140	38.147	0.019
FD	56.410	56.425	0.027
TE	99.867	99.890	0.023
MW	279.373	279.429	0.020
ET	240.183	240.239	0.023
AU	181.212	181.271	0.033
ELTHER	0.401	0.400	-0.261
ELHYDRO	0.101	0.100	-0.261
ELGEO	0.019	0.019	-0.261
ELWIND	0.057	0.056	-0.261
ELSOLAR	0.025	0.016	-35.514
ELNONREN	0.387	0.386	-0.261
ELOT	1.892	1.887	-0.261
CN	3.705	3.706	0.026
TR	7.424	7.427	0.044
OE	269.106	269.192	0.032
TOTAL	**2700.268**	**2701.161**	**0.033**

As a result of the shock, the import of electricity production by solar photovoltaic energy decreased by %35.514. This decrease shows the success of the TFTP, indicating the import dependency for the solar sector has a great potential to reduce, as it drops significantly once the targeted productivity rate is reached. In addition, there is a decrease for all of the other electricity production sectors, both renewables and non-renewables, around %0.261. That is, improving the production of solar PV electricity can be one solution that will help Türkiye overcome its import dependency issue in the energy sector.

The imports increased most for the Mining sector by %0.072. In addition, it raised for the Transportation, Automotive, and Iron & Steel around %0.04. Although these increases are not too high, it still points out that there is still a need for improvement to overcome import dependency, as mining is an energy sector, and others are energy-intensive sectors. Moreover, these increases show that the demand for raw materials for Solar PV systems continues and depends on outside resources, even after the efficiency improvements.

Table 14 shows the changes in the Armington composite goods based on the domestic goods and imports. The composite good increased by %3.981 for ELSOLAR and around %0.129 for other electricity production sectors. These increases in the Armington composite good show that the rise of the domestic good in these sectors compensates for the high amount of decrease in the imports. There are also increases for Mining, Iron & Steel, Textile, and Automotive. These results are expected as domestic goods and imports increase for these sectors.

Table 15 shows the changes in the export levels, another indicator for analyzing the shock's effects on international trade. The exports in ELSOLAR increased the most by %97.429, followed by the other electricity production sectors by %0.656. As domestic production increases in the electricity sector, Türkiye can export more. Although the levels are not as high as the electricity sectors, there is also an increase in the Iron & Steel, Automotive, and Mining. Like the other results, the sectors most related to Solar PV increased their export levels. On the other hand, exports in the Transportation, Food Processing, and Agriculture sectors decreased.

Table 14: Changes in the composite good in Million TLs

Composite good (CC)	Base	Scenario	% Change
AGR	931.853	931.841	-0.001
MINI	610.818	611.253	0.071
PE	397.246	397.295	0.012
CH	747.789	748.007	0.029
CE	259.940	259.997	0.022
IS	552.170	552.542	0.067
PA	170.845	170.879	0.020
FD	746.808	746.828	0.003
TE	501.319	501.485	0.033
MW	539.697	539.836	0.026
ET	329.472	329.561	0.027
AU	259.128	259.232	0.040
ELTHER	95.699	95.822	0.129
ELHYDRO	24.041	24.072	0.129
ELGEO	4.640	4.646	0.129
ELWIND	13.514	13.531	0.129
ELSOLAR	5.994	6.232	3.981
ELNONREN	92.355	92.474	0.129
ELOT	451.448	452.032	0.129
CN	1622.862	1623.104	0.015
TR	1193.276	1193.404	0.011
OE	5986.846	5988.039	0.020
TOTAL	**15537.760**	**15542.114**	**0.028**

Table 16 shows the changes in the household's sectoral consumption. The changes in household consumption are small. The most significant change is the increase in the ELSOLAR by %17.27, as one of the main usage areas for the solar PV panels is the individual use. The rise follows this increase in the other electricity sectors. The increases in these sectors, especially solar, can be explained by price changes.

Household consumption is based on the price of the composite good, as individuals can choose between domestic and imported goods based on the Armington assumptions.

As explained, the composite good's price for all sectors is assumed to be 1 for the model. Table 16 shows how the composite goods price changed after the shock.

Table 15: Changes in the exports in Million TLs

Export (E)	**Base**	**Scenario**	**% Change**
AGR	81.944	81.897	-0.057
MINI	41.874	41.903	0.069
PE	94.043	94.042	-0.001
CH	194.387	194.484	0.049
CE	53.309	53.348	0.073
IS	352.287	353.064	0.221
PA	23.366	23.371	0.022
FD	171.805	171.747	-0.034
TE	445.875	446.107	0.052
MW	215.472	215.577	0.049
ET	184.892	184.999	0.058
AU	228.624	228.847	0.098
ELTHER	0.375	0.377	0.656
ELHYDRO	0.094	0.095	0.656
ELGEO	0.018	0.018	0.656
ELWIND	0.053	0.053	0.656
ELSOLAR	0.023	0.046	97.429
ELNONREN	0.361	0.364	0.656
ELOT	1.767	1.778	0.656
CN	20.183	20.183	0.000
TR	237.451	237.370	-0.034
OE	300.418	300.426	0.003
TOTAL	**2648.623**	**2650.096**	**0.056**

As a result of the shock, the price of ELSOLAR decreased by %14.72, encouraging household consumption in the sector. The prices for the other electricity sector decreased as well by smaller amounts. Other changes are not as significant; still, the price for most sectors fell, coinciding with the increases in household consumption, and vice versa.

Table 18 shows the changes in the GDP in Million TL and Million USD.

Table 16: Changes in household consumption in Million TLs

Household Consumption (CD)	Base	Scenario	% Change
AGR	316.273	316.265	-0.003
MINI	56.298	56.304	0.009
PE	77.783	77.790	0.009
CH	123.756	123.769	0.011
CE	23.099	23.104	0.020
IS	31.750	31.756	0.020
PA	30.665	30.668	0.010
FD	432.579	432.585	0.001
TE	160.615	160.636	0.013
MW	22.635	22.637	0.011
ET	60.369	60.376	0.011
AU	42.819	42.824	0.012
ELTHER	21.509	21.539	0.140
ELHYDRO	5.403	5.411	0.140
ELGEO	1.043	1.044	0.140
ELWIND	3.037	3.042	0.140
ELSOLAR	1.347	1.580	17.274
ELNONREN	20.758	20.787	0.140
ELOT	101.467	101.609	0.140
CN	47.453	47.455	0.006
TR	571.894	571.884	-0.002
OE	2604.890	2605.031	0.005
TOTAL	**4757.443**	**4758.094**	**0.014**

The value of GDP is converted to the USD, using the average exchange of 2021. The GDP of Türkiye increased by %0.024 due to the shock. This change is equivalent to 1.77 million TL and 0.2 million USD. Although the amount is not too high, this result indicates that a slight increase in one energy production sector can contribute to the country's growth. Also, as government consumption depends on the GDP as introduced in the model, as the GDP increases, government consumption increases.

Table 19 shows the changes in the other main macroeconomic variables.

These are Government Revenue (GREV), Current Account Deficit (CAD), Labor Demand, and Unemployment. CAD for Türkiye decreases by %0.02.

Table 17: Changes in the composite good price

Composite Good Price (PC)	**Base**	**Scenario**	**% Change**
AGR	1	1.00012	0.01207
MINI	1	1.00000	0.00010
PE	1	1.00001	0.00083
CH	1	0.99998	-0.00160
CE	1	0.99989	-0.01107
IS	1	0.99989	-0.01096
PA	1	1.00000	-0.00027
FD	1	1.00008	0.00807
TE	1	0.99997	-0.00327
MW	1	0.99998	-0.00192
ET	1	0.99999	-0.00122
AU	1	0.99998	-0.00250
ELTHER	1	0.99870	-0.13012
ELHYDRO	1	0.99870	-0.13012
ELGEO	1	0.99870	-0.13012
ELWIND	1	0.99870	-0.13012
ELSOLAR	1	0.85278	-14.72160
ELNONREN	1	0.99870	-0.13012
ELOT	1	0.99870	-0.13012
CN	1	1.00004	0.00371
TR	1	1.00011	0.01110
OE	1	1.00004	0.00398

Table 18: Changes in the GDP

	Base	**Scenario**	**Change**	**%Change**
GDP in Million TL	7426.69	7428.46	1.77	0.024
GDP in Million USD	835.83	836.03	0.2	

The current account deficit is a critical variable for analyzing the energy-related shock in a country like Türkiye, as the import dependency in the energy sector is a primary contributor to the current account deficit. The efficiency improvements in Solar PV lead to a decrease in the CAD, showing that having more productive and domestic alternatives in the energy sector decreases the dependency on international resources and increases energy independence.

Table 19: Changes in the macroeconomic variables in Million TLs

	Base	**Scenario**	**% Change**
CAD	4325.352	4324.471	-0.02
Labor Demand	2038.9	2039.493	0.029
Unemployment	278.0318	277.4396	-0.213
GREV	1393.863	1394.327	0.033

In addition, the labor demand increased by %0.029, and unemployment fell by %0.213. The increase in labor demand and decrease in unemployment show that TFTP can reach its goal. Moreover, GREV increases by %0.033. The increase in the GREV can be explained by the changes in the variables constituting the GREV, which are all taxes, net unrequited transfers (assumed to be fixed), and public factor income (PFI). Table 20 shows these changes, together with the rest of the variables related to government. The total taxes increased by %0.033, and the PFI increased by %0.0165, explaining the increase in the government revenue.

Table 20: Changes in the rest of the variables in Million TLs

	Base	**Scenario**	**% Change**
TOTAL TAXES	1258.489	1258.914	0.033
PFI	131.5535	131.5753	0.0165

In addition to the macroeconomic effects presented thanks to the CGE model, changes in the electricity production structure have environmental consequences, too. As explained previously, carbon emission will be the primary indicator for environmental effects, and the emission factors will be compared. The scenario presented for the model is that the efficiency of the electricity production from photovoltaic energy increases by 6.5 times to meet the Türkiye's energy plan. After this increase, the share of electricity production from solar photovoltaic energy will be %16.5. The assumption is that the electricity production from solar photovoltaic energy replaces the electricity production from fossil fuels. Table 7 presents the shares of energy resources in electricity production in the previous chapter. Based on the values in this table, the electricity production from solar photovoltaic energy will increase to reach its share of %16.5, as a result of the shock. Then, the remaining shares for the fossil fuels will be calculated in order. It is assumed that the electricity production from solar photovoltaic energy replaces the electricity production from coal, natural gas, and combined cycle plants operated based on natural gas and liquid fuels. There is no assumption solely for liquid fuels because their share in electricity production is too low, %0.05, to be replaced by the increase in solar photovoltaic energy. After the new shares and the new production levels are calculated, the avoided emission based on the emission factors can be calculated, too.

Table 21 shows the new shares, new electricity production for these resources, and the avoided emission for CO2 and CO2 equivalent due to the shock. The avoided carbon emission values show that a large amount of carbon emission can be avoided when electricity production improves towards solar photovoltaic energy.

Table 21: New Shares of electricity production and avoided carbon emission

	New Shares (%)	**New Production (MWh)**	**Avoided emission (MTCO2)**	**Avoided emission (MTCO2-eq)**
Solar replaces Coal	4.85	26646313.455	338.251	339.786
Solar replaces Natural Gas	6.27	34444989.115	28.469	28.853
Solar replaces combined cycle energy plant	6.32	34726477.296	127.228	127.765

If solar photovoltaic energy replaces coal, Türkiye will avoid 338.251 million tons of CO_2 and 339.786 million tons of carbon equivalent. The replacement for the combined cycle energy plants and natural gas follows these values. These results show that replacing fossil fuels with renewable energy resources that do not cause carbon emissions, such as solar photovoltaic energy, contributes to Türkiye's environmental well-being. The total carbon emission for Türkiye, published by TURKSTAT, in 2021 is 564.4 $MTCO_2$-equivalent. Therefore, the potential avoided emission values show the validity and potential of Türkiye's energy plan toward renewable energy resources.

CHAPTER 7

CONCLUSION

Solar PV has a high potential in Türkiye due to its climatic and geographical conditions and has been increasing its share throughout the years due to the government's encouraging policies. However, like fossil fuels, the solar PV systems' production processes depend highly on technology and raw materials imports. Therefore, domestic production should accelerate in the sector to reach its potential. TFTP is a platform aiming to promote the domestic production of solar panels and cells in Türkiye. Improving domestic production in the solar PV sector can help Türkiye to meet growing energy demand, overcome issues of import dependency in the energy sector, strengthen its energy security, and decrease its carbon emissions.

CGESOLAR analyzed the implications of the increased efficiency in the solar PV electricity sector, assumed to occur as a result of the activities of TFTP, and investigated whether the expected outcomes can be achieved. No other study based on the energy-related subjects for Türkiye with a CGE model focused on the pure impact of the solar PV sector. The primary dataset of CGESOLAR is an electricity-detailed 2021 SAM, and it is the latest and most detailed available SAM formed for Türkiye. Several steps followed for the construction of the SAM. First, an aggregated 2021 SAM, without the sectoral details, is obtained based on the national statistics. Then, the sectors are distributed based on the shares of the 2012 IO Table, which is the latest IO table published by TURKSTAT. Another step disaggregated the electricity sector, based on the production values, into electricity production and other activities in the industry. Finally, electricity production is further disaggregated based on the production from the primary energy resources. SAM 2021 is calibrated into the CGESOLAR to give the baseline results.

CGESOLAR is a static model, including 22 sectors. The model has households, firms, government, and the rest of the world. Also, there is an accumulation account. CGESOLAR follows a Cobb-Douglas production function. The total output is transformed into domestic goods and exports. CGESOLAR uses labor and capital for the production. While the capital is fully utilized in the model, there is unemployment. In addition, CGESOLAR follows the Armington assumption to present a more realistic economic structure. To solve the model, households' utility maximization is used. Moreover, the avoided carbon emissions are calculated to focus on the environmental impacts. GAMS is used to solve the model.

The main scenario for the CGESOLAR is based on the TFTP, as explained. It is assumed that the productivity in the solar PV sector increased 6.5 times to reach the share of %16.5, as planned in the National Energy Plan for Türkiye. That is the productivity of electricity production by solar photovoltaic energy increases as a result of the activities of the TFTP.

As a result of the shock, the most affected sector is ELSOLAR, as the shock introduced directly in this sector. Its total output increased by %4.582, domestic output increased by %4.167, and exports rose by %97.429. The other electricity production sectors, both renewable and non-renewable, follow the effects of ELSOLAR. These are the sectors that are most interrelated based on SAM. Moreover, Iron&Steel, Automotive, and Mining sectors are highly affected by the productivity improvements in the ELSOLAR. These sectors have high energy intensity and, therefore, can benefit from the increased electricity from the ELSOLAR. Moreover, they mainly contribute to the production processes of solar PV.

The imports in the ELSOLAR decreased significantly, by %35.514. That is, the import dependency for the solar sector has a great potential to reduce. The imports in the other electricity sectors decreased by around %0.261, showing that improving the productivity in one renewable sector can also benefit the other sectors. However, there are also increases in imports for Mining, Transportation, Automotive, and Iron & Steel. The increases are not too high but indicate the need for further improvements to deal with import dependency in the energy sector and production processes of

ELSOLAR. In addition to these results, household consumption in the ELSOLAR increased by %17.27, as one of the main usage areas for solar PV panels is individual use. The composite good price for the ELSOLAR decreased by %14.72, improving household consumption.

The GDP of Türkiye increased by %0.024 due to the shock. This change is equivalent to 1.77 million TL and 0.2 million USD. Although the increase is not too high, it shows the ability of renewable energy sectors to contribute to economic growth. The current account deficit decreased by %7.323. This result indicates that more productive and domestic alternatives in the energy sector decrease the dependency on international resources. Moreover, unemployment decreased by %0.213, and government revenue increased by %0.033.

In addition, the leading economic indicators, the carbon emissions of Türkiye, are analyzed following the results of the CGESOLAR. After the introduced shock, the electricity from solar PV electricity reached %16.5. This increased production value is assumed to replace the electricity production from coal, natural gas, and combined cycle plants. These sectors' emission factors are used to calculate the avoided emission values. If solar photovoltaic energy replaces coal, Türkiye will avoid 338.251 MTCO2; if it replaces natural gas, the avoided emission value becomes 28.853 MTCO2, and for the combined cycle energy plant, it is 127.765 MTCO2. All of these results indicate the success of the TFTP, as the expected results are obtained after the productivity and domestic production improvements in the ELSOLAR sector are achieved. However, it is also critical to note that the efficiency improvements should be increased and expanded to the other renewable sectors to obtain more considerable improvements in the variables.

Although other methods can be utilized to focus on the same subject, the CGE model is chosen, as it can combine the actual data with the behaviors of the economic agents in the economy. However, CGE models have drawbacks, as they depend on the determined behavioral assumptions and chosen elasticity parameters. On the other hand, they are the most prominent model for comparing the various policy options and analyzing the effects of any change channeled through all actors of the economy. For

CGESOLAR, the critical limitation is its dataset 2021 SAM. As explained, the sectoral distribution of the SAM is based on the 2012 IO Table. Due to a time gap, the matrix may not present accurate sectoral interrelations as they are in 2021. However, no other dataset for Türkiye presents the sectoral information as detailed as the IO Table, and unfortunately, there is no more recent IO table published by TURKSTAT.

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APPENDICES

A. GAMS CODE FOR CGESOLAR

Set

u 'SAM entries' /AGR,MINI,PE,CH, CE, IS, PA, FD, TE, MW, ET, AU, ELTHER,ELHYDRO,ELGEO, ELWIND,ELSOLAR, ELNONREN,ELOT, CN, TR,OE, L, K, Firms, SUBS, DINT,HH,GOV,INCT,NONTR,IMPT,EXT,SALT,CORPT,PFI,ACC,ROW,FDIP,RPT ,TOTAL/

i(u) 'production activities' /AGR,MINI,PE,CH, CE, IS, PA, FD, TE, MW, ET, AU, ELTHER,ELHYDRO,ELGEO,ELWIND,ELSOLAR, ELNONREN,ELOT, CN, TR,OE/

h(u) 'factors' /K,L/;

Alias (u, v), (i, j), (h, k);

Table SAM (u, v) 'social accounting matrix' (INSERT MATRIX HERE)

Parameters

AC(I) Armington shift parameter

AT(I) CET function shift parameter

BC(I) Armington shift parameter

BT(I) CET function share parameter

CLES(I) Sectoral consumption shares

GLES(I) Sectoral government consumption demand

IDLES(I) Private investment demand shares

GIDLES(I) Public investment demand shares

PWE(I) World price of exports

PWM(I) World price of imports

PWTS(I) Price weights

RHOC(I) Armington function exponent

RHOT(I) CET function exponent

SIGMA(I) Elasticity of substitution for CES function

SIGMA2(I) Elasticity of substitution for CET function

AX(I) Shift Parameter for the production function

BX(I) Share Parameter for the production function

PROTAX(I) Production tax rate

SALTAX(I) Sales tax rate

TM(I) Tariff rate

TE(I) Export tax rate

CC0(I) Composite good

CD0(I) Private consumption

DC0(I) Domestic good

E0(I) Exports

GD0(I) Government consumption

INV(i) Total inv demand by sectors

TOTINV Total inv

sinv(I) Inv demand share

HHINV tot HH inv

GOVINV tot gov inv

ID0(I) Private inv demand by sectors

GID0 (I) Public inv demand by sectors

TOTINVE0(I) Total inv demand by sectors

INT0(I) Intermediate input demand

K0(I) Capital demand

LD0(I) Labor demand

M0(I) Imports

PC0(I) Composite good prices

PD0(I) Domestic good prices

PE0(I) Domestic price of exports

PM0(I) Domestic price of imports

PVA0(I) Value added price

PX0(I) Gross output price

RP0(I) Sectoral profits

WL0(I) Sectoral wage payments

WDIST0(I) Sectoral wage coefficients

RKDIST0(I) Sectoral capital return coefficients

XS0(I) Supply

X0(I,J) Intermediate inputs

IO(I,J) Intermediate input use

IMPTAX(I) Import tax

EXPTAX(I) Export tax

FSAV0 Foreign saving

GSAV0 GOV Saving

HHSAV HH Saving

GOVTRANS0 Gov transfer to HH

GFINT0 Gov transfer to row

NURT0 Net unrequited transfers

PFI0 Public factor income from firms to gov

SUBS0 Subsidies

DBIP0 Domestic debt int payments

GOVFOR0 Government foreign interest payments

FDIP0 Foreign debt interest payment

RPT0 Firm transfer to ROW

CURINC0 Currency income

GSR Gov saving rate

GIR gov inv rate

GCR Gov consumption rate

GPRBR Gov primary balance

INCTAX Income tax

NONTAXR Non-tax revenue

HHTAX HH tax

HTAX HH tax rate

CORPTAX Corporate tax

KSUP0 Capital supply

```
 LSUP0 Labor supply
 MPS0 Marginal propensity to save
 RK0 Profit rate
 W0   Wage rate
 Y0   HH income
 alpha(I) Parameter for obj function
 CAD0 Current account deficit
 PROFTRAN0 Profit transfer from firms to HH
 REMIT0 Remittances
 PRODUCTIONTAX(I) Production tax
 GREV0 Gov revenue
 subsrate Subsidy rate
 PROF0 Profit of firm
 RATEPFI PFI rate
 PISB0 Inv-Saving balance
GDP0
 UNEMP0 Unemployment;
*Introduction of the values based on SAM
FSAV0=SAM('ACC','ROW');
 GSAV0=SAM('ACC','GOV');
 GOVTRANS0=SAM('HH','GOV');
 GFINT0=SAM('ROW','GOV');
 INCTAX=SAM('INCT','HH');
 NONTAXR=SAM('NONTR','HH');
 HHTAX=INCTAX+NONTAXR;
 HHSAV=SAM("ACC","HH");
 INV(i)=SAM(i,'ACC');
 TOTINV=sum(j,INV(j));
 sinv(i)=INV(i)/TOTINV;
 HHINV=2092.31928141;
 GOVINV=229.48868713;
```

```
 ID0(I)=sinv(I)*HHINV;
 GID0(I)=sinv(I)*GOVINV;
 PFI0=SAM('PFI','Firms');
 NURT0=SAM('GOV','ROW');
 CORPTAX=SAM('CORPT','Firms');
 REMIT0=SAM('HH','ROW');
 PROFTRAN0=SAM('HH','Firms');
 SUBS0=SAM('SUBS','GOV');
 DBIP0=SAM('DINT','GOV');
  FDIP0=SAM('FDIP','Firms');
 RPT0=SAM('RPT','Firms');
 CURINC0=SAM ('Firms', 'ROW');
PC0(I)=1;
 PD0(I)=1;
 PE0(I)=1;
 PM0(I)=1;
 PX0(I)=1;
 PCE(I)=1;
K0(I)=SAM('K',i);
 LD0(I)=SAM('L',i);
 WL0(I)=SAM('L',i);
 RP0(I)=SAM('K',i);
 X0(i,j)=SAM(i,j);
 PRODUCTIONTAX(J)=SAM('GOV',j);
 XS0(J)=sum(I,X0(I,J))+LD0(J)+K0(J)+PRODUCTIONTAX(J);
 UNEMP0=278.0318402;
LSUP0=SUM(I,LD0(I))+UNEMP0;
 KSUP0=SUM(I,K0(I));
W0=1;
 WDIST0(I)=WL0(I)/(LD0(I)*W0)
RK0= SUM(I, RP0(I))/KSUP0 ;
```

```
 RKDIST0(I)  = RP0(I)/(K0(I)*RK0) ;
IO(I,J)=X0(I,J)/XS0(J);
 INT0(I)=SUM(J, IO(I,J)*XS0(J)) ;
 PROTAX(I) = SAM("GOV",I)/(PX0(I)*XS0(I)) ;
 PVA0(I) = PX0(I)*(1-PROTAX(I)) - SUM(J, PC0(J)*IO(J,I)) ;
IMPTAX(I)=SAM('IMPT',i);
 EXPTAX(I)=SAM('EXT',i);
 M0(I)=SAM('ROW',i)+imptax(i);
 E0(I)=SAM(i,'ROW')-exptax(i);
 DC0(I)=(PX0(I)/PD0(I))*XS0(I) - (PE0(I)/PD0(I))*E0(I);
SALTAX(I) = SAM("SALT",I)/(PM0(I)*M0(I)+PD0(I)*DC0(I)) ;
 CC0(I) = (PM0(I)*M0(I) + PD0(I)*DC0(I))*(1+SALTAX(I))/PC0(I) ;
 TM(I)     = SAM("IMPT",I)/SAM("ROW",I) ;
 TE(I)     = SAM("EXT",I)/SAM(I,"ROW") ;
 PWM(I) = PM0(I)/(1+TM(I)) ;
 PWE(I) = PE0(I)/(1-TE(I)) ;
  CORPTAX = CORPTAX/SUM(I, RP0(I));
Y0      = SUM(I, W0*WDIST0(I)*LD0(I)) + GOVTRANS0 + PROFTRAN0 +
REMIT0;
 HTAX = HHTAX/Y0 ;
 MPS0 = HHSAV/(Y0*(1-HTAX)) ;
IDLES(I)   = ID0(I) / SUM(J, ID0(J) ) ;
GIDLES(I)  = GID0(I)/SUM(J, GID0(J) ) ;
 CAD0=SUM(I, PWM(I)*M0(I)) + RPT0 + PROFTRAN0 + GFINT0- (SUM(I,
PWE(I)*E0(I)) + REMIT0+ NURT0+ FSAV0 +CURINC0) ;
CD0(I)     = SAM(i,'HH');
CLES(I)   = CD0(I)/SUM(J, CD0(J));
PWTS(I)    = CLES(I) ;
GD0(I)  = SAM(i,'GOV');
GLES(I)  = GD0(I)/SUM(J, GD0(J) ) ;
sigma(i)=3;
SIGMA2(I)=4;
```

RHOC(I) = (1/sigma(I)) - 1 ;

RHOT(I) = (1/sigma2(I)) + 1 ;

BC(I) = PM0(I)/PD0(I) *(M0(I)/DC0(I))**(1+RHOC(I)) ;

BC(I) = BC(I)/(1 + BC(I)) ;

AC(I) = CC0(I) / (BC(I)*M0(I)**(-RHOC(I)) + (1-BC(I))*DC0(I)**(-RHOC(I)))**(-1/RHOC(I));

BT(I) = 1/(1 + PD0(I)/PE0(I) * (E0(I)/DC0(I))**(RHOT(I)-1)) ;

AT(I) = XS0(I)/(BT(I)*E0(I)**RHOT(I) + (1-BT(I))*DC0(I)**RHOT(I))**(1/RHOT(I)) ;

BX(I) = RP0(I)/(PVA0(I)*XS0(I)) ;

AX(I) = XS0(I)/(K0(I)**BX(I)*LD0(I)**(1-BX(I))) ;

GREV0=SUM(I, PROTAX(I)*PX0(I)*XS0(I))+SUM(I, SALTAX(I)*(PD0(I)*DC0(I) + PM0(I)*M0(I)))+SUM(I, TM(I)*PWM(I)*M0(I)) + SUM(I, CORPTAX*RK0*RKDIST0(I)*K0(I))+HTAX*Y0+SUM(I, TE(I)*PWE(I)*E0(I)) + NURT0 + PFI0 ;

subsrate= SUBS0/GREV0;

PROF0= (1-CORPTAX)*SUM(I,(RK0*RKDIST0(I)*K0(I)))+SUBS0+DBIP0+CURINC0;

RATEPFI=PFI0/PROF0;

PISB0= SUM(I,GID0(I)) - GSAV0;

GPRMBAL0 = GREV0 - SUM(I,GD0(I)) - SUM(I,GID0(I)) - GOVTRANS0 ;

TOTINVE0(I)=ID0(I)+GID0(I);

GDP0=SUM(I, PC0(I)*(CD0(I)+GD0(I)+GID0(I)+ID0(I)) + PWE(I)*E0(I)-PWM(I)*M0(I)) ;

VARIABLE

PC(I)   Composite price

PD(I)   Domestic price

PE(I)   Export price

PM(I)   Import price

PVA(I)   Price of value added

PX(I)   Gross output price

CC(I)   Composite good

DC(I)   Domestic good

E(I)   Exports

M(I) Imports

XS(I) Output supply

GDP Gross domestic product

LD(I) Labor demand

LSUP Labor supply

K1(I) Capital demand

KSUP Capital supply

W Wage

WDIST(I) Sectoral wage rate differentials

RKDIST(I) Sectoral capital return rate differentials

RK Return rate

TOTINVE(I) Total inv

CD(I) HH consumption

GD(I) Gov consumption

ID(I) HH inv demand based on sectors

GID(I) GOV inv demand based on sectors

INT(I) Intermediate input uses

Y HH income

EXTAX Export tax revenue

TOTPROTAX Production tax revenue

TOTSALTAX Sales taxes revenue

TOTCORPTAX Corporate taxes revenue

TARIFF Tariff revenue

TOTHHTAX Income tax revenue

GFINT Gov foreign interest payments to row

FSAV Foreign savings

GREV Government revenues

GOVCON Government consumption

GOVTRANS Government transfers

GINV Government inv

GSAV Government savings

GPRMBAL Primary budget balance

MPS Marginal propensity to save

PRSAV HH savings

PRINV HH investments

SUBS Government subsidies to firms

DBIP Government domestic interest payments to firms

PROF Profit of firms

FDIP Foreign debt int payments

RPT Profit transfer to row

PROFTRAN Profit transfer to hh

UU Utiliy

REMIT Remittances

PFI Public factor income

NURT Net unrequited transfers

GFINT GOV foreign int debt payments

FSAV Foreign savings

CURINC Currency income

CAD Current account deficit

UNEMP;

*Initialization of the variables

PC.L(I) = PC0(I) ;

PD.L(I) = PD0(I) ;

PE.L(I) = PE0(I) ;

PM.L(I) = PM0(I) ;

PX.L(I) = PX0(I) ;

PVA.L(I) = PVA0(I) ;

CC.L(I) = CC0(I) ;

DC.L(I) = DC0(I) ;

E.L(I) = E0(I) ;

K1.L(I) = K0(I) ;

XS.L(I) = XS0(I) ;

```
KSUP.L     = KSUP0   ;
LSUP.L     = LSUP0   ;
LD.L(I)    = LD0(I)  ;
M.L(I)     = M0(I)   ;
RK.L       = RK0     ;
W.L        = W0 ;
WDIST.L(I)   = WDIST0(I) ;
RKDIST.L(I)  = RKDIST0(I) ;
INT.L(I)   = INT0(I)  ;
CD.L(I)    = CD0(I)   ;
GD.L(I)    = GD0(I)   ;
ID.L(I)    = ID0(I) ;
GID.L(I)   = GID0(I);
MPS.L      = MPS0 ;
TOTPROTAX.L  = SUM(I, PROTAX(I)*PX0(I)*XS0(I) ) ;
TOTCORPTAX.L = SUM(I, CORPTAX*RK0*RKDIST0(i)*K0(I));
EXTAX.L      = SUM(I, TE(I)*PWE(I)*E0(I)) ;
TARIFF.L     = SUM(I, TM(I)*PWM(I)*M0(I)) ;
TOTHHTAX.L   = HTAX*Y0 ;
TOTSALTAX.L  = SUM(I, (PM0(I)*M0(I) + PD0(I)*DC0(I))*SALTAX(I) ) ;
GFINT.L = GFINT0 ;
GINV.L     = SUM (I, PC0(I)*GID0(I));
PROFTRAN.L=PROFTRAN0;
REMIT.L=REMIT0;
PFI.L=PFI0;
NURT.L=NURT0;
GFINT.L=GFINT0;
FDIP.L=FDIP0;
CURINC.L=CURINC0;
GSAV.L     = GSAV0 ;
PISB.L     = GINV.L - GSAV.L;
```

GREV.L = TOTPROTAX.L + TOTSALTAX.L + TOTCORPTAX.L + EXTAX.L + TARIFF.L + TOTHHTAX.L + NURT.L + PFI.L ;

GOVCON.L = SUM(I, PC0(I)*GD0(I)) ;

GOVTRANS.L = GOVTRANS0;

GPRMBAL.L = GREV.L - GOVCON.L - GINV.L - GOVTRANS.L ;

PRSAV.L = MPS0*Y0*(1-HTAX);

FSAV.L = FSAV0 ;

PRINV.L =PRSAV.L + FSAV.L - PISB.L ;

GDP.L = SUM(I, PC0(I)*(CD0(I)+GD0(I)+GID0(I)+ID0(I)) + PWE(I)*E0(I)-PWM(I)*M0(I)) ;

DROP.L = 0.0 ;

GIR = GINV.L/GDP.L ;

GVTR = GOVTRANS.L/GDP.L ;

GSR = GSAV.L/GREV.L ;

GCR = GOVCON.L/GDP.L ;

CAD.L=CAD0;

Y.L = Y0;

TOTINVE.L(I)=TOTINVE0(I);

SUBS.L=SUBS0;

DBIP.L=DBIP0;

PROF.L=PROF0;

RPT.L=RPT0;

UNEMP.L=UNEMP0;

EQUATIONS

PMDEF(I) Domestic import prices

PEDEF(I) Domestic export prices

PCDEF(I) Price for domestic sales

PXDEF(I) Price for output

PVDEF(I) Value added

ACTIVITY(I) Production

FOCLABEQ(I) Focs for labor

FOCKAPEQ(I) Focs for capital

LABMKTEQM Labor market equilibrium

KAPMKTEQM Capital market equilibrium

CET(I) Cet function

ESUPPLY(I) EXPORT SUPPLY

ARMINGTON(I) Composite good

COSTMIN(I) F.O.C. FOR COST MINIMIZATION OF COMPOSITE GOOD

PRINCEQ HH income

GREQ Gov revenue

PROTAXDEF Production taxes

SALTAXEQ Sales tax

TARIFFEQ Tariff

CORPTAXEQ Corporate tax

EXTAXEQ Export tax

HHTAXDEF HH tax

CDEQ(I) HH consumption

GDEQ(I) Gov consumption

INTEQ(I) Intermediate uses

GDPDEF GDP

PRSAVEQ HH savings

GOVSAV GOV savings

PISBDEF Saving inv balance for public

GOVTRANSE Gov transfers

GOVCONEQ Gov cons TO

GPRBGDPRAT Primary balance

GPRBALEQ Primary budget balance

IDEQ(I) HH inv demand

GIDEQ(I) Gov inv demand

WALRAS Walras law

PRINVEQ HH inv

SUBSEQ Subsidy equation

PROFEQ Firms profit

```
PFIEQ Public factor income
COMBAL(I) Goods market equilibrium
CAEQ        Current account balance
OBJ         Objective function ;
PMDEF(I)..  PM(I) =E= PWM(I)*(1+TM(I)) ;
PEDEF(I)..  PE(I) =E= PWE(I)*(1-TE(I))  ;
PCDEF(I)..  PC(I)*CC(I) =E= (PD(I)*DC(I) + PM(I)*M(I)) * (1+SALTAX(I)) ;
PXDEF(I)..  PX(I)*XS(I) =E= PD(I)*DC(I) + (PE(I)*E(I)) ;
PVDEF(I)..  PVA(I) =E=  (1-PROTAX(I))*PX(I) - SUM(J, PC(J)*IO(J,I)) ;
ACTIVITY(I)..  XS(I) =E= AX(I)*(K1(I)**BX(I)*LD(I)**(1-BX(I))) ;
FOCLABEQ(I)..  W*WDIST(I)*LD(I) =E= (1-BX(I))*PVA(I)*XS(I) ;
FOCKAPEQ(I)..  RK*RKDIST(I)*K1(I) =E= BX(I)*PVA(I)*XS(I) ;
LABMKTEQM..   UNEMP=E=LSUP-SUM(I,LD(I));
KAPMKTEQM..   SUM(I, K1(I))  =E= KSUP ;
CET(I)..  XS(I) =E= AT(I)*( BT(I)*E(I)**RHOT(I) + ( 1-BT(I) )*DC(I)**RHOT(I)
)**(1/RHOT(I)) ;
ESUPPLY(I)..  E(I)/DC(I) =E= ( PE(I)/PD(I)   *(1-BT(I))/BT(I) )**(1/(RHOT(I)-1)
) ;
ARMINGTON(I)..   CC(I)  =E=  AC(I)*(  BC(I)*M(I)**(-RHOC(I))   + (1-
BC(I))*DC(I)**(-RHOC(I)) )**(-1/RHOC(I)) ;
COSTMIN(I)..   M(I)/DC(I)  =E=  (  PD(I)/PM(I)*BC(I)/(1-BC(I))  )**(1/(1  +
RHOC(I)) ) ;
PRINCEQ..     Y   =E=  SUM(I,  W*WDIST(I)*LD(I)  )  +  GOVTRANS  +
PROFTRAN + REMIT  ;
GREQ..   GREV =E=TOTPROTAX + TOTSALTAX + TARIFF  + TOTCORPTAX
+ TOTHHTAX+EXTAX + NURT + PFI;
PROTAXDEF..  TOTPROTAX =E= SUM(I, PROTAX(I)*PX(I)*XS(I) );
SALTAXEQ..     TOTSALTAX  =E=  SUM(I,  SALTAX(I)*(PD(I)*DC(I)  +
PM(I)*M(I)) ) ;
TARIFFEQ..   TARIFF =E= SUM(I, TM(I)*PWM(I)*M(I)) ;
CORPTAXEQ..       TOTCORPTAX    =E=    SUM(I,
CORPTAX*RK*RKDIST(I)*K1(I));
HHTAXDEF..   TOTHHTAX =E= HTAX*Y ;
EXTAXEQ..   EXTAX =E= SUM(I, TE(I)*PWE(I)*E(I)) ;
```

```
GDEQ(I)..      PC(I)*GD(I) =E= GLES(I)*GOVCON ;
  CDEQ(I)..     PC(I)*CD(I) =E= CLES(I)*(1-MPS)*Y*(1-HTAX)  ;
 INTEQ(I)..     INT(I) =E= SUM(J, IO(I,J)*XS(J));
 GDPDEF..                  GDP   =E=   SUM(I,   PC(I)*(CD(I)+GD(I)+GID(I)+ID(I))+
PWE(I)*E(I)-PWM(I)*M(I) ) ;
 PRSAVEQ..       PRSAV =E= MPS*Y*(1-HTAX);
  PRINVEQ..       PRINV=E=PRSAV + FSAV - PISB ;
GOVSAV..        GSAV=E=GSR*GREV;
  PISBDEF..       PISB =E= GINV - GSAV;
 GOVTRANSE..    GOVTRANS =E=GVTR*GDP;
 GOVCONEQ..      GOVCON =E= GCR*GDP ;
 GPRBGDPRAT..      GPRMBAL  =E= GPRBR*GDP ;
GPRBALEQ..    GPRMBAL  =E= GREV - GOVCON - GINV - GOVTRANS ;
 IDEQ(I)..     PC(I)*ID(I) =E= IDLES(I)*PRINV;
GIDEQ(I)..    PC(I)*GID(I) =E= GIDLES(I)*GINV;
  WALRAS..      PRSAV + GSAV + FSAV =E= PRINV + GINV + DROP;
  SUBSEQ.. SUBS=E=subsrate*GREV;
 PROFEQ..                              PROF=E=                              (1-
CORPTAX)*SUM(I,(RK*RKDIST(I)*K1(I)))+SUBS+DBIP+CURINC;
 PFIEQ.. PFI=E=RATEPFI*PROF;
 COMBAL(I)..  CC(I)=E=INT(I) + CD(I) + GD(I) + ID(I) + GID(I );
CAEQ..    CAD=E=SUM(I, PWM(I)*M(I)) + RPT + PROFTRAN+ GFINT- (SUM(I,
PWE(I)*E(I)) + REMIT+ NURT+ CURINC) ;
 OBJ..              UU     =e= prod(i, CD(I)**CLES(I));
*Fixed variables
PROFTRAN.FX=PROFTRAN.L;
REMIT.FX=REMIT.L;
NURT.FX=NURT.L;
CURINC.FX=CURINC.L;
DBIP.FX=DBIP.L;
FDIP.FX=FDIP.L;
W.FX       = W.L ;
LSUP.FX    = LSUP.L ;
```

```
WDIST.FX(I) = WDIST0(I) ;
KSUP.FX    = KSUP.L ;
RKDIST.FX(I) = RKDIST0(I) ;
FSAV.FX   = FSAV.L ;
GFINT.FX = GFINT.L;
CURINC.FX  = CURINC.L;
RPT.FX  = RPT.L;
MPS.FX     = MPS.L ;
MODEL  CGESOLAR  /ALL/  ;
SOLVE CGESOLAR MAXIMIZING UU USING NLP;
*Introduction of the shock
AX('ELSOLAR')=6.5*AX('ELSOLAR');
SOLVE GENEQM MAXIMIZING UU USING NLP;
```

B. TURKISH SUMMARY / TÜRKÇE ÖZET

Türkiye'de enerji talebi ekonomik gelişmelere ve nüfus artışına bağlı olarak hızla artmaktadır. Ancak talep artışı, ülkedeki yerli enerji üretimi ile karşılanamamaktadır. Bu da enerji arzının büyük bir kısmının, özellikle de elektrik üretiminde yüksek payı olan fosil yakıtların, ithalata bağımlılığını beraberinde getirmektedir. Türkiye enerji üretiminde kullanılan neredeyse tamamını ithal etmektedir. Yerli petrol üretimi toplam talebin 7%'sini oluştururken ve yerli üretimde daha yüksek bir paya sahip olan kömürünün ise 58%'ini ithal edilmektedir (IEA, 2021). Enerji tedariğinde ithalata olan yüksek bağımlılığın ülkenin enerji güvenliğini zayıflatması ve üretim süreçlerini tehdit etmesi, Türkiye'nin enerji arzını korumaya, geliştirmeye ve sürdürülebilirliğe öncelik vermesine yol açmaktadır. Ayrıca yurt içi ve küresel gelişmeler Türkiye'yi sürdürülebilir enerji sistemlerine odaklanmaya zorlamaktadır. COVİD-19'dan başlayarak enerji arzına ilişkin sorunlar ortaya çıkmış ve Rusya'nın Ukrayna işgaliyle beraber artan fiyatlar nedeniyle bu sorunlar tüm dünyada hızlanmıştır.

Üstelik Türkiye’nin Paris İklim Anlaşması'nın Ekim 2021'de onaylanması ve sıfır emisyona ilişkin taahhütler, Türkiye'nin enerji geçişini hızlandırmasını gerektirmektedir çünkü büyük ölçüde fosil yakıtlara dayanan mevcut enerji karışımı, Türkiye'nin hedefine ulaşmasına yardımcı olacak seviyede değildir. Ayrıca 6 Şubat 2023 tarihinde Kahramanmaraş merkezli yaşanan deprem ve ardından bölgede yaşanan sel felaketleri önemli can ve mal kayıplarına yol açmış ve doğal afet sonrası enerji arzının önemini göstermiştir (SHURA, 2022). Dolayısıyla yenilenebilir enerji kaynakları, ülkenin bu sorunları aşmasında ve enerjiye geçişinde en önemli çözüm olarak öne çıkmaktadır.

Türkiye'de yenilenebilir enerji kaynaklarının payı son on yılda, hükümet politikalarının öncülüğünde büyük ölçüde artmıştır ve özellikle yenilenebilir kaynaklardan elde edilen elektrik neredeyse üç katına çıkmıştır (IEA, 2021). Bu artıştan en çok yenilenebilir enerji sektörleri, özellikle güneş, rüzgâr ve jeotermal etkilenmiştir. Güneş enerjisi, iklim ve coğrafi koşulları nedeniyle Türkiye'de yüksek bir potansiyele sahiptir. Yenilenebilir enerji kaynaklarının elektrik üretimindeki payının 2035 yılına kadar 54,7%'ye ulaşması beklenmektedir ve bu paydaki en büyük katkı güneş enerjisi kurulu gücüne aittir (ETKB, 2022). Türkiye coğrafi ve iklim koşulları sayesinde, özellikle Güneydoğu Anadolu ve Akdeniz Bölgesinde güneş enerjisi için önemli potansiyele sahiptir. Türkiye'de güneş ışınımı yoğunluğu yüksektir ve ülke güneş enerjisi üretmek için kullanabilecek boş ve geniş alanlara sahiptir (Şeker ve Kahraman, 2021). Ülkenin güneş enerjisi potansiyeli 380 milyar kWh, yıllık ortalama güneşlenme süresi 2766,5 saat, yıllık ortalama radyasyon yoğunluğu metre kare başına 1527,1 kWh olup; güneş enerjisinden verimli bir şekilde 110 güne kadar yararlanılabilmektedir (ETKB, 2023). Son yıllarda güneşten elde edilen enerji miktarı artmasına rağmen dünyanın geri kalanıyla ve diğer gelişmekte olan ülkelerle karşılaştırıldığında Türkiye'de güneş fotovoltaik enerjisinden elektrik üretimi, potansiyel daha yüksek olmasına rağmen geride kalmaktadır (PwC, 2021). Güneş enerjisi sistemlerinin kurulumuyla ilgili en çok konuşulan tartışmalardan biri de üretimdeki yerlilik seviyesidir. Güneş enerjisinden elde edilen elektriğin yerli üretimin payı, Türkiye'nin sektör lideri olmaması ve teknoloji, üretim süreçleri, altyapı ve hammadde ithalatına bağlı olması nedeniyle potansiyelini karşılayabilecek kadar yüksek değildir (IEA, 2021). Dolayısıyla yenilenebilir elektriğin payı artmasına rağmen sektörün ithalat bağımlılığının devam etmesi aşılması gereken bir konu haline gelmektedir.

Türkiye Fotovoltaik Teknoloji Platformu (TFTP), sektördeki firmaları, Ar-Ge organizasyonlarını, küçük ve orta ölçekli işletmeleri ve araştırmacıları bir araya getirerek Türkiye'de güneş fotovoltaik teknolojilerinin yerli üretimine katkıda bulunmak amacıyla kurulmuştur ve yerli üretimi ve yüksek verimli güneş pili türlerinin ve ilgili teknolojilerin her düzeyde geliştirilmesini teşvik etmeyi amaçlamaktadır. TFTP'nin öncülük ettiği güneş enerjisi teknolojilerindeki gelişmelerin, ülkenin ekonomik büyümesine katkı sağlaması, enerji sektöründe ithalata bağımlılığı ve cari açığı azaltması, istihdam yaratması ve olumlu çevresel etki yaratması beklenmektedir. Bu tez, TFTP'nin eylemleri sonucunda güneş fotovoltaik elektrik sektöründe yaşanan gelişmelerin, önde gelen ekonomik göstergeler ve çevre açısından beklenen sonuçları getirip getirmediğini analiz etmeyi amaçlamaktadır. Bu amaçla TFTP'nin öngörülen sonuçlara ulaşılıp ulaşılamayacağını analiz etmek için Hesaplanabilir Genel Denge, CGESOLAR, modeli kullanılacaktır. Güneş fotovoltaik elektrik sektörünün Türkiye üzerindeki ekonomik ve çevresel etkisine hesaplanabilir genel denge modeli kullanılarak odaklanan başka bir çalışma yoktur.

Hesaplanabilir genel denge modelleri, seçilen değişkenlerin ekonomide ortaya çıkan bir şoka veya politika değişikliğine nasıl tepki verdiğini gösterebildiğinden bu tür analizler için uygundur. Hesaplanabilir genel denge modelleri tüm ekonomik aktörleri, üreticileri, haneleri, firmaları ve devleti birleştirir ve aktörlerin davranışlarını denklemler aracılığıyla sunar. Tanımlanan aktörlerin optimal davranışlarına ve varsayımlara dayanarak ekonomi bir dengeye ulaşır. Dengeye ulaşan ekonomiye tanıtılan şok sonucunda değişkenlerin yeni bir denge elde etmek için nasıl oluştuğu gözlemlenebilir. Gerekli veriler mevcut olduğu sürece modeldeki üretim yapısı istenildiği gibi şekillendirilebilir, sektörlere göre ayrıştırılabilir ve modelin kapsamı ihtiyaca göre seçilebilir. Hesaplanabilir genel denge modellerinin teorik tasarımı, modeldeki aktörler açısından değişikliklerin yorumlanmasına ve ekonomideki üretim faktörlerinin ve malların akışlarının izlenmesine olanak tanır (Cai ve Arora, 2015) ve tüm bu özellikleri ile enerjiyle ilgili alanları araştırmak için uygundur. Hesaplanabilir genel denge modelleri kullanılarak iklim değişikliği, enerji verimliliği, enerji sübvansiyonları ve vergileri, yenilenebilir enerji kaynaklarının entegrasyon ve enerji güvenliği gibi enerjiyle ilgili çeşitli hususları ve enerji yapısındaki olası sorunları analiz edilebilir.

Literatürde hesaplanabilir genel denge modeli kullanılarak iklim değişikliği, karbon emisyonu ve hedefleri ve vergisi, emisyon ticaret sistemi, enerji verimliliği, çevre kirliliği, yenilenebilir enerji kaynakları gibi enerji ile ilgili farklı alanlara odaklanan çalışmalar bulunmaktadır. Bu çalışmalar özellikle yenilenebilir enerji kaynaklarının ülkelerin mevcut enerji üretim sistemlerine entegre edilmesinin etkilerine odaklanmaktadır. Bu çalışmalardan en çok öne çıkan Cansino ve ark. (2014)'nın

İspanya'da fotovoltaik güneş enerjisi üretim kapasitesinin arttırılmasının sosyoekonomik etkilerini hesaplanabilir genel denge modeli kullanarak inceleyen araştırmadır. Bu tezde oluşturulan model için de bu makale örnek alınarak statik bir HGD modeli, CGESOLAR oluşturulmuştur.

Türkiye için hesaplanabilir genel denge modeli kullanarak enerji alanına odaklanan birçok farklı makale bulunmaktadır. Farklı makalelerde kurgulanan modellerin CGESOLAR'ın kurgusu ile benzerlik ve farklılıkları bulunmaktadır ve devam eden kısımda bu benzerlik ve farklılıklar açıklanacaktır. Örneğin Karapınar ve ark. (2019), Türkiye'nin makroekonomik göstergelerinin karbon vergisi ve emisyon ticaret sisteminden nasıl etkilendiğini analiz etmek için bir model kullanmıştır. Telli ve ark. (2008), Kyoto Protokolüne uygun politika senaryolarının ekonomik sonuçlarına odaklanmak için bir HGD modeli oluşturmuştur. Ayrıca Olçum ve Yeldan (2013), çok bölgeli, çok sektörlü bir HGD model kullanarak Türkiye'nin uygulamayı düşündüğü çeşitli emisyon ticaret sistem rejimlerinin uyum mekanizmalarını ve ekonomik refah sonuçlarını incelemiştir. Ayrıca Kat ve ark. (2018), Paris Anlaşması'nın etkilerini, enerji sektörünün ayrıntılı bir temsiliyle Türkiye için değerlendirmiştir. CGESOLAR, Telli vd. (2018)'de olduğu gibi üretim seviyelerine göre farklılaştırılmış CO2 emisyonlarını içermediğinden tanıtılan bu konulara doğrudan odaklanmayacaktır. CGESOLAR'da Olçum ve Yeldan (2013)'nın sunduğu modeldeki gibi Türkiye'nin bölgelere ayrıştırılması yoktur ve Kat ve ark. (2018)'ın ortaya koyduğu dinamik yapının aksine CGESOLAR statik bir modeldir. Ancak bu modellerle CGESOLAR arasında benzerlikler de vardır. Örneğin Karapınar ve ark. (2019) modele işsizlik ve enerji sektörlerinin kaynaklarına göre ayrıştırılmasını da eklemiştir. Ayrıca şok, yenilenebilir enerji sektörlerindeki verimlilik artışlarına dayanmaktadır. CGESOLAR bu konularda benzer yaklaşımlar izleyecektir.

Ek olarak, diğer çalışmalar enerji politika araçlarının etkilerine odaklanmaktadır. Tartışma genellikle farklı politikaların ekonomik büyümeyi ve istihdamı artırıp artırmadığı ve Türkiye'nin karbon emisyon seviyelerini etkileyip etkilemediğiyle ilgilidir. Örneğin Kumbaroğlu (2003), enerji-ekonomi-çevre hesapları içeren HGD kullanarak çevre politikası kararlarının enerji teknolojilerinin ve sosyoekonomik göstergelerin benimsenmesine etkilerini incelemiştir. Modelde, enerji sektörlerinin detaylandırılması olsa da CGESOLAR'dekine kıyasla daha az sektörel ayrıntı göstermektedir. Ayrıca Akkemik ve Oğuz (2011) elektrik piyasasında tam serbestleşmenin verimlilik ve rekabet üzerindeki potansiyel etkilerini incelemiş ve serbestleşmenin ekonomi üzerindeki etkilerini analiz etmiştir. Her ne kadar elektrik sektörü CGESOLAR'da amaçlandığı gibi ayrıştırılmış olsa da ayrıştırma seviyeleri farklılık göstermektedir. Burada ayrıştırma elektrik üretimi, iletimi ve dağıtımını içermektedir. Ancak CGESOLAR elektrik üretimini enerji kaynaklarına göre ayrıştıracaktır. Bouzaher ve ark. (2015), teknolojinin benimsenmesini ve sürdürülebilir büyümeyi hızlandırmak için yeşil politika araçlarının ve kamu politikası müdahale mekanizmalarının etkisini incelemek için bir model geliştirmiştir. Ayrıca Kolsuz ve Yeldan (2017), çevresel kirlilik azaltım araçları ile yeşil istihdamın sürdürülmesine yönelik politikalar arasındaki sinerjiyi incelemek için genel denge modeli kullanmıştır. Bu modellerin CGESOLAR'dan farkı dinamik yapıları ve sera gazlarını ve kirliliği modellerine dahil etmeleridir. Yeldan ve ark. (2015) iklim politikası araçlarının ve kamu politikası müdahale mekanizmalarının etkilerini değerlendirmiş ve hem firmalardan hem de hanelerden kaynaklanan karbon emisyonlarına ve ilgili piyasa azaltım araçlarına odaklanmışlardır. Elektrik sektörleri, başta güneş ve rüzgâr olmak üzere yenilenebilir enerji kaynaklarına göre ayrıştırılmaktadır. Ayrıca Şahin (2004), Türkiye'nin çevre ve ekonomi politikaları arasındaki etkileşimi analiz etmek için bir HGD modeli kullanmıştır. Model, Türkiye'nin bölgelerinin sanayileşme düzeylerine göre bölgesel olarak ayrıştırılmıştır.

Aydın ve Acar (2011), bu konuların aksine dinamik, çok sektörlü bir genel denge modeli kullanarak petrol fiyatı şoklarının Türkiye ekonomisini nasıl etkilediğini analiz etmiştir. Ekonomik etkiler arasında GSYİH, enflasyon, dolaylı vergi gelirleri, ticaret dengesi ve karbon emisyonları yer almaktadır. Öte yandan Aydın ve Acar (2010), Türkiye'nin Avrupa Birliği'ne olası katılımının ekonomik ve çevresel etkilerini ölçmek için HGD modelini kullanmıştır. Diğerlerinden ve CGESOLAR'dan farklı bir yaklaşım olarak bu modelde göç de vardır. Yani emek, sınırların dışındaki yabancı firmalara da geçebilir. Ayrıca, Acar ve Yeldan (2016), bölgesel olarak farklılaştırılmış bir HGD modeli kullanarak, enerji politikası araçlarının, özellikle de kömür sübvansiyonlarının ve bunların kaldırılmasının, Türkiye'deki makro göstergeler ve çevresel sonuçlar üzerindeki etkilerini analiz etmiştir. Bölgesel farklılaşma gelire dayalıdır: Yüksek Gelirli ve Düşük Gelirli Bölgeler. Belirtildiği üzere tüm bu makaleler incelendiğinde Türkiye için özel olarak fotovoltaik enerji üretimine hesaplanabilir genel denge modeli kullanarak odaklanan başka bir çalışma bulunmadığını görülmektedir ve tez literatürdeki bu boşluğa katkıda bulunmayı hedeflemektedir.

Bu benzer konuları analiz etmenin Girdi-Çıktı analizi, Sosyal Muhasebe Matris analizi veya ekonometrik modeller gibi başka yöntemleri de vardır. Bu yöntemler hesaplanabilir genel denge modellerinden tamamen farklı değildir; aralarında benzerlikleri vardır ve aynı bağlamda kullanılabilirler. Örneğin, Girdi-Çıktı tablolarında ekonomi, her birinin bir çıktı ürettiği ve diğer endüstrilere veya tüketime gittiği sektörlere bölünmüştür. Girdi-Çıktı tabloları şeffaf analize izin verir, yalnızca birkaç varsayıma dayanır, hızlı bir şekilde ulusal hesaplara dayalıdır ve enerji analizi için kolayca kullanılır. Öte yandan Sosyal Muhasebe Matrisi, belirli bir döneme ait ekonominin resmini verir ve girdi-çıktı tablolarının uzantısı olarak düşünülebilir. Girdi-Çıktı tabloları nihai talep ile üretim arasındaki ilişkiyi açıklarken, sosyal muhasebe matrisi üretim süreçlerinin talep üzerindeki etkilerini göstermektedir (Cansino vd., 2014).

Ayrıca zaman serisi uygulamaları, VAR modelleri ve tahmin gibi ekonometri yöntemleri oldukça tercih edilir ve şirketler, tüketiciler, hükümetler ve uluslararası kuruluşlar gibi sektördeki tüm aktörlerle ilgili niceliksel argümanlar sağlayarak birbirine bağlı enerji piyasalarının incelenmesini genişletir. (Chevalier, 2007). Fakat ekonometrik yöntemlerin optimizasyon sağlamaması nedeniyle politika analizine göre tahmin yapmaya daha uygun olduğu söylenebilir.

Bu modeller dünyada ve Türkiye'de enerji konularının tartışılmasında önemli bir çerçeve sunmaktadır. Bununla birlikte, hesaplanabilir genel denge modelleri ekonominin tamamı için makroekonomik analiz sunar ve bir faktördeki değişikliklerin ekonominin geri kalanına nasıl kanalize edildiğinin izlenmesine olanak tanır. Bu nedenle, ekonominin girdi-çıktı tabloları ve sosyal muhasebe matrisindeki statik temsilinden farklı olarak davranışsal eylem ve senaryo analizine olanak sağlaması nedeniyle bu makale için en öne çıkan modeldir. Ayrıca hesaplanabilir genel denge modelleri, farklı enerji ve çevre politikalarının ekonomik etkilerinin karakterini ve büyüklüğünü ortaya koyabilmektedir (Wing, 2009).

Tez için kurgulanan CGESOLAR statik bir model olup, açıklandığı üzere Türkiye'de fotovoltaik güneş enerjisinin yerli üretiminin arttırılmasının etkilerini analiz etmeyi amaçlamaktadır. Ulusal hesaplarda fotovoltaik güneş enerjisi için ayrı bir sektörel detay bulunmadığından analiz elektrik sektörü ve üretimine dayanmaktadır. Modeldeki ana aktörler hane halkı, firmalar, devlet ve dünyanın geri kalanıdır. Ayrıca modelde yatırım ve birikim girdi ve çıktılarını temsil eden bir hesap da bulunmaktadır. CGESOLAR, üretim faktörleri emek ve sermaye olan Cobb-Douglas üretim fonksiyonunu takip eder. Üretilen toplam çıktı sabit esnekliğe sahip dönüşüm fonksiyonunu takip ederek yerli mal ve ihracata dönüşmektedir. Ayrıca CGESOLAR için Armington varsayımı kabul edilmiştir, yani ithalat ve yerli üretim arasındaki ilişkide sabit bir ikame esnekliği vardır. Ek olarak modele işsizlik tanıtılmış ve modelin çözümü için hane halklarının fayda fonksiyonlarını maksime ettiğini varsayılmıştır. Açıklanan tüm bu denklemler ve varsayımlar sayesinde ana makroekonomik değişkenler tanımlanabilir. Ek olarak çevresel etki analizini de yapabilmek için Türkiye’nin kaçınabileceği karbon emisyon miktarı hesaplanacaktır. Modelin çözümünde amaca uygun olduğu ve optimizasyon problemlerini hızlı bir şekilde çözebildiği için GAMS kullanılmıştır. CGESOLAR için GAMS kodu ve denklemlerin başlangıç noktası Yeldan (2014)’tir.

Hesaplanabilir genel denge modelleri, ekonomik aktörler arasındaki ilişkileri gösteren dengeli bir kare matris olan Sosyal Muhasebe Matrislerine (SMM) dayanmaktadır. CGESOLAR için Türkiye için elektrik sektörünü detaylı yansıtan SMM oluşturulmuştur. SMM’nin oluşturulması için farklı adımlar izlenmiştir. Öncelikle 2021 yılı için sektörel detayları içermeyen ve ekonomideki toplam değerlere dayanan toplulaştırılmış bir SMM oluşturulmuştur. Daha sonra TÜİK tarafından 2012 yılı için yayınlanan Girdi-Çıktı (GÇ) tablosuna dayanarak SMM’deki toplu değerler sektörlere ayrıştırılmıştır. GÇ tablosunda elektrik sektörü toplu tek bir sektör olarak verilmiştir, elektrik üretimine odaklanabilmek için TÜİK tarafından yayınlanan üretim değerleri kullanılarak elektrik sektörü, elektrik üretimi ve diğer elektrik olarak ayrıştırılmıştır. Benzer şekilde GÇ tablosunda güneşten elde edilen elektrik sektörünü temsil eden ayrı sektör bilgisi de bulunmadığı için farklı kaynaklardan üretilen elektrik oranlarına bağlı olarak elektrik üretimi detaylandırılacaktır. Tüm bu adımlar sonucunda 2021 yılı için 22 sektör içeren ve elektrik üretimini enerji kaynaklarına bağlı olarak ayrıştıran SMM elde edilmiştir. Veri setlerinin hiçbirinde güneş enerjisi sektörünün ayrıştırılmasına ilişkin başka bilgi bulunmamaktadır; bu nedenle güneş enerjisinin tamamının fotovoltaik sistemler tarafından üretildiği varsayılmaktadır. 2021 yılı için oluşturulan elektrik sektörü detaylı SMM Türkiye oluşturulan en güncel ve detaylı sosyal muhasebe matrisidir. Türkiye için başka hiçbir SMM elektrik sektörünü bu kadar detaylı sunmamaktadır. Ayrıştırılmış ve ayrıntılı 2021 SMM oluşturulduktan sonra, temel sonuçların elde edilmesi için SMM CGESOLAR'a kalibre edilecek ve ana senaryo sonuçları elde edilmiş olacaktır. Kalibrasyon süreci CGESOLAR'da bulunan değişken ve parametrelerin SMM sonuçlarını verecek şekilde hesaplanmasını içerir.

TFTP'nin etkilerini ortaya koyan şok, Milli Enerji Planına (ETKB, 2022) dayanmaktadır. Plana göre güneş enerjisiyle elektrik üretiminin payının 16,5%'e ulaşması beklenmektedir. TEİAŞ'ın yayınladığı elektrik üretim verilerine göre bu pay 2021 yılı için 2,54%'tür. Bu artışın TFTP'den kaynaklanacağı ve fotovoltaik güneş enerjisinden üretilen elektrik sektöründe verimlilik artışı olarak ifade edileceği varsayılacaktır. Bu şokun CGESOLAR'a uygulanmasının ardından yeni sonuçlar temel senaryo ile karşılaştırılacak ve TFTP'nin vaat edilen hedeflere ulaşıp ulaşmadığı analiz edilecektir. CGESOLAR'ın oluşumu ve şokun tanıtılması için GAMS kullanılacaktır. Ayrıca, elektrik sektöründe hâkim olan fosil yakıtların aksine, güneş enerjisi temiz bir enerjidir ve elektrik üretiminde fotovoltaik güneş enerjisinin payının artmasının pozitif çevresel etkileri olması beklenmektedir. Çevresel etki analizi karbon emisyonları üzerinden yapılacaktır. Fotovoltaik elektrik üretimi arttığında fosil yakıtlara olan ihtiyaç azalacaktır. Fotovoltaikten gelen yeni elektrik üretiminin, fosil yakıtlardan elektrik üretiminin yerini alacağı varsayılarak, kaçınılabilecek karbon emisyon miktarı hesaplanacaktır.

Tanıtılan şok sonucunda ekonomide toplam çıktı 0.032% oranında artmıştır. Sektörel değişiklikler şokun etkileri hakkında daha fazla bilgi verecektir. Bu sektördeki verimlilik artışının şok olarak sunulması nedeniyle üretimin en çok 4.582% ile fotovoltaik elektrik üretim sektöründe arttığı görülmektedir. Bu artışı, 0.18% ile Demir-Çelik sektörü takip etmektedir. Fotovoltaik elektrik üretimi sektöründeki gelişmeler enerji yoğun olan Demir-Çelik sektörünün üretimini artırmaktadır. Ayrıca çelik, fotovoltaik güneş panellerinin yapısal ve elektrik bileşenlerinin üretiminde kullanılan temel hammaddelerden biridir (Carrara vd., 2020). Dolayısıyla fotovoltaik güneş enerjisi üretiminde üretim arttıkça çelik ihtiyacının da etkisiyle demir-çelik sektörünün üretimi de artmaktadır. Demir-Çelik artışını diğer elektrik üretim sektörleri de 0.133% civarında artışlarla takip etmektedir. Bu sektörler, tanıtılan sosyal muhasebe matrisine göre fotovoltaik elektrik sektörü ile daha fazla etkileşime giren sektörlerdir. Dolayısıyla bu sektörde yaşanan bir gelişme onları da olumlu etkilemiştir. Ek olarak otomotiv sektörünün üretim çıktısı 0.089% artmıştır. Solar fotovoltaik enerji sistemleri elektrikli otomobillerin üretim ve kullanım süreçlerinde kullanabilir. Örneğin, Ford'un Güney Afrika'daki üretim tesisi, tesisin elektriğinin 35%'ini üretebilecek Solar PV otopark projesini hayata geçirmiştir (FORD Medya Merkezi, 2022). Bu sektörlerin birbirine bağımlılığı CGESOLAR için de benzerdir; Otomotiv endüstrisi, daha verimli güneş PV üretimi sayesinde gelişme göstermiştir.

Madencilik sektörü de Demir-Çelik ile aynı nedenle yüzde 0.070 arttığı görülmektedir. Fotovoltaik güneş panellerinin üretiminde madencilik yoluyla elde edilen hammaddelere ihtiyaç vardır. Ek olarak, Elektronikte 0.052%, Tekstil ve Hazır Giyimde ise 0.044% artış yaşanmıştır. Her iki sektör de enerji yoğun sektörler olduğundan daha verimli bir enerji kaynağına sahip olmak üretimlerini arttırmıştır. Ayrıca güneş fotovoltaik panellerinde kullanılan farklı tipteki akülerin imalatı Nace-Rev 2 sektörel ayrımına göre Elektronik sektörüne aittir. Fotovoltaik güneş hücrelerinde kullanılan malzemelerin başında gelen silikonu içeren Kimya sektörü üretimini 0,040% artarken, bunu Makine, Çimento ve Kâğıt ve Matbaa takip etmektedir. Güneş fotovoltaik üretimindeki gelişmeler bir kez daha enerji yoğun sanayilerin üretimini olumlu yönde etkilemiştir. Ayrıca güneş enerjisi santrallerinin bileşenleri arasında malzeme yoğunluğunu çelikten sonra ikinci sırada takip eden betonun da yer aldığı Çimento sektöründe de 0.034% oranında artış yaşanmıştır. (Jean ve diğerleri, 2015). Toplam üretim en çok tarım sektöründe azaldığı görülmektedir. Değişim oranı,0.009%, yüksek olmasa da fotovoltaik güneş sistemlerinin çiftliklerde uygulanabilmesi ve fotovoltaik güneş sektöründe verimliliğin artırılmasının Tarıma da fayda sağlaması beklenmekteydi. Bu sebeple çıktıda bu düşüş beklenen bir sonuç değildir. Ancak CGESOLAR için bu durum Türkiye'deki tarımın yapısından kaynaklanıyor olabilir.

Modeldeki en kritik parametrelerinden biri olan yerli üretimdir. TFTP'nin ana amacı fotovoltaik enerjinin ve aşağıdaki teknolojilerin tamamının yerli üretimini teşvik etmektir. Bu hedef doğrultusunda toplam yerli üretimde 0.027% artış gözlemlenmektedir. Sektörlere bakıldığında en fazla artış gösteren sektör 4.167% ile fotovoltaik elektrik üretimi olurken, bunu hem yenilenebilir hem de yenilenemeyen diğer elektrik üretim sektörleri takip etmektedir. Bu sonuçlar, güneşte olduğu gibi yenilenebilir enerji sektörlerinde de daha fazla verimlilik artışının diğer enerji sektörlerini de olumlu yönde etkileme potansiyeline sahip olduğuna işaret etmektedir. Demir-Çelik sektöründe de artış görülmektedir, bu artışı toplam çıktıya benzer şekilde Madencilik, Otomotiv, Elektronik, Tekstil-Giyim, Makine ve Kimya takip etmektedir.

Diğer önemli bir parametre ithalattaki değişimlerdir. Enerji sektöründe yerli üretimin payının artırılması, Türkiye'nin en kritik sorunlarından biri olan enerji sektöründe ithalata bağımlılığın azaltılmasını hedeflemektedir. Yaşanan şok sonucunda güneş fotovoltaik enerjisinden elektrik üretimi ithalatı 35.514 % oranında azalmıştır. Bu düşüş TFTP'nin başarısını göstermektedir; hedeflenen verimlilik oranına ulaşıldığında önemli bu sektördeki ithalat oranı büyük ölçüde düştüğü için enerjide ithalat bağımlılığının azalacaktır. Ayrıca yenilenebilir ve yenilenemeyen diğer elektrik üretim sektörlerinin tamamında 0.261% civarında bir azalma söz konusudur. Yani fotovoltaik güneşten elektriği üretiminin arttırılması, Türkiye'nin enerji sektöründe ithalata bağımlılık sorununu aşmasına yardımcı olacak bir çözüm olabilir.

Ek olarak ithalat en çok 0.072% ile Madencilik sektöründe artmıştır. Ayrıca Ulaştırma, Otomotiv ve Demir Çelik sektörlerinde de 0.04% civarında artış görülmektedir. Bu artışlar çok yüksek olmasa da madenciliğin bir enerji sektörü, diğerlerinin ise enerji yoğun sektörler olması nedeniyle ithalat bağımlılığını aşmak için hala iyileştirmelere ihtiyaç olduğuna işaret etmektedir. Üstelik bu artışlar, verimlilik iyileştirmelerinden sonra bile fotovoltaik güneş sistemleri için hammadde talebinin devam ettiğini ve dış kaynaklara bağımlı olduğunu işaret eder. Benzer sektörler için ihracat seviyelerinde de artış görülmektedir.

Türkiye'nin GSYH'si şok nedeniyle 0.024% artmıştır. Bu değişim 1.77 milyon TL ve 0.2 milyon ABD Dolarına karşılık gelmektedir. Miktar çok yüksek olmasa da bu sonuç, bir enerji üretim sektöründeki hafif bir artışın ülkenin büyümesine katkı sağlayabileceğini göstermektedir. Ayrıca, modelde tanıtıldığı gibi kamu tüketimi GSYİH'ye bağlı olduğundan, GSYH arttıkça kamu tüketimi de artmaktadır. Ek olarak Türkiye'deki cari açığın 0.02% azaldığı görülmektedir. Cari açık, enerji sektöründeki ithalat bağımlılığının cari açığın başlıca etkeni olması nedeniyle, Türkiye gibi bir ülkede enerji kaynaklı şokun analizinde kritik bir değişkendir. Fotovoltaik güneş sektöründeki verimlilik artışları cari açığın düşmesine neden olmuştur, bu da enerji sektöründe daha verimli ve yerli alternatiflere sahip olmanın uluslararası kaynaklara bağımlılığı azalttığını göstermektedir. Ayrıca işgücü talebi 0.029% artarken, işsizlik 0.213% azalmıştır. İşgücü talebindeki artış ve işsizliğin azalması TFTP'nin amacına ulaşabileceğini göstermektedir.

Hesaplanabilir genel denge modelinin gösterdiği makroekonomik etkilerin yanı sıra, elektrik üretim yapısındaki değişikliklerin çevresel sonuçları da vardır. Daha önce de açıklandığı gibi, çevresel etkilerin birincil göstergesi karbon emisyonu olacak ve çevresel etki analizi emisyon faktörleri üzerinden yapılacaktır. Model için sunulan senaryo, fotovoltaik enerjiden elektrik üretiminin verimliliğinin Türkiye'nin enerji planını karşılayacak şekilde artmasına dayanmaktadır. Bu artış sonrasında güneş fotovoltaik enerjisinden elektrik üretiminin 16.5% olacaktır. Varsayım, güneş fotovoltaik enerjisinden elde edilen yeni elektrik üretim miktarının, fosil yakıtlardan elde edilen elektrik üretiminin yerini aldığı yönündedir. Güneş fotovoltaik enerjisinden elektrik üretiminin, kömür, doğalgaz, doğalgaz ve sıvı yakıtlara dayalı olarak işletilen kombine çevrim santrallerinden elde edilen elektrik üretiminin yerini alacağı varsayılmaktadır. Sadece sıvı yakıtlar için herhangi bir varsayım yapılmamaktadır, çünkü elektrik üretimindeki payları güneş fotovoltaik enerjisindeki artışla değiştirilemeyecek kadar düşüktür (0.05%). Yeni paylar ve yeni üretim seviyeleri hesaplandıktan sonra emisyon faktörlerine göre kaçınılan emisyon da hesaplanabilmektedir. Hesaplamalara göre güneş fotovoltaik enerjisi kömürün yerini alırsa Türkiye 338.251 MTCO2 ve 339.786 MTCO2 karbon eşdeğerinde emisyonu önleyebilir. Güneş fotovoltaik elektrik üretimi kombine çevrim enerji santrallerinin yerini alırsa 127.228 MTCO2 ve doğal gaz elektrik üretiminin yerini alırsa 28.469 MTCO2 emisyon önlenebilir. Bu sonuçlar, fosil yakıtların güneş fotovoltaik enerjisi gibi karbon emisyonuna neden olmayan yenilenebilir enerji kaynaklarıyla değiştirilmesinin Türkiye'nin çevre refahına katkı sağladığını göstermektedir. Türkiye için TÜİK tarafından 2021 yılında yayınlanan karbon emisyonu 564,4 MTCO2 eşdeğeridir. Dolayısıyla kaçınılan potansiyel emisyon değerleri, Türkiye'nin yenilenebilir enerji kaynaklarına yönelik enerji planının geçerliliğini ve potansiyelini göstermektedir.

Özet olarak CGESOLAR'ın sonuçları TFTP’nin beklenen ve hedeflenen etkileri gösterebileceğini kanıtlamaktadır. Model sonuçlarına göre sektördeki verimlilik iyileştirmelerinin üretim artışına, yerli üretim ve ihracatın artmasına ve ithalat seviyelerinin azalmasına yol açtığını göstermektedir. Şoklardan en çok etkilenen sektörler, fotovoltaik elektrik ile en çok ilgili olan sektörler, yenilenebilir ve fosil elektrik sektörleri, Demir-Çelik, Otomotiv ve Madencilik gibi sektörlerdir. Bu sektörlerin enerji yoğunluğu ve kullanımı farklıdır. Ayrıca güneş fotovoltaik elektrik üretim süreçlerinde kullanılmaktadırlar.

Ayrıca şok, Türkiye'de GSYİH'da iyileşmeye, cari açıkta iyileşmeye ve işsizliğin azalmasına yol açmıştır. Ek olarak güneş fotovoltaik elektriğinin fosil yakıtların yerini almasıyla karbon emisyon seviyelerinde azalmalar gözlemlenmiştir.

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YAZARIN / AUTHOR

Soyadı / Surname : İpek
Adı / Name : Ezgi
Bölümü / Department : İktisat / Economics

TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): ANALYZING THE EFFECTS OF SOLAR PHOTOVOLTAIC SYSTEMS IN TÜRKİYE BY A COMPUTABLE GENERAL EQUILIBRIUM MODEL

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