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Drivers and challenges of solar photovoltaics (PV) adoption by Turkish manufacturers

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Abstract

This study addresses the critical gap in literature caused by previous qualitative studies on PV adoption focusing primarily on households, which have limited access to specific industry sectors across different countries. As far as we know, no other research has investigated the manufacturing and industrial firms' perspective on Renewable energy and, specifically, PV adaptation in Türkiye. We use a qualitative semi-structured survey approach accommodated in Turkish Organized Industrial Zones. According to the interviews carried out within the scope of this study, an increase in electricity prices and a decrease in the payback period by PV installment are seen as the most critical drivers of PV adoption in the manufacturing sector. Energy security concerns and climate change policies also help increase the pace of PV adaptation. One of the biggest challenges in PV adoption seems to be technical challenges due to the limited capacity of the transformer, bureaucratic problems due to PV applications, supply side problems due to long wait times by the suppliers, knowledge and information problems, architectural and space problem that are also linked to the legal constraints and financial difficulties due to the lack of access to credit due to the macroeconomic situation of the country.

Keywords Solar energy · Opportunities and challenges of solar PV · Semi-structured interviews · Industrial adaptation of renewable energy

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1 Introduction

Global environmental concerns and the urgent need to transition to sustainable energy sources have made solar energy a pivotal strategy to reduce fossil fuel dependency and achieve carbon neutrality. Thanks to its industrial prowess, Türkiye arguably assumes a strategic position within the crossroads of Europe and Asia as a rapidly growing economy. A wide range of manufacturers and producers are accommodated in Turkish Organized Industrial Zones (OIZs), thus acting as vital hubs of economic activity. Solar energy adoption within these OIZs becomes increasingly essential as the country contends with climate change challenges and renewable energy opportunities.

This paper aims to delve into the complexities surrounding integrating solar energy systems within Turkish OIZs through a qualitative approach. We will analyze semi-structured interviews with key stakeholders – especially the OIZ managers, industry representatives, policymakers, and energy experts- to better understand how motivations, barriers, and enablers shape solar energy adoption decisions. Firsthand experiences of OIZ managers could summarize the multifaced interplay of economic, environmental, technological, and regulatory aspects that influence the extent to which solar energy is embraced within these industrial zones.

This study holds immense significance as it contributes to the existing literature on renewable energy adoption within industrial contexts and offers valuable insights for policymakers and industry stakeholders seeking to devise effective strategies that promote sustainable energy transitions. The research focuses specifically on the Turkish OIZ landscape and underscores the importance of qualitative methodologies in capturing the intricate narratives and subjective perspectives that quantitative analyses may overlook. Therefore, this study is an essential resource for anyone interested in promoting sustainable energy initiatives and making informed decisions.

This study analyzes the existing literature on renewable energy adoption in industrial settings, provides an overview of the Turkish OIZ ecosystem, provides information on the methodology employed in conducting the interviews, and presents thematic findings from the qualitative analysis. Our objective is to foster a deeper understanding of the motivations and challenges faced by manufacturers agglomerated in OIZs in embracing solar energy and contribute to informed decision-making processes that align economic growth with environmental sustainability. This study is a crucial resource for anyone looking to make sustainable energy transitions or gain insights into renewable energy adoption in industrial contexts. Previous qualitative studies on PV adoption in the extant literature focus primarily on households, and only a few investigate specific sectors in different countries. However, to the best of our knowledge, no study has been conducted to understand manufacturing and industrial firms' approach to PV adoption in Türkiye. This study aims to fill this gap in the literature and provide valuable insights into renewable energy adoption in industrial contexts.

1.1 Energy utilization in Türkiye and organized industrial zones (OIZs)

Not long after declaring its national intention to become a net-zero country by 2053, Türkiye officially joined the club of countries determined to deliver best national practices to limit and reduce global warming with the ratification of the Paris Agreement on 11 October 2021. Showing its commitment to the agreement, Türkiye announced the

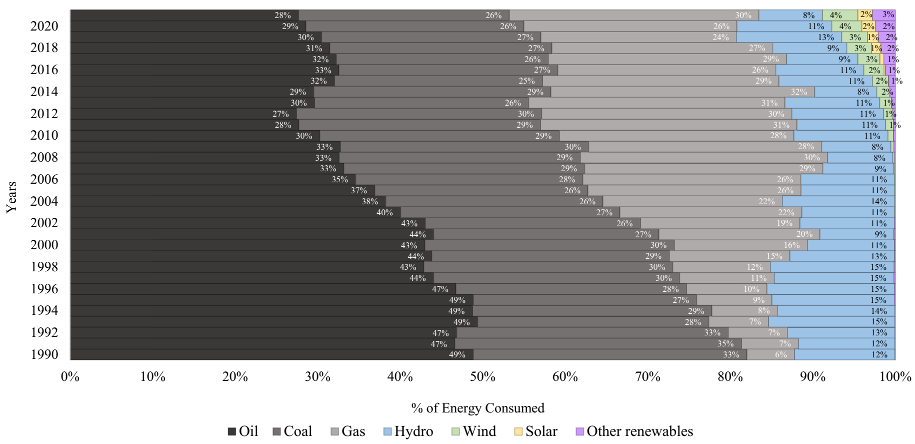

Fig. 1 Share of energy consumption by source in Türkiye between 1990 and 2020. *Source* Ritchie et al., 2020

establishment of the *Ministry of Environment, Urbanization, and Climate Change* – a restructuring of the former Ministry of Environment and Urbanization with added directorates and departments devoted to climate change and carbon reduction.

Notwithstanding its national ambition and planned commitments to achieve net zero, as a developing country yet to fully complete its industrialization, it is indeed a challenging task for Türkiye to create feasible carbon reduction policies that do not contradict its industrialization trajectories. What is more is that Türkiye is a net energy importer whose industry is greatly dependent on energy produced from oil and gas via an array of countries – i.e., the US, Russia, and Iran that are at odds in the international arena in politics, trade, and defense.

On the one hand, the reduction of national emissions for Türkiye lies at the heart of altering its energy production from imported fossil fuels to renewable ones. On the other hand, with a constantly growing economy needing energy and export markets, Türkiye must preserve an economic balance that is inevitably linked to regional and domestic politics with its energy exporter partners.

According to the latest estimates, Türkiye emitted around 524 million tonnes of CO_2-equivalent greenhouse gases in 2020, of which not less than 70% has been cast by its energy sector in the last two decades (TurkStat, 2023a). The reason why the energy sector has caused a significant share of emissions unfolds when the distribution of employed energy sources is examined. The percentage of fossil fuels used in energy consumption in Türkiye has been 87% on average over the last three decades, no less than 81% for any given year (Fig. 1). However, the composition of fossil fuels, i.e., oil, coal, and gas, seems to have changed significantly over the years. While the share of oil in energy consumption decreased from 49 in 1990 to 28% in 2021, the percentage of natural gas increased from 6 in 1990 to 30% in 2021. Fluctuating between 26 and 36%, the share of coal in energy consumption seems to be relatively constant over the last three decades. Although new renewable energy sources such as wind and solar have been deployed in more recent years, they seem only to be able to replace the fall in hydro energy but not contribute to decreasing the use of fossil fuels. Overall, the diversification of energy sources towards renewables appears to be an excellent sign to target

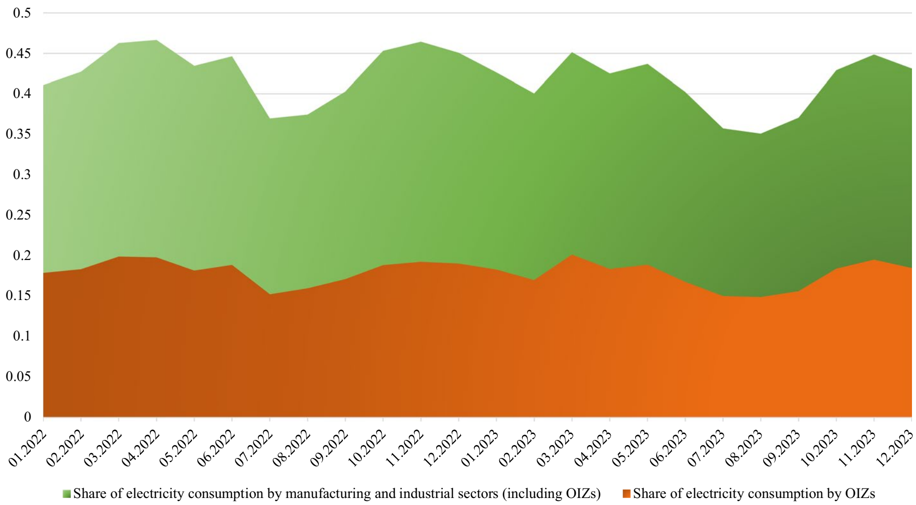

Fig. 2 Share of electricity consumption by manufacturing and industrial sectors and by Organized Industrial Zones. *Source EPDK* (Energy Market Regulatory Authority), 2022a, 2023; *OSBÜK* (Supreme Board of Organized Industrial Zones), 2022, 2023a

emissions reduction. Still, the target does not seem achievable unless there is a significant contraction in fossil fuel usage.

Energy-intensive sectors, i.e., electricity, heat, transport, and manufacturing, are the most significant contributors to the aggregate greenhouse emissions in Türkiye (Ritchie et al., 2020). Although any policy towards net zero must necessarily address the reduction of fossil fuel usage in these sectors, the flexibility of Türkiye in creating effective policies is constrained by multifaceted factors that depend on each other. Overall, replacing conventional energy with renewables is crucial in achieving Türkiye's net-zero claims by 2050. Manufacturing and industrial sectors can potentially assume the central role in implementing such a change via their electricity generation by renewables, given that they are responsible for 40–45% of the aggregate electricity consumption in Türkiye (Fig. 2). Thus, understanding, documenting, and assessing how manufacturing and industrial firms' approach to renewables, particularly photovoltaic (PV) systems, is an important task. For conducting research towards this end, firms in Organized Industrial Zones (OIZs) are naturally good representatives of the industrial sector. This is because, first, almost half of the electricity consumption by the whole industrial sector in Türkiye is assumed by firms located in OIZs. Second, although production statistics specific to OIZs are not available, the variations of monthly electricity consumption by the whole industry and by OIZs are closely akin, which suggests a similar trend in production (Fig. 2). Third, one-third of the industrial employment is sustained in OIZs (Kütükçü, 2024; TurkStat, 2024a). Fourth, the value of exports by firms in OIZs make up one forth of the manufacturing exports of the whole country (Kütükçü, 2024; TurkStat, 2024b).

OIZs are semi-governmental sites established with the sole aim of hosting manufacturing firms. They are established either by a decree of the cabinet of ministers before the presidential system or a presidential decree afterward. The administrative processes at the initial establishment phase are being conducted by the Ministry of Industry and Technology (or the Ministry of Agriculture and Forestry if the OIZ is aimed at agro-businesses).

After the necessary infrastructure is built and firms start to locate, the management is handed down to the board of management formed among participating firms. A team of managers appointed by the board of management deals with sustaining security, providing utility services, conducting technical tasks, and maintaining relations with the firms and relevant governmental institutions.

Although the establishment of the OIZs dates back to the 1960s in Türkiye, a unified legislative basis for regulation was not drawn until the early 2000s. With the Organized Industrial Zones Law (No.4562) in 2000, followed by the Organized Industrial Zones Application Regulation in 2002, the formation, related administrative organs, administrative processes, management, and audit of OIZs were regulated. Also, with the Production Reform Package (Law no. 7033), all OIZ legal entities were required to be members of the Supreme Board of Organized Industrial Zones (*OSBÜK*). An effort to boost industrial clustering with a legislative foundation was fruitful. While 60 OIZs existed in Türkiye between 1962 and 2002, there are 375 OIZs scattered across the country as of 2022.

Of the 375 OIZs, 341 were established through the Ministry of Industry and Technology, and 34 were established through the Ministry of Agriculture and Forestry. While 72% of these OIZs are operative and actively housing numerous firms, the rest are still in development. The fully operative OIZs (270 out of 375) occupy approximately 94 thousand hectares of land on which 50,385 parcels are available for firms. As of 2022, while around 70% of these parcels host active production activities, the rest either belong to some passive firms without production or are not allotted to any firms (OSBÜK, 2023b).

2 Literature review

The present study aims to identify the existing or potential drivers and challenges of solar PV adoption by the manufacturing sector in the Turkish context, which, to our knowledge, have not been investigated previously. Research aiming to explore the non-residential sector's behavior, perception, and preferences about renewables is an important and promising area to explore (Best & Burke, 2023). However, compared to the vastly expanding literature focusing on the behavior of the residential sector, research on understanding the non-residential uptake of renewables, particularly solar PV, is limited.[1] Here, research dealing with the non-residential uptake of renewables could be grouped into two. The first line of research consists of studies attempting to identify the determinants of renewables' adoption by the non-residential sectors. These studies could be characterized mainly by their employment of econometric models/methods and their reliance on secondary data sources. On the other hand, the second line of research comprises studies attempting to explore the existent and/or potential drivers, opportunities, challenges, and risks of various renewable

[1] Readers interested in residential uptake on renewables can refer to some most recent works such as Wang et al. (2023), Alipour et al. (2022), Ahmar et al. (2022), de Freitas (2022), Lau et al. (2022), Nilson & Stedman (2022), Anupama & Thilakam (2021), Balta-Özkan et al. (2021), Filgueira et al. (2021), Kim et al. (2021), Sommerfeldt et al. (2021), Tanveer et al. (2021), Entele (2020), Huang et al. (2020), Mundaca and Samahita (2020), Setyawati (2020), Abreau et al. (2019), Doğan and Muhammad (2019), Graziano et al. (2019), Jacksohn et al. (2019), Karjalainen and Ahvenniemi (2019), Lukanov and Krieger (2019), Padmanathan et al. (2019), Bashiri and Alizadeh (2018), de Groote and Verboven (2018), Guta (2018), Mah et al. (2018), Qureshi et al. (2017), Wolske et al. (2017), Palm (2016), Rai et al. (2016), Graziano and Gillingham (2015), Korcaj et al. (2015), Schaffer and Brun (2015), Vasseur and Kemp (2015), Müller and Rode (2013), Mills and Schleich (2009).

technologies in non-residential sectors. This latter group of studies could be characterized by their employment of a descriptive narrative and their reliance on primary data collected from the interested non-residential sector by the researchers. Within the sphere of these two lines of research, we will briefly touch upon some recent works, of which the targeted sample space partially or fully overlaps with that of the present study, namely the manufacturing industry and the commercial sectors.[2]

Best and Burke (2023) endeavored to understand the effect of a national policy, namely the Small-scale Renewable Energy Scheme (SRES), on non-residential solar PV uptake in Australia. Their results indicate that government initiatives have a significantly positive relationship with non-residential PV installation count and non-residential solar PV capacity. Also, they found that the agricultural and manufacturing shares of businesses in regions have a significantly positive association with non-residential PV utilization. Notwithstanding, the underlying factors behind this positive relationship were unexplored in a more in-depth fashion, especially for the manufacturing sector.

The research by Dhingra et al. (2023) coincides with our study of the renewable technology they focused on. It aimed to identify the barriers to implementing rooftop solar technologies in industrial and commercial sectors in India. They used questionnaire data from experts and policymakers to apply the Fuzzy Analytical Hierarchy technique and identify the priority of barriers observed in the extant literature. Their results show that market-wise and financial challenges are the most substantial barriers, followed by institutional, regulatory, technical, and location-based barriers. However, they only focused on the impeding factors, contrary to the present study, where we also tried to explore the driving factors behind PV uptake by the manufacturing sector.

Tay et al. (2022) focused on small and medium enterprises (SMEs) in Singapore regarding their willingness to adopt green electricity plans (GEP) – a national electricity subscription option that ensures the supply of electricity is generated via renewables. Results of a questionnaire survey conducted with 71 SMEs, with half of them manufacturing firms, indicate that firms' willingness to switch to GEP primarily depends on the electricity provider's price and reliability. They also found that the sustainable awareness of firms contributes to their desire to adopt a GEP. Although they focused on the green subscription trend, their result with respect to firm behavior to the price level might also be relevant in the case of direct renewable technology adoption explored in our research.

Qamar et al. (2022) employed a structural modeling approach based on collected survey data to understand the drivers and barriers to SMEs' adoption of solar energy technologies in Pakistan. According to their analysis, while firm size, technology's ease of use, and technological reliability are the most crucial driving factors, the price of the solar technology, competitive pressure in the market, and energy cost intensity were significant barriers.

Ismail et al. (2022) attempted to explore the industrial understanding of solar thermal technologies and the suitability of solar thermal applications in manufacturing processes in Malaysia as a country representative of ASEAN. Based on heat profiles of production

[2] Readers interested in non-residential uptake on renewables in other non-residential sectors can refer to some most recent works such as Rahmani and Naeini (2023), Everest (2021), Hsiao et al. (2021), Powell et al. (2021), Borchers et al. (2014) for the agriculture sector, Strazzabosco (2022), Igogo et al. (2021), Nasirov and Agostini (2018) for the mining sector, Unuigbe et al. (2022), Korosic et al. (2021), Lau et al. (2021), Reindl & Palm (2021), Lu et al. (2019) for building integrated PV (BIPV) in construction and building sectors, Springsklee and Scheller (2022), Bayındır (2021), Devereux (2021), Strazzabosco et al. (2021), Strazzabosco et al. (2020) for the public and utilities sectors, Bunea et al. (2022), Tırmıkçı (2021) for general multiple sector comparisons without emphasis on industry/manufacturing sectors.

processes appropriated through a questionnaire with industry executives, solar thermal is most suitable for sectors operating with low- and medium-temperature processes. Although they focused on only one specific sector, their work is relevant to the present research in terms of the challenges they identified. Certain technical challenges, high initial investment costs, and lack of knowledge in technology were identified as the main barriers before the accelerated dissemination of solar thermal in Malaysia. Previously, the research group also, through desk research, investigated the challenges and opportunities of solar thermal in the Malaysian palm oil industry based on the heat demand profile of the manufacturing processes (Ismail et al., 2020).

The study conducted by Anaba and Olubusoye (2021) also carries importance in terms of determinants of PV uptake among Nigerian SMEs, including manufacturing firms. The logistic regression results with collected survey data suggest that the price of electricity from the grid, poor quality electricity distribution service, and governmental support were the most critical drivers of solar energy use by SMEs.

Crago and Koegler (2018) examined the drivers of solar PV capacity across the commercial sector in Columbia, US. Their Tobit model estimations based on publicly available secondary data show that financial concerns, including electricity price, installation cost, rebates, and tax waivers, play the most crucial role in determining the size of solar PV installed. In addition, they found little to no evidence of a relationship between pro-environmental concerns and solar PV size across commercial installations. Although the study was focused on the commercial sector, the identified determinants could also be relevant in the manufacturing sector, as in the case of the present study, given economic concerns prioritized and shared by firms across sectors.

Using publicly available secondary data on PV system applications, Frey and Mojtahedi (2018) studied the effect of subsidies for solar PV on the non-residential (including industrial and manufacturing sectors) intake in California, US. Their log-linear models suggest a statistically significant positive relationship between the size of the installed PV system and sectoral characterization of firms in mining and extraction, manufacturing, transportation and warehousing, and retailing. Accounting for subsidies, the result indicates the need to further explore the underlying mechanisms behind solar PV adoption in these specific sectors.

Rahbauer et al. (2016) interviewed representatives from metalworking and furniture manufacturing SMEs in Germany to understand the adoption factors of and potential barriers to green electricity adoption by firms. Entrepreneurs' personalities, technical systems, economic aspects, firm characteristics as purchase-related factors, and the sales market and green marketing activities as sales-related factors were identified as the primary determinant factors and potential barriers to green energy adoption. Rahbauer et al. (2018), as a follow-up, found empirical evidence towards the relevance of certain purchase- and sales-related factors in SMEs' green electricity adoption, i.e., altruistic motives of SME decision-makers, past pro-environmental behavior, trust in the continual availability of green electricity, environmental sustainability of green energy providers, perception of price for green electricity, being a microenterprise, and customer appreciation of an SME's greenness.

Overall, recent studies focusing on the non-residential sectors reached some common conclusions regarding renewables uptake by firms in different settings. First of them is the manufacturing sector's tendency to adopt PV compared to other sectors, given their high electricity consumption compared to commercial or agricultural sectors. The second is that the price of electricity and initial endowment cost are the main barriers before the price of electricity, and the initial endowment cost is the main barrier before the adoption of the respective renewable technology. Third, the institutional, regulatory, and technical concerns were found to be significant determinants of renewable technology adoption. The present study not only contributes to validating these common results reached by previous studies but also serves to unearth additional knowledge in manufacturing firms' adoption of renewable energy systems.

3 Methodology, research design, and sample descriptions

Identification of drivers and challenges before manufacturing firms adopt PV systems is a significant priority for Türkiye, where industries' acquaintance with renewables is in its infancy. Thus, we adopted a qualitative research methodology (Creswell, 2003) suitable for exploring this relatively untouched area in Türkiye and identifying possible research routes in the PV-Industry nexus. Due to the intertwined relationships across sub-topics under firms' PV adoption, we set to employ semi-structured interviews that we deem appropriate to understand perceptions and opinions on complex issues (Barriball & While, 1994; Horton et al., 2004).

Our population space was immense, covering all manufacturing firms and stakeholders in relation to their adoption of PV systems within the country. Hence, we decided to use purposive sampling to select certain population members with the greatest knowledge and experience and are likely to provide the most valid information on the research interest (Guarte & Barrios, 2006). Accordingly, we directed our attention to the OIZs scattered around the country due to the intense clustering of manufacturing firms therein. Most OIZ managements own an electricity distribution license to provide electricity to OIZ firms. Firms who intend to establish a PV system are required by law to apply to the electricity distribution agent in their region. This means that all PV projects belonging to OIZ firms are filed to and handled by the respective OIZ management and can only be sent to other governmental institutions for necessary permissions afterward. In other words, OIZ managements play the role of mediators between firms and government bodies in the case of a PV project investment. This institutional and regulatory set-up amounts to OIZ managements accumulating extant knowledge and experience in firms' behavior towards adopting PV systems and the problems rooted in regulations and government institutions. In this setting, OIZ management becomes a natural candidate for the sample space, if not a necessary starting point. Therefore, to investigate the main drivers and potential challenges before the manufacturers adopted PV systems, we decided to conduct interviews with selected OIZ managers to pursue our research aim.

When selecting the sample of managers to interview, we focused on 17 OIZs directly represented in *OSBÜK* (the Supreme Board of Organized Industrial Zones).[3] This had two reasons. First was the ease of access and trusted communication with the managers through the umbrella organization when the president of the OIZ is a direct representative at *OSBÜK*. Second, due to the natural advantage of their position as nationally elected representatives, their managements are assumed to have a relatively broader understanding and knowledge of country-wise issues besides their own OIZs.

[3] OSBÜK is the umbrella organization that was established by Organized Industrial Zones Law (No.4562) in 2000 to supervise all OIZs in Türkiye. The Board of Management and the Board of Supervisors are being elected by the representatives of all OIZs in a General Assembly every four years.

In preparation for interviews, we listed questions and themes related to the PV-Industry nexus relevant to Türkiye based on preliminary analysis. To ensure the relevance, coverage, and formulation of the questions, we conducted expert assessments with researchers in *ODTÜ-GÜNAM* (Middle East Technical University-Solar Energy Research Center) and managers in *OSBÜK*. After the modifications based on expert assessments, we conducted a pilot interview with an OIZ manager for further verification about how relevant and understandable the predetermined questions and themes were (Barriball & While, 1994; Krauss et al., 2009; Turner, 2010).

Eventually, we conducted 17 semi-structured interviews. 16 of them were with OIZ directors and managers, and one was with *OSBÜK*'s energy consultant. During some interviews, technical and/or administrative staff of the respective OIZs were also present to provide informational support to the directors. Some descriptive information about the OIZs represented in interviews is provided in Table 1.

All interviews were conducted online with the mediation of OSBÜK between May and August 2022. The interview sessions, on average, took around 1 h. We asked a total of 13 questions. The talks between interviewers and researchers have been either noted down during the interview or transcribed later if a video/sound record was available.

After all the interviews were done, we aggregated relevant answers to each question under common themes and topics. In the next section, we present and discuss the main qualitative findings concerning drivers of and challenges before Turkish manufacturers' adoption of PV systems, as well as significant policy suggestions.

4 The qualitative findings on the adoption of PV systems in OIZs

The interviewees generally held a positive stance towards PV systems, whether for the benefit of the firms or the country in general. They frequently mentioned the advantages of PV systems related to energy input cost, production, finance, energy security, and emissions. Notwithstanding, their approach to the adoption and usage of PV systems was not exempt from reservations. The interviewees provided essential insights about the challenges before PV adoption en masse, such as the lack of transformer capacity, supply chain problems in solar panels, and bureaucratic inertia. They also mentioned some pitfalls that often go unnoticed, such as safety risks and risk of capital loss in case of delayed firefighting due to increased electricity within a PV system. The interviewees' responses, in general, displayed in-depth knowledge about how the regulations in place, technical necessities, and workings of PV systems relate to the production and investment decisions of manufacturing firms located in OIZs. In the upcoming two sections, we summarize and discuss the main topics and some overlooked areas in PV adoption by manufacturing firms as perceived drivers and challenges. Suggestions coming from the interviewees on how to overcome specific challenges will be presented in a separate section that follows.

4.1 Drivers of PV system adoption by manufacturer firms

The interviews revealed six dominant arguments under three topics as the drivers of manufacturing firms' adoption of PV systems. (i) Energy prices, (ii) energy security, and (ii) structural changes around national and global climate change policies were listed as the common topics with mention rates of 100%, 65%, and 53%, respectively, among the responses. Except for one, all the interviewees mentioned at least two of the listed topics

Table 1 Descriptive information of the interviewed OIZs *Source* (OSBÜK, 2023b)

Interviewee						OIZ							
Interview #	Interviewee role	Age	Gender	Education level	Education field	Region	Foundation year	Operational status	Area (ha.)	# of lots in OIZ	Occupancy rate	# of firms	Elec. dist. license
#1	OIZ Director	42	M	Bachelor	Labour Economy and Industrial Relations	Mediterranean	1973	Active	2227.4	566	99%	385	Yes
#2	OIZ Director	55	M	Masters	Electrical Engineering	Mediterranean	1976	Active	734.6	330	100%	331	Yes
#3	OIZ Director	57	M	Bachelor	Mechanical Engineering	Aegen	1975	Active	503	214	100%	136	Yes
#4	OIZ Director	51	M	Bachelor	Architecture	South-eastern Anatolia	1990	Active	921	384	96%	210	Yes
#5	OIZ Director *acc. by Deputy Director*	50	M	Bachelor	Geomatics Engineering	Marmara	2011	Active	753.4	244	56%	120	No
#6	OIZ Director *acc. by Energy Manager*	45	M	Bachelor	Mechanical Engineering	South-eastern Anatolia	1969	Active	4447	1465	100%	1132	Yes

Table 1 (continued)

Interviewee						OIZ							
Interview #	Interviewee role	Age	Gender	Education level	Education field	Region	Foundation year	Operational status	Area (ha.)	# of lots in OIZ	Occupancy rate	# of firms	Elec. dist. license
#7	OIZ Director	50	M	Masters	Urban Systems and Transportation Management	Marmara	2002	Active	151	249	100%	768	No
#8	OIZ Director *acc. by Electrical Engineer*	44	M	Masters	Civil Engineering	Marmara	2000	Active	741.6	376	98%	974	Yes
#9	OIZ Director acc. *by Energy Op. Manager*	46	M	Bachelor	Mechanical Engineering	Central Anatolia	1976	Active	2199.3	1225	99%	1179	Yes
#10	OIZ Director	50	M	Bachelor	Geodesy and Photogrammetry	Marmara	1998	Active	847.96	528	63%	229	Yes
#11	OIZ Director	54	M	Bachelor	Electrical Engineering	Central Anatolia	1976	Active	2273	784	99%	790	Yes

Table 1 (continued)

Interviewee						OIZ							
Interview #	Interviewee role	Age	Gender	Education level	Education field	Region	Foundation year	Operational status	Area (ha.)	# of lots in OIZ	Occupancy rate	# of firms	Elec. dist. license
#12	OIZ Director *acc. by Elec. Op. Manager*	43	M	Masters	Civil Engineering	Aegen	1999	Active	85.52	41	95%	38	Yes
#13	OIZ Director *acc. by Electrical Engineer*	51	M	Bachelor	Architecture	Mediterrenean	1993	Active	756	230	99%	211	Yes
#14	OIZ Director	51	M	Bachelor	Business and Accounting	Marmara	2001	Active	234	286	100%	300	Yes
#15	OIZ Director	51	M	PhD	Elec. Engineering / Electronics & Communication Engineering	Marmara	2015	Building Phase	315	189	62.27%*	90*	No
#16	OIZ Director	54	M	Bachelor	Civil Engineering	Black Sea	1994	Active	161	98	100%	76	Yes

Table 1 (continued)

Interviewee						OIZ							
Interview #	Interviewee role	Age	Gender	Education level	Education field	Region	Foundation year	Operational status	Area (ha.)	# of lots in OIZ	Occupancy rate	# of firms	Elec. dist. license
#17	Energy Consultant	47	M	PhD	Electrical Engineering/Solar Energy Technologies								

*According to initial firm demand for available lots during the construction phase

Table 2 Interviewee-topic matrix for drivers and challenges of PV systems among manufacturers

Topic	*Argument*	*Respondents* #1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	*Mention Rate*	
Electricity Prices	Decreased payback period	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	100%	100%
	Stabilization of production cost											■							6%	
Energy Security	Concern over energy security		■	■	■			■		■	■	■	■		■	■	■		65%	65%
Climate Change Policies	Importance for export firms				■		■	■	■		■					■		■	41%	53%
	Global policies on emissions reduction	■			■	■	■		■		■								35%	
	Prestige gained using green energy										■								6%	
Infrastructure and Technical	Low transformer capacity and intransparent approach per TEİAŞ	■			■	■	■			■		■			■	■	■	■	59%	59%
	Risk of oscillation when PV electricity ratio is high or PV maintanance not done						■								■				12%	
	Decreased effort in promoting PV due to limited transformer capacity											■							6%	
	Priority problems in allocating available capacity between firms											■							6%	
Architecture and Space	Inappropriate architectural capacity of buildings		■		■	■		■	■								■	■	41%	53%
	Problems due to sharing a building and/or firms being renter							■	■					■					18%	
	Space constraints on roofs and firm parcels as well as in OIZ campuses	■						■										■	18%	
	Obtaining architectural letter of consent from architectures to renovate for PV								■										6%	
Bureaucracy	Prolonged application time and bureaucracy		■	■		■		■	■	■			■					■	47%	47%
Panel Market	Supply shortages in PV systems due to increased demand	■		■			■	■		■								■	35%	35%
	Customs tariffs that lead to low quality panels to be imported and used																	■	6%	
	Lack of standardization and audit in PV panel market						■												6%	
Knowledge and Information	Lack of knowledge in PV panel technologies and models			■			■								■				18%	35%
	Lack of knowledge in official application processes				■														6%	
	Information mismanagement that show PV application as a complicated process															■			6%	
	EPDK's insufficient communication with manufacturers		■																6%	
Finance	Limited access to finance due to high interest rates and dollar exchange	■				■									■				18%	30%
	High investment cost										■		■						12%	
	Rural mindset of older manufacturers to work only with public banks															■			65	
Remuneration and Payments	Netting problems when PV production site is in another distribution area						■								■				12%	24%
	Netting problems between OIZs, distribution, supply firms, and EPİAŞ												■				■		12%	
Risks in Disasters	Inability to deactivate PV systems in case of fire		■				■												12%	12%

(Table 2). Details about topics and arguments are given in the next sub-sections with the support of additional secondary data from relevant sources.

4.1.1 Electricity prices

As the main driver behind firms' adoption of PV systems, all interviewers, without exception, strongly emphasized the role of increased electricity prices and, relatedly, the decreased payback time of PV investment. Since electricity from the grid and electricity from their own PV systems could be considered substitute goods, it was rational for firms to invest in a feasible project like establishing a PV system when the price of electricity from the grid skyrocketed. Throughout the last 3 years, the market exchange price of electricity per kWh in Türkiye has increased by more than 1100% in Turkish Lira terms (Fig. 3). Thus, one of the most feasible ways to subdue the effect of increased

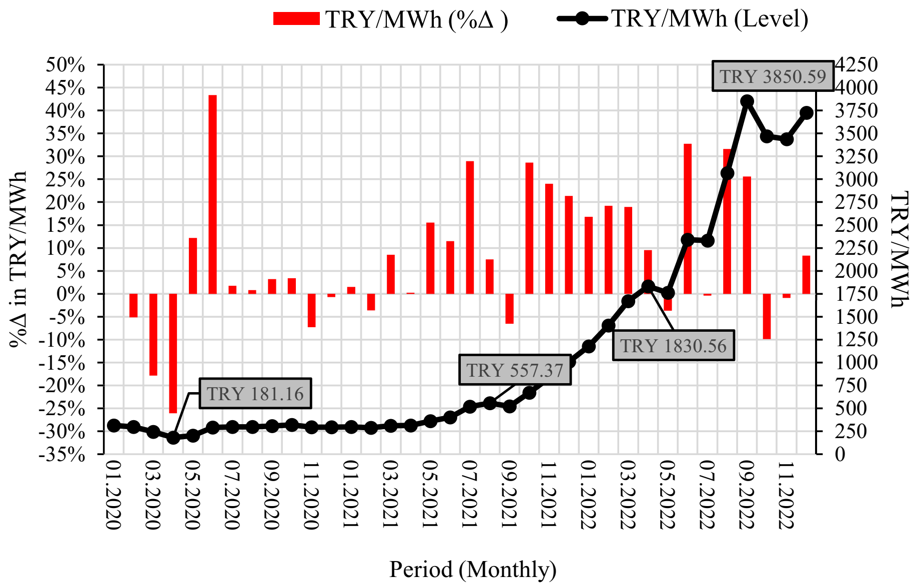

Fig. 3 Price of electricity per kWh in TRY between January 2020 and December 2022. *Source* EPİAŞ (Electricity Exchange Istanbul), 2023

energy input cost was incorporating some form of renewable energy, such as PV systems, into production.

> I think prices have greatly influenced firms' behavior of switching to PV systems, as most recent applications were filed after the recent increases in electricity prices. (#10)
> Energy prices rose around 500% in recent periods, and the payback time of PV investment reduced rapidly. As firms felt the pain of increasing energy prices, they began realizing the importance of PV systems in standing out among their rivals. The number of PV project applications has intensified, so we now need to hire an additional electrical engineer to handle official processes. (#3).

According to most interviewers, OIZ firms have relatively easy access to finance to cover the initial investment cost of a PV system. Thus, in most cases, the investment decision was made based on the payback time of the investment, i.e., how many years will the cost of investing in a PV system be fully recovered? As electricity prices from the grid rise, the marginal benefit of consuming electricity from its own PV system increases, which, in turn, contributes to faster payback of the initial investment cost. According to most interviewers, the payback time of PV investment has recently been reduced from 8–10 years to 2.5–5 years.

> With the rise in electricity prices in the last one and a half years, the payback time of the initial investment cost of a PV system decreased to 3–5 years. This, indeed, accelerated the firms' interest in adopting PV systems greatly. (#2).
> Firms' interest in PV systems started at the beginning of 2022 with the horrifying rise in electricity prices. The payback time of PV investment also decreased to 2.5 years, given current electricity prices. Increases in energy costs lead to

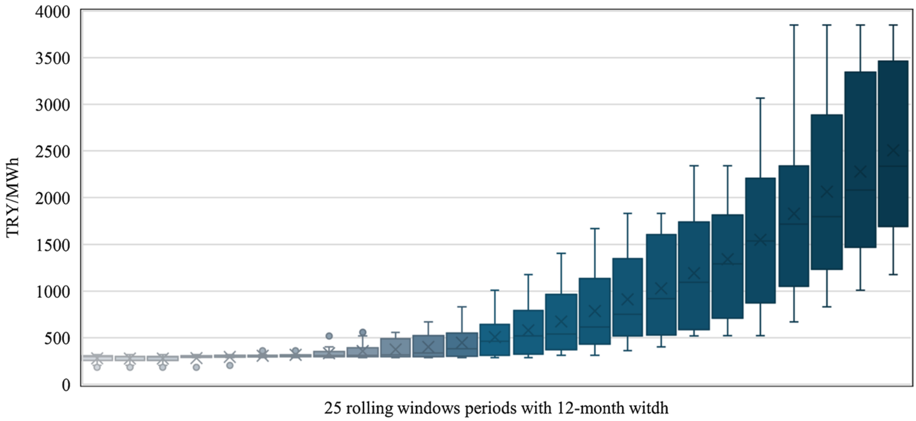

Fig. 4 Rolling windows Box and Whiskers diagrams of electricity prices per kWh in TRY in Türkiye with 12-month window width between January 2020 and December 2022. *Source* EPİAŞ (Electricity Exchange Istanbul), 2023

> increasing interest in PV systems. There is no need for any other motivation for firms. (#12).

Apart from the absolute rise in electricity prices from the grid, the volatility also contributes to the firms' interest in switching to PV systems. Box and Whiskers diagrams of electricity prices for consecutive periods of 12 months in Fig. 4 show the increasing deviation of prices from its 12-month mean, especially for the most recent periods.

> "Uncertainty in energy costs causes troubles in production. The firm is somewhat protected from price volatility when a PV system is used. The main driver behind the rise in PV system applications is, thus, to fix the costs and protect from volatilities." (#11).

While most interviewers framed the increasing interest of firms in PV systems as a necessity to survive in the wake of energy crises and global green policies, some put it as a good investment opportunity to seize.

> PV systems became very feasible and attractive to investors due to the rise in electricity prices. For this reason, establishing a PV system is more of a profitable investment than a necessity. However, considering Green Deal policies, it might be considered a partial necessity for firms. (#1).

4.1.2 Energy security

Around 65% of the interviewers stated some form of concern over Türkiye's energy security and its relation to manufacturing firms' willingness to adopt PV systems. These concerns particularly pointed to the negative effect of the Russia-Ukraine war and electricity shortage due to a recent cut of imported Iranian gas.

> The war between Russia and Ukraine, I presume, will enhance firms` adoption of PV systems. Also, dependency on a few other countries in terms of energy supply is a very risky situation. When Iran cut the natural gas flow at the beginning of 2022, we

> could not produce enough electricity to provide to the firms. In this regard, renewables are the most important alternative. (#4).
> The Russia-Ukraine war will definitely accelerate the adoption of PV systems. In the recent crisis, production was negatively affected due to a reduction in electricity production capacity. When there is no energy to buy, prices become irrelevant. For this reason, I consider energy security to be more important than energy prices when adopting PV systems. (#14).
> Production was negatively affected in the latest energy crises [with Iran]. If there is no energy, cost does not mean anything. For this reason, in transition to PV systems, energy security is a more crucial point than increased energy cost. (#10).

Türkiye's electricity production, to a large extent, historically depends on natural gas and coal imported from an array of countries – i.e., Russia, Iran, and Azerbaijan (Table 3). This, in turn, translates to occasional energy crises in case of any technical, political, or military conflict in the immediate region or in case of any domestic problem occurring within exporter countries. Recently, for example, the amount of natural gas supplied to the combined natural gas cycle power plants for electricity generation was cut by 40% by the Turkish Petroleum Pipeline Corporation (*BOTAŞ*) when Iran ceased the transfer of natural gas in the midst of winter in January 2022 (BOTAŞ, 2022). As a consequence, electricity supply to the industrial subscribers was limited by the Turkish Electricity Transmission Corporation (TEİAŞ) to balance supply and demand of electricity in Türkiye (TEİAŞ, 2022). In some regions, the reduction in electricity supply to industrial subscribers reached 75–90% for three consecutive days (Antalya Organized Industrial Zone, 2022; Denizli Organized Industrial Zone, 2022).

> The crises with Russia affected tourism and food sectors in the past. There is no guarantee that it will not affect the manufacturing sector in case of a similar problem with Russia. Any minute issue with Russia, Iran, and Azerbaijan negatively affects our energy supply. In the most recent case with Iran, we could barely balance electricity demand by partially pausing the production of some firms. If the situation extended, the energy crisis would be a huge problem for the country. Around 60% of the manufacturers in our OIZ are exporters. Stopping production directly translates to delays in orders. (#7).
> In recent periods, energy security has become more vital than the cost of energy for production. We are ready to pay any going price, but do not want energy cuts. (#14)

4.1.3 Climate change policies

50% of the interviewers mentioned the importance of global climate change policies and carbon reduction initiatives in relation to firms switching to renewable energy systems. While some consider the use of PV systems as a necessary requirement for firms to survive post-Green Deal, others emphasize certain advantages gained. However, no interviewer agreed that environmental awareness and concerns have an effect on firms' decision to adopt PV systems, given their indifference to these issues. Thus, as far as climate change policies are concerned, it seems that firms' demand for PV systems is not driven by their environmental awareness but by their attempt to adapt to the economic and political structure transforming around global carbon reduction policies.

Table 3 Share of imported natural gas by source country *Source EPDK* (Energy Market Regulatory Authority), 2022b

Country	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)	2020 (%)	2021 (%)	2022 (%)
Russia	57.90	54.76	55.31	52.94	51.93	47.02	33.61	33.62	44.87	39.47
Iran	19.28	18.13	16.16	16.62	16.74	15.64	17.11	11.06	16.07	17.21
Azerbaijan	9.38	12.33	12.74	13.98	11.85	14.97	21.20	24.00	15.03	15.93
USA	0.00	0.00	0.00	0.52	1.39	0.88	2.70	6.19	8.07	10.32
Algeria	8.65	8.48	8.09	9.24	8.36	8.99	12.56	11.58	10.20	9.62
Others	4.57	6.30	7.71	6.69	9.75	12.51	12.81	13.57	5.76	7.47

> Renewable energy is a necessity for firms partially due to the Green Deal process. However, I reckon that firms switching to PV systems are mostly driven by economic advantages gained than environmental responsibilities concerned. (#1).
> National and global agenda shapes around renewable energy as the most immediate response to carbon emissions. Türkiye needs to produce clean energy in order not to pay the price of falling behind in the transition to renewable energy. In this framework, it is inescapable for firms to adopt PV systems. (#5).

While being a signatory party to the UN Framework Convention on Climate Change (UNFCCC) since 2004, Türkiye restated its commitment to combat climate change by ratifying the Paris Agreement in 2021. In accordance with this, Türkiye has declared its national intention to become a net-zero country by 2053. Under the newly founded Climate Change Directorate, Türkiye has also started monitoring, reporting, and verifying (MRV) emissions caused by industrial sectors without enforcing any legal charges yet. However, more stringent actions will be taken soon for sectoral emission requirements through a national ETS that is currently in the research and development stage.

> It will be inescapable for firms to adopt PV systems due to carbon reduction regulations in the near future. (#4)

Despite environmental concerns, all these national initiatives concerning climate change and emissions reductions could also be argued to stem from Türkiye's economic and geographic connectivity to European countries. For example, Türkiye's exports to the EU out of aggregate exports have been between 36 and 43% since 2013. This ratio exceeds 55% when non-EU European countries are also included. Thus, any economic and political developments concerning trade between Türkiye and the EU, such as the expansion of ETS or the expected implementation of CBAM, directly affect the Turkish economy, especially the exporting manufacturers.

Notwithstanding, responses received from the interviewers do not indicate a strong comprehension of the long-term implications of the EU climate change policies on Turkish manufacturers. Although the context of exporting manufacturers emerged a couple of times during the interviews, the EU was only underlined with respect to how its general economic situation affects exporters without any direct mention of climate change policies.

> Especially the exporting firms demand to adopt PV systems to reduce cost and benefit from the prestige gained. (#10)
> Decreased demand due to the bad economic situation in Europe negatively affects the production of exporting firms. In this situation, revenue accrued from electricity sale produced via own PV systems becomes important for cash flows. (#6).

4.2 Challenges of PV system adoption by manufacturer firms

The interviews revealed nine distinct topics regarding the challenges manufacturing firms face before adopting the PV system. (i) Infrastructural and technical constraints, (ii) architectural and space-wise constraints, and (iii) bureaucratic constraints seem to be the most notable challenges, with 59%, 53%, and 47% of topic mention rates over respondents. (iv) Panel market problems and (v) knowledge and information problems are identified as the second most notable challenges, with 35% topic mention rates for both. Lastly, (vi) financial constraints, (vii) remuneration problems, and (viii) security risks indicate less significant challenges with less than 30%, 24%, and 12% topic mention rates, respectively. Details on topics and arguments are discussed in the next subsections with the help of additional secondary data from relevant sources.

4.2.1 Infrastructure and technical

Around 60% of the interviewees stated the existence of an infrastructure constraint in front of mass PV adoption by firms. The main technical constraint appeared to be the low transformer capacity in OIZ electricity distribution areas and the consequential problems that followed. As the demand for PV systems skyrocketed in OIZs in response to volatilities in electricity prices and government incentives, the capacity of transformers installed in OIZs was drained up in very short periods (*TEİAŞ*-Turkish Electricity Transmission Corporation, 2023). Consequently, firms willing to install a PV system started to be denied by the Turkish Electricity Transmission Corporation (*TEİAŞ*) or discouraged by OIZ managements.

> We did not put any effort to encourage PV systems for the last 2–3 years because applications are being rejected due to capacity constraints anyways. (#11)

Moreover, although capacities at the transmission level are announced every month by *TEİAŞ*, available transformer capacities at the distribution level are usually unknown to firms to plan their PV system investments accordingly in advance. In consequence, many manufacturing firms were rejected from installing a PV system after they went through all the decision-making processes, including financial preparation and official application documentation. This, in turn, translates to a loss of time, effort, and money at best, if not create a negative atmosphere with respect to PV systems and government policies toward renewables in general.

> People do not know the available capacities in advance. Investors go through exhaustive application processes, only to be informed 5–6 months later that the transformer capacity is not sufficient to sustain the proposed PV project. (#5).

Infrastructure insufficiency is so prevalent that even OIZs that are in the building phase and do not host any firms yet are currently worrying about the capacity problem.

> We try to build buildings that are appropriate for carrying full-scale solar panels on the roof and even informally require all newly located firms to have a PV system installed. However, once the OIZ becomes fully operative, we cannot escape the capacity problem unless TEİAŞ improves the infrastructure. (#15).

Insufficient infrastructure also causes additional problems, such as the inefficient allocation of capacity across firms. In some cases, the available capacity in an OIZ is seen by firms as a scarce resource to be competed for its own sake, even without any tangible plan to operate a PV system.

> Energy consultancies exploit the limited capacity argument in order to convince manufacturing firms to apply for a PV project to secure a spot in the system, even if they do not need it. As a result, some firms who could efficiently use a PV system but have not applied yet will be rejected in the future. (#14).

Moreover, although capacities at the transmission level are announced every month by *TEİAŞ*, available transformer capacities at the distribution level are usually unknown to firms to plan their PV system investments accordingly in advance. In consequence, many manufacturing firms rejected the installation of a PV system after they went through all the decision-making processes, including financial preparation and official application documentation. This, in turn, translates to a loss of time, effort, and money at best, if not create a negative perception toward the practicability of PV systems and the government's renewable policies in general.

> People do not know the available capacities in advance. Investors go through exhaustive application processes, only to be informed 5–6 months later that the transformer capacity is not sufficient to sustain the proposed PV project. (#5).

The interviewees also revealed the rather technical challenge of oscillation problems that inherently exist in grids with integrated PV systems. Due to changing weather conditions or insufficient maintenance, extreme volatilities in the amount of electricity produced from PV systems cause undesirable oscillation problems in the greater grid system of the OIZ.

> When the weather is cloudy, electricity drawn from the grid extremely increases. As the renewable share rises in aggregate electricity production, incidences of oscillations in such cases become more likely to occur. Thus, uncontrolled penetration of PV systems is very risky when the grid system is considered as a whole. (#6).
>
> PV systems have the potential to destabilize the greater grid system with oscillations. Although the sole firm that owns a PV system in the OIZ takes maintenance seriously and produces electricity in a very controlled manner, we still observe oscillations in the system. Firms need to maintain periodic configuration of panels, but I expect most of them will just not do it. (#14).

4.2.2 Architecture and space

With a 53% prevalence rate among interviews, architectural and space-wise constraints were reported as the second most prevalent challenge in the adoption of PV systems by manufacturing firms. Available lots in OIZs are valuable properties, and firms generally prefer to dedicate the land for production or storage purposes. The most appropriate space left for solar panel installation is the rooftop of the factories and storage buildings. However, it seems that most facilities built in the past were just not designed to carry heavy weights, such as solar panels. Thus, firms who wish to install a PV system are obliged to bear the additional cost of strengthening the rooftop if it can be achieved architecturally.

> The first thing almost all firms consider before engaging in PV application is whether they need to shoulder any additional cost due to strengthening of facilities. (#11)
>
> Firms who use facilities built in 15–20 years ago do not have any chance of installing solar panels because the rooftops are not appropriate to carry solar panels according to the static analyses. (#2)
>
> There are facilities that were built according to the standards in place 50 years ago. We require special permission based on static analyses to allow solar panel installation on rooftops. (#5)

Even when firms agree to bear the monetary and time costs, they cannot always succeed in strengthening their facilities due to the intellectual property rights of the architect who designed the building many years ago.

> Architects are sometimes uncooperative and do not agree with the changes required by TEİAŞ for solar panel installation. Architectural consent is an intellectual right, but we faced cases where it just totally blocks the whole process. (#8).

Property ownership in OIZs was also reported as a considerable challenge to manufacturing firms' willingness to adopt PV systems. If the firm is operating in a rented building located in OIZ lots, installing solar panels becomes problematic. On the one side, when the renting firm moves out, the PV system installed and paid for by the firm cannot be easily and cost-effectively transferred to the new location. On the other side, it is an unbeneficial investment for the property owner to bear the cost of PV system installation if she will not directly use it.

> Many firms do not want to engage in establishing a PV system only because they are renters in the buildings. When the rent contract is over, the PV system will stay on the building. (#7)
> Property ownership is a big issue [in OIZs] in İstanbul, Kocaeli, and Bursa. Most firms are renters. This situation has the potential to cause a lot of trouble in switching to PV systems in the future. (#8)

Moreover, the PV systems are associated, by law, with individual electricity memberships. This means that the production and consumption of electricity cannot be separated if they both occur in the same location. This situation has the potential to further the issue between the owner and renter with respect to PV system installation. Even when the property owner agrees on some rent compensation in return for the installation of a PV system, it still needs to be registered under the renting firm's electricity membership. However, as the rental contract ends, the renter cannot easily take the system with herself, nor can the PV registration easily change hands.

> Recently, we have been facing different requests from firms. The owner of the facility wants to rent the facility with an installed PV system. However, she demands to keep the electricity production from the PV system on herself but would like the electricity consumption to be shouldered by the renter. We do not allow this. (#13).

Lastly, interviewees also reported cases when challenges of property ownership and the association of single electricity membership with the PV system are combined.

> Some individual buildings are shared by a couple of firms. Establishing a PV system is very hard because who is entitled to use the roof and whose membership is to be associated with the system are problematic. Also, it is hard to predict the property owner's behavior in terms of agreeing on a PV system in the future since the rents rise significantly. (#7).

4.2.3 Bureaucracy and legal aspects

The third most prevalent challenge before manufacturing firms' adoption of PV systems was reported to be bureaucratic constraints during application processes, with a 47% prevalence rate. With an average of 34 days, Türkiye ranks 25th among other countries with respect to time to complete all procedures required to obtain a new electricity connection, according to the Doing Business Index (World Bank, 2020). Notwithstanding, when it comes to setting up a PV system, the required procedural time for all bureaucratic processes extends greatly.

> Firms who installed PV systems complain about the bureaucratic and procedural hardships such as inability to submit actual project designs initially, the prolonged waiting period for permissions, and general inertia in every stage of the application process. (#5).
> Project approvals and permission processes take so long. For instance, the whole period between initial application and full activation of a PV system recently installed in our OIZ took 8 months. (#12)

According to the Regulation for Unlicensed Electricity Production in Electricity Market (Regulation No: 31502) (Turkish Presidency Official Gazette No: 30772), all the bureaucratic processes, including application, official evaluation, permission, connection, and initiation of operation can possibly take close to 1 year given the official time allowances for all steps. Notwithstanding, the prolonged waiting time for official permissions is, by some, not regarded as entirely negative.

> It is a fact that firms are only able to receive an official answer to their PV projects 2 months after the application. However, they use this period to strengthen their infrastructure and buildings, which also take time anyways. (#9).
> Firms need to go through meetings and complete procedures with the OIZ management [as the electricity distribution agent], TEDAŞ General Directorate, and the Energy Ministry. Due to a high number of applications, receiving connection permission takes a lot of time. Meanwhile, firms prepare their projects and order PV systems from the supplier. (#3).

Although only reported by one interviewer, regulatory changes also bear the potential to inhibit the acceleration of switching to PV systems. Between September 2020 and March 2023, the Regulation for Unlicensed Electricity Production in the Electricity Market has been subjected to changes seven times, in which a total of 135 individual changes have been applied in various articles.[4] Frequent and sometimes misfit changes in laws and regulations might cause firms in the decision-making and application processes to spend additional time revising their investment considerations.

> Most problems are derived from EPDK's (Energy Market Regulatory Authority) energy policies and management. They do not communicate with people in the field, nor do they have any idea about what manufacturers do. Laws, regulations, and communiqués are insufficient, and they are subjected to changes inappropriately. (#2).

Several legal and institutional factors contribute to the underdevelopment of Turkiye's solar energy sector, with some of these barriers also impacting solar energy use in OIZs. Turkiye has implemented various mechanisms to encourage investment in renewable energy, including 10-years feed-in tariffs (FIT) through the YEKDEM[5] support program. The new YEKDEM program is announced to cover electricity generation facilities with renewable energy source certificates that will be put into operation from July 1, 2021,

[4] Number of changes in articles were examined and counted by the authors using the official text of the Regulation for Unlicensed Electricity Production in Electricity Market (Regulation No: 31502) (Turkish Presidency Official Gazette No: 30772).

[5] The Renewable Energy Resources Support Mechanism in the Electricity Market (YEKDEM) was established in 2001 in Turkey to promote the use of renewable energy sources in electricity generation. Producers of electricity from renewable sources, such as wind, solar, geothermal, biomass, and hydropower, are provided with a feed-in tariff for the electricity they generate under YEKDEM.

to December 31, 2025. The YEKDEM price application period will be 10 years, and the domestic contribution price application period will be 5 years. Prices will be determined in Turkish Lira and will be updated quarterly. The update is based on both PPI and CPI, as well as the US dollar and Euro buying rates. Additionally, incentives such as priority connections, reduced license fees, and streamlined land acquisition processes are available. Notably, many solar projects are exempt from licensing requirements, except for ground-mounted installations and self-consumption projects with a maximum capacity of 5 MW. In recent years, further changes have been made to facilitate energy generation in unlicensed projects and for self-consumption. Despite these positive steps, challenges persist, including grid capacity constraints, complex permitting procedures, and uncertainties in support mechanisms. In 2019, a new regulation aimed at roof-based unlicensed projects was introduced, increasing tariffs and providing an additional 3 month period for project completion. Additionally, the Renewable Energy Law of 2020 (Act No 5346) reduced or eliminated service fees, incentivizing individuals and entities to build energy generation facilities for self-consumption purposes. A detailed understanding of the political context influencing energy policy ambivalence can be found in Bayulgen (2013).

4.2.4 Panel market

A significant share, 35%, of interviewers mentioned problems in the quantity and quality of solar panels supplied in the market. The fundamental challenge that obstructs the adoption of PV systems by manufacturing firms appears to be the prolonged waiting time to receive solar panels from suppliers due to a shortage of solar panels.

> You can only receive the solar panels for your project around 8–12 months after placing an order. (#11)
> Increased electricity prices induced significant supply side problems in the market of solar panels. Solar panel firms take orders to be delivered in at least 6 months. (#9)

The interviews also revealed that a shortage in the quantity of solar panels has the potential to translate to the usage of low-quality panels. This, in turn, leads to the inefficient utilization of solar radiation relevant at a location, if not create additional technical and maintenance problems in the medium and long run.

> High-quality solar panels are supplied within a longer period. Thus, some firms prefer low-quality panels to make the PV system operational as soon as possible. It is crucial to audit panel efficiencies. #17
> Technical standards and their audit are missing in the panel market. (#6)

Notwithstanding, regulations put in place in recent years by the Turkish government indicate certain awareness of the potential problems related to the importation of low-quality solar panels. Despite the risk of intensifying the shortage problem, Türkiye applied an anti-dumping tax on the importation of photovoltaic modules and panels (HS: 8541.40.90.00.14) from Chinese suppliers not long ago.[6] Also, in most recent years, the

[6] After an investigation by the then Turkish Economy Ministry, Chinese solar panel suppliers were subjected to an anti-dumping tax of $25/mt^2 in solar panel imports to Türkiye in 2017 (Turkish Presidency Official Gazette No: 30025). The 63% share of China in Turkish imports of photosensitive/photovoltaic/LED semiconductor devices (HS: 85.41.40) in 2016 was reduced to 8% after the anti-dumping application was effectuated in 2017 (Observatory of Economic Complexity).

Turkish Trade Ministry began surveillance of assembled and unassembled photovoltaic cells under certain customs values in 2020 (Turkish Presidency Official Gazette No: 31152) and 2023 (Turkish Presidency Official Gazette No: 32187), respectively. However, not all outcomes resulting from the trade measures taken have been regarded positively by the interviewers.

> Türkiye is applying an antidumping regime in panel imports. The tax, once taken proportional to weight, has now changed to be proportional to the surface area of the panels. It is nonsense that a panel that costs 30 cents internationally comes to Türkiye at 40 cents, leading to a 10% cost increase in a PV system investment as a whole. Thus, customs tariffs cause suppliers to import lower quality solar panels. (#17).
> Around ten firms could not finalize their decision to make the investment. During the planning stage, they decided not to apply due to the negative effect of exchange rate hikes on the cost of PV systems… With the establishment of domestic production firms, panel prices tended not to increase for a while. However, panel prices again started to rise because recent exchange rate hikes increased the cost of raw materials imported for production of domestic panels. (#7).

4.2.5 Knowledge and information

The next most commonly encountered challenge is the existence of knowledge and information constraints, according to 35% of the interviewers. One informational constraint is the lack of information about the application process for PV projects, e.g., under which regulation article to apply, which documents must be submitted, and for how much MWh one is allowed to apply. Publicly available official regulation papers and a list of application documents announced by OIZs do not seem to solve the informational problems related to the application process. For example, in one OIZ (#11), the application rejection rate due to missing or wrong documents is as high as 20%.[7]

> There are PV applications that have been rejected due to missing documents or application under wrong regulatory article. (#4)

Another informational constraint is the existence of asymmetric information in panel specifications between applicants (the manufacturing firms) and EPC companies. Due to the time and monetary cost of accessing, comprehending, and evaluating technical information, applicants tend to give full responsibility to EPC companies to set up a PV system. Here, having higher technical information and access to internal knowledge of the panel market provides EPC companies with greater bargaining power over the applicants (manufacturing firms). This, in turn, carries the potential to establish inefficient PV systems due to, for example, the supply of underperforming panels and/or project designs inappropriate to the building or location.

Manufacturing firms are usually dependent on EPC contractors when it comes to

[7] There were also OIZs, in which rejection rate due to missing or wrong documents seem to be lesser as 10% (#9). However, in those cases, additional communication with the electricity department of the OIZ revealed that the personnel put extra effort not to accept applications with missing documents. Instead, they warn the applicants to complete the missing documents, then apply. References to the announcements made in OIZ websites about rejection details are not provided not to reveal the particular OIZ identity.

> panel choice, where extensive quality differences exist. Given shortages in panel supply, firms tend to accept any kind of panel without bothering to learn crucial information about what they buy. I expect that, in 5 years, firms will accumulate a certain level of information and realize their use of poor-quality or sub-capacity panels. (#6).
> We are afraid of [panel and grid-wise] problems that might prevail within 3–5 years due to manufacturing firms getting carried away by uncredited EPC companies in PV projects. (#14)

Also, inconsistency and/or complexity of information provided by EPC companies might be regarded as a negative signal by the manufacturing firms who are considering a PV application. Excessive provision of technical and application-wise information by EPC companies carries the potential to create insecurity on the applicant's side.

> Lack of information is widespread among the investors. To exploit this, EPC contractors give missing or complicated information to make more money out of a PV project. Technical and regulatory information is transmitted in a very intense and complicated manner that scares away investors. (#15).

4.2.6 Finance

Although around 30% of the interviewers referred to finance as a constraint for PV investments, they did not deeply elaborate on it or attach a high significance to it. There was a general understanding across most interviewers that manufacturing firms possess relatively easier access to finance compared to the rest of the socio-economic strata. The rationale behind this was the creditworthiness of firms and greater interaction with banks.[8]

Thus, the financial constraints were framed as not concrete obstacles but bumps on the road that prevent the acceleration of a car. Finance-related problems mentioned by interviewers were high interest rates and high initial investment costs due to the depreciation of the Turkish Lira against foreign currencies.

> Firms generally make PV investments by using loans. Access to finance does not really constitute an issue, but the high interest rates make it harder to decide to use loans. (#1)
> Due to increased exchange rate [in USD/TRY], the initial investment costs are very high. Either the exchange rate should be decreased, or additional funding schemes/loans should be offered. (#12)

However, according to one interviewer, the reason financial constraints were not attached to greater significance was the high opportunity cost of not investing in a PV system, given high electricity prices.

[8] Also, two interviewers (#6, #17) clearly suggested that no financial constraint exists across manufacturing firms before PV system adoption. While acknowledging interviewers' take on financial constraints given their day-to-day experience with manufacturing firms in OIZs, we still maintain that additional interviews or a deeper survey study should be conducted with the actual manufacturers to understand this sub-topic. Basically, existence of a selection bias by the interviewers (the OIZ managements) must be eliminated before reaching any conclusion with the interview outputs with respect to financial constraints. The selection bias might occur across interviewers because, in relation to PV investments, their interaction is more frequent with firms who apply for a PV project. Naturally, the probability that the applicant firms have higher financial capabilities compared to non-applicant firms operating in the OIZs.

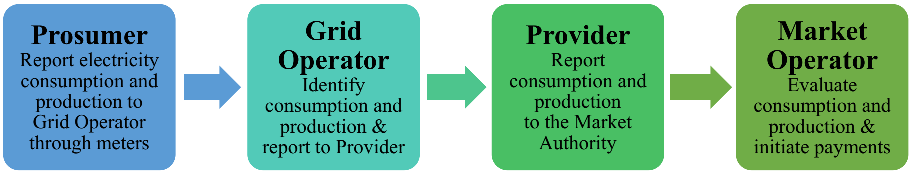

Fig. 5 Workings of the Turkish Electricity Market

> There are indeed financial barriers, but they do not really seem impassable since the cost of electricity constitutes a greater problem. (#14)

Interestingly, one interviewer (#15) mentioned a possible financial problem related to the financial mindset of manufacturers located in less-developed regions of Türkiye. He reported that business owners in rural areas prefer to work with public banks and abstain from doing business with private banks. This, in turn, might hinder the use of possible loan opportunities with better rates of interest offered by certain Turkish banks for green investments.

> Manufacturers of rural areas might have certain doubts about working with private banks, as they usually prefer public banks. However, the second generation of manufacturers does not possess this mindset. The young generation is more open to changes and new ideas. (#15).

4.2.7 Remuneration and payments

Around 24% of the interviewers mentioned some remuneration problems with respect to the lagging payments received for the production of electricity. In the Turkish electricity market, consumption and production of electricity are measured, verified, reported, and approved in at least four official steps (Fig. 5). Only after these steps are all completed is a sequence of payments for the production of electricity initiated by the market operator (*EPİAŞ- Energy Exchange Istanbul*) towards entities located in lower levels of the market. Money flows from the market authority to the provider, then to the grid operator in case of excess consumption, or to the producer in case of excess production.

In the former case, the grid operator (as the electricity distributor collects bill payments based on the net consumption of electricity but pays the provider for *gross* consumption within the present period. Then, the grid operator could only receive payments from the provider a couple of months after the actual electricity production. Due to this systemic lag in remuneration, the grid operator is forced to finance the difference between gross and net electricity consumption until it receives payments.

> The remuneration process is complicated. We receive payment from the electricity members based on net electricity consumption but pay the provider based on gross consumption. We can, then, only receive payment for electricity production after 2 months. (#12).

In the latter case, where there is excess electricity production, the producer receives remuneration from the provider upon the market authority's payment to the provider. The same systemic lag in payments and further postponement of payments by the providers have the potential to distort manufacturing firms' financial plans related to PV investment.

> Receiving remuneration payment from the providers is problematic. Firms told us that they cannot get their payment on time. Firms began asking if there is a chance of further netting of the receivable remunerations with payables from electricity bills in upcoming months. (#16).

Two interviewers also drew attention to payment problems that might prevail in the future. With the latest changes in the Regulation for Unlicensed Electricity Production in the Electricity Market (Regulation No: 31502) (Turkish Presidency Official Gazette No: 30772), consumption and production facilities can now be set up in two different electricity distribution regions. In this case, an additional grid operator will be involved in the already problematic sequence of payments starting from the market authority.

> We guess conflicts between electricity distribution companies will emerge due to different distribution fees, netting applications, and remuneration processes. (#14)

4.2.8 Risks in disasters

One interviewer (#6) mentioned a case in the OIZ where firefighters abstained from responding to a fire due to solar panels. Fires fed by electricity are classified under fire safety class C according to the US system. In the case of electrified fire, some other extinguishers, such as CO2, need to be used rather than water or regular foam. When a PV system is mounted on a building, the fire carries the risk of becoming a class C fire. However, not all fire trucks have CO_2-based extinguishers on their vehicles.[9] Thus, they need to be transported to the disaster site from the fire station once firefighters realize the risk of a class C fire upon arrival at the disaster site. The problem is not related to the fire safety standards of the materials used in PV systems but to the firefighters' preparedness and responsiveness.

> Firefighters abstain from responding to fire due to the continuation of electricity production in solar panels. Machines and equipment worth multiple times more than a PV system are, therefore, exposed to the risk of destruction. This negatively affects firms' investment decision on PV systems. (#6).

5 Conclusion and policy suggestions

This paper employs a qualitative research approach to comprehensively explore the integration of solar energy systems within Turkish Organized Industrial Zones (OIZs). Through semi-structured interviews with key stakeholders, including OIZ managers, industry representatives, policymakers, and energy experts, we examine the nuanced motivations, barriers, and enablers that shape the decisions surrounding solar energy adoption in these pivotal economic hubs.

First, we review the existing literature on renewable energy adoption in industrial settings, highlighting the gaps in previous research that this study aims to fill. Next, we provide an overview of the Turkish OIZ ecosystem and detail the methodology employed in conducting the interviews. We then present the thematic findings from the qualitative

[9] Information was gathered from the fire departments of Ankara and Gaziantep municipalities.

analysis, including a discussion of the key factors driving or inhibiting the adoption of solar energy systems in OIZs.

Our study unveiled the primary considerations across three categories that motivate manufacturing firms to embrace PV systems: energy price fluctuations, energy security concerns, and structural adjustments prompted by national and global climate change policies. The interviews highlighted nine specific areas concerning the obstacles manufacturing firms face in adopting PV systems in Türkiye. Among these, infrastructural and technical limitations, spatial constraints, and bureaucratic hurdles emerged as the most noteworthy challenges. Following closely are issues in the panel market and constraints related to information, identified as the second most prominent challenges. Lastly, financial limitations, difficulties in accounting, the mindset toward investment, and concerns about security risks were also recognized as significant impediments.

From a policy perspective, this study has identified several recommendations that could help address the infrastructure and technical problems associated with solar energy adoption in Turkish Organized Industrial Zones (OIZs). These recommendations are summarized in Table 4 in the Appendix.

To overcome architecture and space barriers, interviewees suggested allowing OIZs legal entities or firms of OIZs to rent unused rooftops for PV installation. Increasing transformer capacities in OIZs and investigating battery options could help solve infrastructure and technical problems. Prioritizing big-scale PV systems, giving available capacities to the more prominent firms, and prioritizing self-use could also be effective mechanisms to ease infrastructure and technical problems.

To combat financial barriers, interviewees recommended increasing lower interest rate loans for solar investments and providing increased public grants. Additional incentives for exports based on green energy consumption rates could also be implemented, and PV ownership could be made a precondition for unlocking grants, loans, and tax breaks.

To ease bureaucratic barriers, increasing the number of personnel working in the Turkish Electricity Distribution Corporation (*TEDAŞ)* could speed up the bureaucratic process. The panel market itself could be regulated based on PV efficiencies, and unique supply chain systems with local and international PV producers could be implemented to address supply chain issues.

To tackle knowledge and information problems, interviewees suggested conducting educational seminars and workshops within OIZs and disseminating knowledge using media sources. Increased communication between different OIZs regarding PV adoption could also help reduce the information problem.

These policy suggestions provide valuable insights for policymakers and industry stakeholders seeking to promote sustainable energy transitions in Turkish OIZs. By addressing the infrastructure, technical, financial, bureaucratic, and knowledge barriers to solar energy adoption, these policies could help unlock the full potential of solar energy in OIZs and promote environmental sustainability while driving green economic growth.

This study examines the potential opportunities and challenges of integrating solar energy systems in Turkish Organized Industrial Zones (OIZs) from the perspective of key stakeholders. One limitation of the study is its generalizability. While OIZs are a good representation of the Turkish industrial sector, future studies focusing on manufacturers outside of OIZs could further generalize the results. A second limitation is related to the sources of information. Although OIZ management can be considered hubs where information on firms' adoption of PV is highly accumulated, future research could directly focus on firm owners and managers to verify the results we obtained. Further research is needed to expand the macro-political and planning aspects of PV adoption by industrialists. This research should examine potential social impacts, such as gender distribution in manufacturing, employment, occupational hazards, and job security, from the perspective of end-user industrialists. Additionally, explicit case studies or exemplars showcasing successful photovoltaic (PV) adoption instances could be included to support the present study. In future research, these additions will provide practical explanations on using the study's findings and highlight the tangible effects of PV adoption in industrial settings.

Appendix

See Table 4.

Table 4 Suggestions by interviewees

	Topic	*Argument*	*Respondents*																	*Mention Rate*	
			#1	*#2*	*#3*	*#4*	*#5*	*#6*	*#7*	*#8*	*#9*	*#10*	*#11*	*#12*	*#13*	*#14*	*#15*	*#16*	*#17*		
Suggestions	Infrustructure and Technical Problems	Increase transformer capacity in OIZs											■			■				12%	29%
		Investigate if big battery systems could be integrated to OIZs															■			6%	
		Prioratize big scale PV systems, so oscillations can be controlled from one location														■				6%	
		Give available capacity to bigger firms						■												6%	
		Prioratize firms with high self consumption of electricity (otherwise it becomes a business to sell for profit)									■									6%	
	Architecture and Space	Allow OIZs legal entities or firms to establish solar farms outside of OIZs solely for electricity supply to OIZ firms	■	■									■	■		■		■		35%	53%
		Allow OIZs legal entities or private firms to rent unused rooftops for PV installment								■		■					■			18%	
	Bureaucracy	Increase number of personell working in TEDAŞ to speed up bureaucratic processes			■															6%	12%
		Fasten bureaucratic processes						■	■											6%	
	Panel Market	Regulate market based on tightened inspection of PV panel efficiencies																	■	6%	12%
		Implement a special supply-chain system with local and international PV manufacturers	■																	6%	
	Knowledge and Information Problems	Prioritize households in PV adoption to have prior experience and knowledge to invest in PV at firm level in larger scale						■												6%	12%
		Educate manufactureres through seminars and workshops (by OIZ management)			■																
		Increase knowledge dissemination through media (by government)							■												
		Increase communication between OIZs for knowledge sharing in PV adoption						■												6%	
	Finance	Ease access to finance by means of public grants and lower interest rates	■			■	■							■			■			29%	29%
		Provide additional incentives in exports based on green energy consumption rate				■														6%	
		Make PV ownership a precondition to accessing additional tax, grant, and loan deals															■			6%	
	Remuneration / Payment Problems	Allow firms to do netting between its different buldings		■																6%	6%
	Other	Make OIZs use the health and security band areas for PV systems															■			6%	18%
		Make mandatory for manufactureres in OIZs															■			6%	
		Prioratize different renewable systems according to the suitability of the regions																	■	6%	
		Give electricity distribution license to all OIZs and prepare feasibility reports							■											6%	

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