Sector coupling for grid integration of wind and solar

About SHURA Energy Transition Center

SHURA Energy Transition Center, founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University, contributes to decarbonisation of the energy sector via an innovative energy transition platform. It caters to the need for a sustainable and broadly recognized platform for discussions on technological, economic, and policy aspects of Turkey's energy sector. SHURA supports the debate on the transition to a low-carbon energy system through energy efficiency and renewable energy by using fact-based analysis and the best available data. Taking into account all relevant perspectives by a multitude of stakeholders, it contributes to an enhanced understanding of the economic potential, technical feasibility, and the relevant policy tools for this transition.

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Disclaimer

This report and the assumptions made within the scope of the study have been drafted based on different scenarios and market conditions as of the end of 2019. Since these assumptions and the market conditions are subject to change, it is not warranted that the forecasts in this report will be the same as the actual figures. The institutions and the persons who have contributed to the preparation of this report cannot be held responsible for any commercial gains or losses that may arise from the divergence between the forecasts in the report and the actual values.

elementenergy

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LIST OF ACRONYMS

BRP	balance responsible parties
BEV	battery electric vehicle
CAPEX	capital expenditure
CDDs	cooling degree days (EUROSTAT definition used)
CO_2	carbon dioxide
DSR	demand-side response
ENTSO-E	European Network of Transmission System Operators for Electricity
EUROSTAT	Statistical Office of the European Union
EAF	electric arc furnace
EV	electric vehicle
GIZ	German Corporation for International Cooperation
GW/GWh	gigawatt/gigawatt-hour
HEV	hybrid electric vehicle
HDDs	heating degree days (EUROSTAT definition used)
HP	heat pump
ICT	information and communication technology
kW	kilowatt
MENR	Ministry of Energy and Natural Resources
MFH	multi-family homes
MW/MWh	megawatt/megawatt-hour
OPEX	operational expenditure
PHEV	plug-in hybrid electric vehicle
PV	photovoltaic
SFH	single-family homes
SHURA	SHURA Energy Transition Center
TMP	thermal mass parameter
TWh	terawatt-hour
TYNDP	Ten Year Network Development Plan
VRES	variable renewable energy sources

Key messages

- Coupling the power system with end-use sectors through the electrification in the heating and transport sectors has the potential of providing considerable flexibility to the power system, which will facilitate a secure and reliable system with 30% share of wind and solar energy in Turkey's total electricity output by 2030.

- The largest system benefits from activating demand-side response potential comes from the avoidance of constructing new generation and distribution network capacity, which would be otherwise needed to cover the growing peak demand driven by electrification. Activating the full techno-economic potential of demand-side response options in Turkey can reduce peak demand by 10 GW by 2030, and nearly 6 GW of net peak demand reduction may come from flexible space heating and smart electric vehicle charging.

- Activating demand-side response can lead to operational efficiency savings of up to €122 million per year through reduced generator fuel use and redispatch requirements, while savings due to avoided capacity expansion of generation and distribution networks nearly €500 million per year. Total costs are €72 million, indicating net benefits of €550 million per year in 2030.

- These benefits will not materialise without a strategic approach to flexibility as well as new market regulations and innovative business models that recognise and reward demand-side response services and attract investment. There is a need for Turkey to further develop its power system strategy that includes electrification and coupling to achieve higher shares of wind and solar energy. The implementation of adequate demand-side response infrastructure and appropriate non-discretionary markets will be required.

Executive Summary

The electrification of energy end-use sectors such as heating and transport is poised to be a vital component of Turkey's energy transition strategy. Electrification enables improving the system efficiency and provided that the needed electricity is supplied by renewable power, it raises the share of renewable energy. However, the impact of unmanaged electrification could significantly increase system peak demand by 2030, which would consequently require the expansion of both generation capacity and grid infrastructure. The increase in peak demand would also cause spikes in wholesale electricity prices, as well as increases in the carbon intensity due to higher utilisation rates of low efficiency thermal generators. Supplier costs could thus raise tariffs and consumer prices.

Demand-side response (DSR) has the potential to make this electrification "smart" and could avoid investments in the power system, improve power generation efficiency, and strengthen the capability of the system to accommodate high penetrations of variable renewable energy sources (VRES) of wind and solar. By shifting their active time-of-use (TOU), the combination of flexible heating and cooling in buildings and smart electric vehicle (EV) charging could reduce peak demands in summer and winter by up to 10 GW in Turkey's power system to help accomodate 30% of wind and solar energy in total electricity output by 2030, according to the findings of this study.

The analysis explores the flexibility potential in 2030 of DSR from a technology portfolio including space heating and domestic hot water from 1.9 million heat pumps, space cooling from air conditioners in up to 80% of buildings, and smart charging from 2.5 million EVs in Turkey based on SHURA Energy Transition Center's (SHURA) earlier studies. The study also evaluates the DSR potential of several energy-intensive industrial processes including the paper, cement, and steel industries considering examples in other countries.

While previous assessments of DSR potential in other countries assume a fixed percentage of total sectoral demand, this study employs a state-of-the-art, bottom-up modelling approach that reflects the full temporal (hourly to seasonal) volatility of a power system with high VRES shares and significant electrification. The approach determines detailed DSR potentials for each of the building, transport, and industry sectors with an hourly representation of power demand and respective flexibility capacity. Feeding this potential into a whole system model of the Turkish power system allows for the evaluation of the net-system benefits from unlocking DSR due to avoided capacity additions, deferred grid investments and system operational savings. The background data used for the purpose of this study largely relies on Turkey data from SHURA's earlier work and other statistical information. In cases where national data was unavailable, comparable international data have been used to complete the data needs of the power system model employed.

Flexible space heating and smart EV charging are found to have relatively high technical potentials to deliver DSR, together accounting for over 6 GW of net peak demand reduction potential in 2030. This is due to a combination of large sector sizes, i.e., the total peak capacity that can flexibly respond, and high annual levels of utilisation, i.e., the total amount of energy than can be shifted throughout the year. The ability of smart EV charging to respond to system needs and provide net-system benefits affirms SHURA's finding of a 2019 dated study that the integration of 2.5 million EVs into Turkey's distribution grid is both technically feasible and even economically desirable.

Of the electricity-intensive industrial processes, the cement and paper sectors demonstrate the greatest potential flexibility response. Flexible operation of cement production can be utilised for over 900 GWh per year in 2030, while paper mills can provide DSR of nearly 400 GWh annually by that year.

The technical potential of flexible space cooling is somewhat marginal, but still comparable with the industry. While it does have a high potential to reduce peak demands in summer, over 5 GW, utilisation levels are low. Flexible cooling is on offer for just over 1,000 GWh per year in 2030, compared to over 5,000 GWh per year for heating. Simply put, the opportunities to adjust heating demands during longer winter months last much longer than for the shorter summer heatwaves.

To be economically viable, the cost of activating DSR must be offset by system savings that arise from the increased flexibility and reduced peak demand that DSR use engenders. In general, for DSR options that are connected to distribution grids, e.g., space heating and cooling and EV charging, operational costs are small compared to capital costs. The capital investment of enabling DSR (hardware and communication system) becomes affordable when spread across many hours of utilisation. Space heating and hot water are the cheapest sources of DSR to enable with costs ranging from 39-51 €/MWh (2020 values).

Table 1: *Total cost, utilisation and levelized cost of response (LCOR) for different demand sectors*

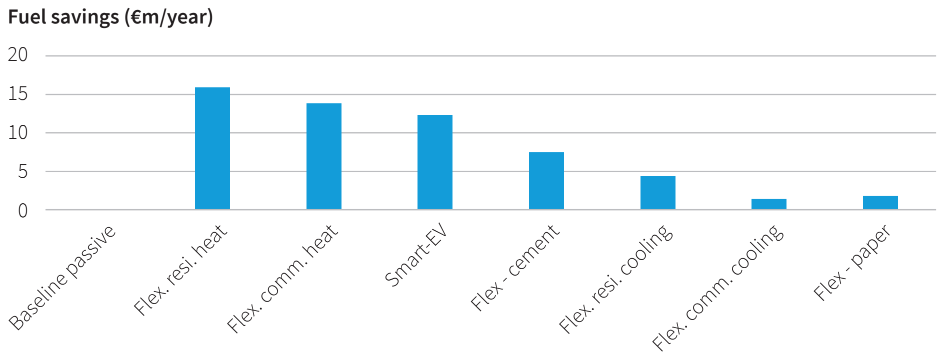
Sector	CAPEX (€m)	Aggregation cost (€m/y)	OPEX (€m/y)	Utilisation (GWh/y)	Utilisation (%)	LCOR* (€/MWh)
Comm. heating	440	42	11	2,348	21%	39
Res. heating	449	58	13	2,829	26%	51
Work EV	97	19	0	615	68%	53
Home EV	194	39	0	1,231	68%	57
Cement	1	0	100	906	5%	110
Paper	1	0	58	385	6%	150
Comm. cooling	460	44	9	254	19%	368
Res. cooling	1,325	170	28	903	34%	458
White goods	172	206	0	300	5%	780
Ventilation	1,160	110	23	74	1%	3,161
Non-ferrous metals	0	0	0	0	0%	6,000
Steel	0	0	0	0	0%	6,000

The LCOR is the minimum cost of providing one unit of flexible energy to the system (10% discount rate in residential, 6% in commercial applications).

When deployed to provide system flexibility, DSR can reduce system costs through several mechanisms that improve the efficiency of system operation (reducing fuel use and redispatch) and avoid additional capacity investments for generation and distribution infrastructure.

Shifting loads out of peak times allows more electricity to be generated by more efficient thermal baseload plants and saves between €10-15 million per year each from residential space heating, commercial space heating, and smart EV charging. Responsive cement production saves approximately €7 million per year (Figure 1).

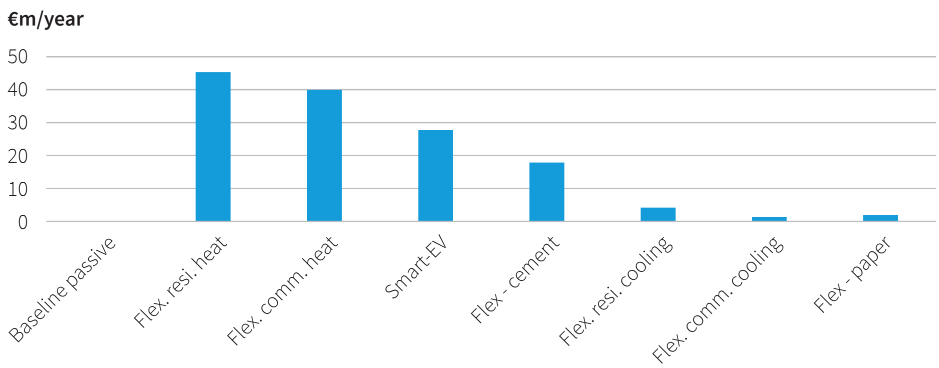
Figure 1: *Annual savings of each DSR sector due to reduced fuel use in thermal peaking plants*



Note: cumulative savings may be less than sum of parts.

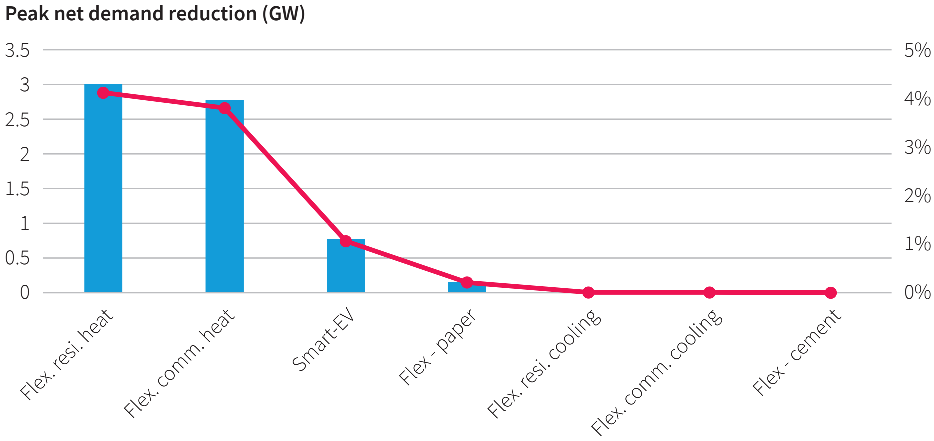
Reducing the redispatch of thermal power plants leads to savings between €80-85 million per year from flexible space heating, while smart EV charging saves nearly €30 million per year (Figure 2).

Figure 2: *Annual savings due to each DSR sector reducing the need for thermal generator redispatch*



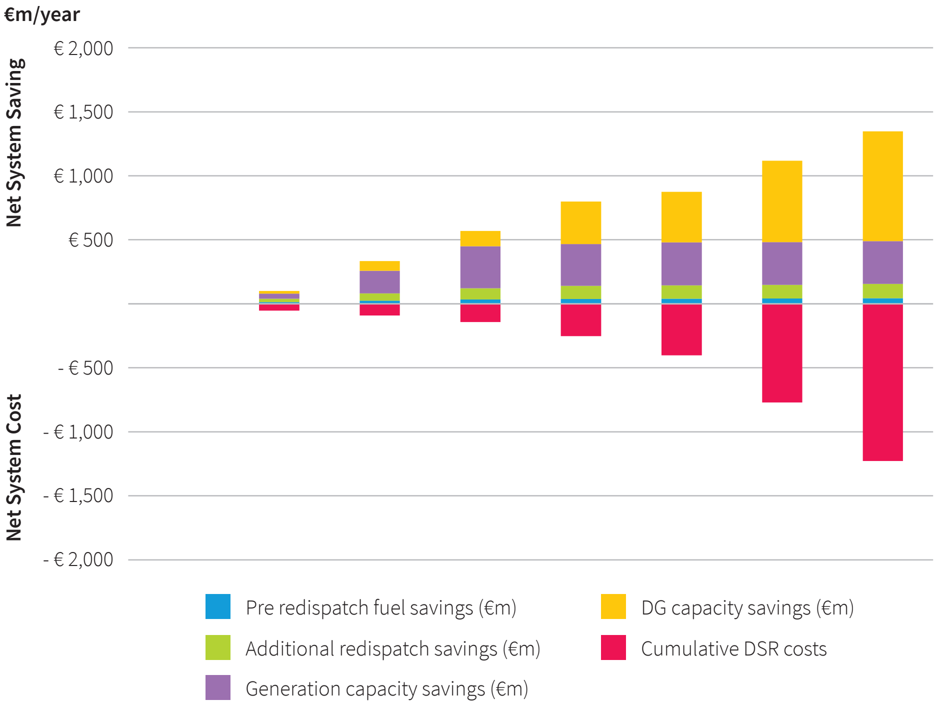
The greatest system savings, however, come from avoiding additional capacity investments in generation and distribution grids, with the greatest contributions coming from flexible heating and smart EV charging. This is due in part to the fact that when both these sectors are operating passively (no DSR), they add to peak demand. EVs, despite their relatively small total annual demand compared to heating, have the ability to offer a relatively high reduction in peak demand as almost all EV charging can be shifted away from peak hours (Figure 3).

Figure 3: *Contribution of each DSR sector to system capacity savings via reduced peak net demand*



Activating DSR can lead to operational efficiency savings of up to €122 million per year through reduced generator fuel use and redispatch requirements, while savings due to avoided capacity expansion of generation and distribution networks nearly €500 million per year. Due to their low costs of response, large sector sizes and high utilisation potentials, flexible heating and smart EV charging show the highest net system benefit, demonstrating that the costs of activating DSR in these sectors is lower than existing system flexibility costs. Cement and paper industries DSR also create a net benefit, while the net benefits from flexible cooling are marginal (Figure 4). As system costs are ultimately borne by consumers, this represents substantial potential savings for consumer power bills.

Figure 4: *Cumulative DSR costs and system benefits*



The analysis presented in this study shows that DSR could add significant technical value to Turkey's future power system in need of greater flexibility when operated with higher shares of wind and solar, and that a proportion of that flexibility could be procured at costs far less than the wider system benefits they generate. Yet, unlocking the full potential of DSR is by no means assured, and will require, among others, integrated strategic approaches, enabling market designs, new technical standards, and innovative information and communication technologies.

Turkey has been working on several legislations and regulations that deal with DSR. The role of the DSR is already set out in the National Energy Efficiency Action Plan – Action E10 – Build a Market Infrastructure for Demand-Side Response, thereby highlighting the multiple role DSR can contribute to transformation of Turkey's energy system. Turkey's 11th Development Plan (2019-2023) also mentions the establishment of a market infrastructure to ensure demand side participation in the power system. These recommendations may therefore be of further utility for the deployment and operationalisation of DSR in Turkey's power system.

Strategic approaches that integrate the development of wind and solar resources and distribution networks with the activation of DSR potential will be crucial to accommodating higher shares of VRES into the grid.

- This could include encouraging the collocation of wind and solar power plants with DSR demand. The ability of DSR to balance VRES is limited by the network capacity between them.
- Ensuring that the electrification of demand and the 'smartness' of demand are deployed in parallel would mitigate system demand spikes, unlocking additional flexibility in the system.

Enabling market designs and incentives will encourage new business models that can unlock the full economic benefits of DSR options.

- As the lion's share of system benefits due to DSR deployment come from avoiding additional capacity investments, mechanisms that effectively monetise this benefit are needed.
- Monetising operational efficiency savings is, on the other hand, relatively easier as these costs could be recovered through wholesale markets where the savings are passed on to the DSR provider via dynamic or static TOU tariffs.
- The development of markets for local flexibility provision and congestion avoidance would help maximise the efficiency of existing distribution networks and to avoid unnecessary network investments.

Minimum technical standards can ensure that the prerequisite technical and system infrastructure is in place to support DSR development.

- Buildings should be required to include smart meters, while reducing the lower limit for energy consumption could allow for new opportunities to decrease power consumption to be identified.
- Standards related to data acquisition and management will be needed to improve system security ensuring consumer data privacy.
- Any government supported expansion of EV charging infrastructure should include the ability for smart changing to ensure that this DSR option can be fully realised.

The majority of DSR potential from buildings and EV charging will come from increasingly smaller demands, i.e. at the kilowatt scale, and will predominately be connected to distribution networks at the lowest voltage level. Aggregators offer a great promise to link these small DSR assets together with other small-scale flexibility assets to control and dispatch them to maximise flexibility services.

- Aggregators are still in a nascent stage of development and will require further developmental support.
- A reliable and rapid communication system will be required to control the vast number of distributed DSR assets.
- Aggregators will need to be able to understand the requirements of each DSR asset to a level and to ensure that the delivery of primary services are guaranteed.

Finally, given the clear net system benefits of pursuing smart flexible space heating in both residential and commercial buildings in Turkey, operationalising flexible heating should be prioritised. Already, the relatively fast uptake of smart home technologies indicates that customers are willing to relinquish control of heating services to third parties to capitalise on reduced energy bills.

1. Introduction

1.1 Integrating renewable energy into the power system – the need for flexibility

Integrating a growing proportion of renewable energy sources into the electrical grid could be challenging. Variable renewable energy sources (VRES) such as wind and solar are not dispatchable and the energy output depends on the resource quality determined by weather conditions and the time of day and year. The increasing share of VRES in the power system can therefore make balancing demand and supply more challenging if necessary flexibility is not provided.

According to the SHURA grid (SHURA, 2018) and flexibility (SHURA, 2019 b) studies, doubling the installed wind and solar capacities to 40 GW is feasible without additional investment in the transmission system. Tripling the installed capacity to 60 GW by 2026 would make solar and wind the largest sources of electricity generation in Turkey with a total share of 31%, and lead to increased flexibility requirements. According to a recent study released by SHURA (SHURA, 2020 b), compared to the baseline of 15%-20% of wind and solar share in total generation, 30% VRES share (63.6 GW installed capacity) is possible and cost effective if necessary flexibility is provided (SHURA, 2020 b). The SHURA energy efficiency study (SHURA, 2020 d) reveals that an additional 10% reduction in electricity demand is also possible with various energy efficiency options, nearly all being cost effective. As shown in these studies, introducing a portfolio of flexibility measures will ease the challenge of integrating higher solar and wind shares. Flexibility can be offered by storage (2 GW pumped hydro and battery storage were modelled) and by more flexible thermal generation through modernized coal-fired plants and DSR mechanisms. Turkey has 23 GW of reservoir hydropower currently installed, that could also add significant flexibility services to the system if adequately remunerated. The additional flexibility provided would have a positive albeit small effect on curtailment, which is already low without such additional flexibility, with levels in a high wind and solar energy scenario well below 1% for both solar and wind (SHURA, 2019 b).

The increasing share of VRES in the power system can make balancing demand and supply more challenging if necessary flexibility is not provided.

Technical flexibility is closely related to the physical structure of the system. Technical flexibility refers to the combination of technologies that determine 1) the ability of supply to follow rapid changes in net load, 2) avoiding peak demand times (for network benefit) or peak net demand times (for generator), 3) the ability of demand to follow rapid changes in supply, 4) the ability of energy storage to balance mismatches between supply and demand at all time scales and 5) adequate grid infrastructure to allow least-cost supply to reach demand at all times, anywhere in the power system (IRENA, 2018).

A flexible generator is one that can quickly ramp up or down, has a low minimum operating level and fast start-up and shutdown times. For example, hydro generators and open-cycle gas turbines are considered to be among the most flexible conventional generation types, while large steam turbines, such as those in coal generators, usually are on the less flexible side of the spectrum. Domestic lignite reserves have low calorific values and require extensive mining operations, which imposes to incline in more beneficial flexibility options. However, due to the current emphasis on system flexibility, modern designs offer improved performance, especially for coal technologies.

Electricity storage systems have been used primarily to shift the timing of electricity supply by storing electricity when its value is the lowest and discharging when the value is the highest. The value of electricity in this type of application comes from preventing more expensive generators from running and from reductions in the overall generation cost. When associated with VRES generation, storage can be used to facilitate high shares of VRES by mitigating the impacts of VRES on grid operations.

The role of battery storage has been under discussion for several years in Turkey. In 2021, a draft legislation on energy storage was released for public consultation. In addition, energy companies are looking into options for investing in battery storage technologies and related business models to operate them. Energy storage is under development with various R&D initiatives, including those led by TUBITAK and the Investment Office of the Presidency of Turkey, as well as the Turkey Electric Vehicle Project (TOGG), creating synergy with the energy sector. The Energy Institute Battery Technologies Laboratory covers all process steps of battery manufacturing in various R&D projects (TÜBİTAK, 2020). While the issue is attracting much interest, there is a need to better understand in which areas investments should be directed and to what extent storage capacity should be built (SHURA, 2019 b).

Technologies such as pumped hydro, compress air energy storage (CAES), hydrogen, long-duration batteries and thermal storage provide flexibility over longer time periods. In the short- to medium-term, batteries can potentially offer a wide range of services in addition to those offered by pumped hydro, such as providing multiple ancillary services at once, displacing fossil fuels for mobility when batteries are installed in EVs, enabling high shares of renewables in mini-grids and supporting self-consumption of rooftop solar power. Storage technologies were extensively assessed in SHURA's battery technologies report (SHURA, 2019 c).

Turkey is starting now with the development of its EV sector, with nearly 2,000 EVs being driven currently. However, with the increasing ownership of cars and growing population, there is a significant potential to increase EV use in the country. Integration of EVs into the power system is a major concern since their charging, when uncontrolled, can create negative impacts on the operation of distribution grids. To limit these impacts and manage the additional electricity load of EVs, smart charging concepts and business models are emerging to support cost-effective charging by EV users and encourage more efficient grid use. According to the recent SHURA report on EVs (SHURA, 2019 a), there is a potential to integrate up to 2.5 million EVs with an annual electricity demand of 4 TWh in Turkey's distribution grid by 2030, which requires strategies that enable smart charging (SHURA, 2019 a). On the other hand, Ministry of Energy and Natural Resources (MENR) announced that 1 million EVs are expected on Turkey's roads by 2030 (AA, 2019). This study therefore considers EV charging as a flexibility source when determining the optimal system configuration.

Grid flexibility refers to the existence of a robust transmission network to balance supply and demand over larger balancing areas, as well as cross-border interconnections to enable the exchange of flexibility across national or other jurisdictional borders (if the market allows for it) (IRENA, 2018). The analysis suggests that to integrate a total wind and solar energy share of 30%, additional transmission grid investments of up to 10% would be needed over the transmission system operator's planning (SHURA, 2018). However, grid expansion does not offer a fully adequate solution for Turkey when current infrastructure and conditions are taken into account, requiring other flexibility options to be introduced.

1.2 Turkey's power system and sector coupling

In 2018, 33% of the final energy consumption was realised in the industry sector, 30% in buildings and 26% in the transport sector. In 2019, Turkey's total electricity generation reached nearly 305 terawatt-hours (TWh) per year. Due to negligible levels of cross-border electricity trade, almost all of the total electricity production in the country is directed to end users. While the share of electricity consumed in buildings corresponds to 42% of total consumption, the share of industrial electricity demand is around 39%. A large part of the remaining 19% share cannot reach the end user due to power plants' own consumption, and losses in the transmission and distribution grids. Of the total 305 terawatt-hours of electricity generated in 2019, coal's share was 37%, hydropower 29%, natural gas 19%, wind, solar, geothermal and other renewables 15%. Turkey's residential, commercial and industrial electricity demand are increasing at a significant pace. Energy intensive industries such as iron, steel and cement comprise significant shares of the total electricity demand. With the increasing car ownership and growing population, there is a significant potential of EV use increase in the country. These loads are partly flexible, however a detailed assessment of the extent of their flexibility is still missing (SHURA, 2020 d).

The need for increasing power system flexibility in end-use sectors imposes to understand the 'sector coupling' idea. Sector coupling refers to the idea of interconnecting or integrating the energy consuming sectors - buildings (heating and cooling), transport, and industry - with the power sector. In order to achieve higher shares of renewables, and of VRES in particular, there is a growing recognition that it will be necessary to increase the interconnectedness of these different end-use sectors.

Sector coupling refers to the idea of interconnecting or integrating the energy consuming sectors - buildings (heating and cooling), transport, and industry - with the power supply sector.

Coupling sectors to create synergies in transitioning the energy system to one that is more efficient and renewable based is becoming a central part of Turkey's energy strategy. Efforts are focussed specifically on how DSR can be connected to surplus renewable energy in the system (e.g. activating loads on highly windy or sunny days, when the existing supply in the system is higher, and the marginal costs of generation are lower). As thermal loads (air conditioning, as well as space and water heating) and other loads become increasingly electrified, and as demand from electric vehicle charging continues to grow, the potential for smarter, real-time management of demand side resources expands significantly, increasing the opportunity to achieve higher shares of VRES (Münster et al, 2020).

Sector coupling implies an energy conversion process, where the converted energy (net of conversion losses) can be used in a different sector. Such energy conversions mean energy can be stored more easily than inside the electric system, for time-shifted, successive re-conversion to electricity. It can also be consumed in another sector if it is cheaper and/or cleaner than other energy sources typically used. It can be transported as heat or gases or liquid in some cases. Transport infrastructure can be more efficient than the one for transmitting and distributing electricity. In addition, heat pumps are considered a key technology to integrate the heating sector into the electricity-based energy system. The installation of heat pumps must go hand-in-hand with the insulation of buildings to make sure that less heat is lost, the heat pump size is optimised and that the whole sector becomes more efficient. The integration and coupling of different sectors will require the digitalisation of numerous processes to better synchronise supply and demand (Münster et al, 2020).

Many possible combinations of sector coupling options pose a complex multi-variables optimisation problem, with the objective of minimizing design and operational costs (CAPEX + OPEX), given the decarbonisation targets, system-inherent boundary conditions and operational constraints. A further element is the electrification of other sectors, which affects the picture by increasing the overall coupling potential and the potential locations in terms of DSR.

1.3 Demand-side response in Turkey

DSR refers to specific types of demand-side management programmes where the demand pattern is shifted or shedded to better match electricity supply.

DSR refers to specific types of demand-side management programmes where the demand pattern is shifted or shedded to better match electricity supply. DSR is an effective method that provides an opportunity for consumers to play a role in the operation of the grid by adjusting their electricity consumption subject to price signals or long-term direct-control agreements. DSR is key to achieving multiple aspects of an energy system transformation including integration of large scale and distributed renewable energy resources, increasing energy system efficiency, and enabling electrification of heat and transport at lowest cost. DSR can be used along with energy storage to further reduce VRES curtailment.

There are a number of examples of DSR implementation that are working across several countries, which are key to inform Turkey's DSR strategy. The capacity mechanism in France is open to DSR and is based on a 'decentralised market', where market participants contract directly amongst themselves. Belgium has taken significant steps to open its ancillary services to DSR through a series of changes in the product requirements. DSR can participate in the primary, secondary and tertiary reserves, as well as in the interruptible contracts programme. In Korea, legislation was passed allowing DSR to participate in the wholesale capacity market in April 2014. Korea is actively promoting DSR to help ensure reliability, encourage competition, and develop an ecosystem of IT-based energy businesses (SHURA, 2020 d).

DSR providers (industrial loads in particular) can offer load shedding to balance responsible parties (BRPs), such as energy suppliers, via bilateral agreements outside of organized markets. However, this is rarely implemented due to the difficulty of volatility and price determination for this service between parties. A regulatory framework for aggregation, which helps to decrease the overall system costs via demand side availability in both the ancillary services and spot power markets, does not yet exist in Turkey (SHURA, 2020 d).

Even though it has been considered in policy debates in Turkey for many years, DSR has not yet been investigated in detail. According to Turkey's 11th Development Plan, electricity generation from renewable energy sources will be increased and necessary planning and investments will be realized in order to ensure the safe integration of renewable energy generation to the grid, including storage technologies (Eleventh Development Plan, 2019).

Turkey has not begun to operationalize DSR apart from the TOU program supported with smart meters. In the Electricity Market Ancillary Services Directive, which entered into force in 2018, the terms of the DSR infrastructure have been defined. Turkey's National Energy Efficiency Action Plan (2017-2023) requires the implementation of a technical and regulatory environment enabling DSR in the short term. According to the plan, the necessary legislative framework was to be developed in 2018-2019, the institutional infrastructure was to be completed in 2020 and 2021, and the implementation to start in 2022 (NEEAP, 2017).

The need to develop DSR will be even greater in the short term in Turkey because of the large potential for distributed energy systems and the government's push in this area. As mentioned in SHURA's rooftop solar energy potential report (SHURA, 2020 a), a technical potential of 15 GW could be achieved in Turkey's buildings across different climate zones and building types. As electricity generation will become more decentralized, the need for smart operations to balance demand and supply between on-site generation and the power system will be the key to establish a flexible and resilient electricity network.

Taking all the above-mentioned information as an input, there is a gap Turkey needs to close in terms of assessing the DSR potential of different end-use sectors and their ability to support a power system with high wind and solar penetration. This report investigates DSR options in Turkey across several sectors with a particular focus on buildings. The study aims to show the potential of DSR and how that can be operationalised to 2030, contributing to the integration of higher shares of renewable energy, which ultimately enables increased energy efficiency and deployment of electrification options such as electric vehicles, heat pumps, and distributed energy resources. The assessment quantifies the DSR potential of different sectors, and the impact of DSR on renewable energy integration, as well as on power system investments and operational costs.

1.4 Approach to the assessment of the demand-side response potential in Turkey

Typically, the industrial sector is most mature in terms of providing DSR in different parts of the world while DSR from residential assets has not been proven at scale yet (UK Parliamentary Office of Science & Technology, 2014). The industrial sector is providing DSR to a large extent in the form of load shedding at large industrial sites which have high electricity consumption[1]. However, such load shedding could come at high utilisation cost due to production losses (Umweltbundesamt, 2015). Within the current market framework, and because of high cost of interruptions due to load shedding, such DSR from industry is therefore only applied very rarely at times of high system stress, such as in the case of a power line or generator fault.

While loads of individual households and non-energy intensive businesses might be small compared to the total load of the power system, they can be aggregated to form large cumulative loads. The technical potential of aggregated residential and commercial loads to provide DSR is immense, especially when considering electrification of heat and transport, which are likely to increase the electricity consumption of households and businesses significantly (IRENA, 2019).

Despite the potential, there are a number of barriers to deployment and growth. Costs are currently prohibitive as significant capital investment in smart information and communication technologies (ICT) at each of the aggregated loads is required (Nursimulu, 2016). Also, potential revenues (which could support high CAPEX) are not determined. As these aggregated loads represent new kinds of market participants,

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[1] Some sites are also able to provide DSR due to availability of on-site energy storage or electricity generation. However this form of response from industrial sites will not be discussed further in this report since fundamentally it refers to different technologies, namely flexible generation and energy storage.

their expected utilisation is very uncertain. Determining the economics of aggregated DSR requires an understanding of its utilisation, yet there are few system-level assessments of power systems with DSR.

Any impact on customer convenience and comfort needs to be minimised and the response will only be able to operate within the constraints given by customer preferences and needs. The DSR asset may be available only at certain times of day, or at certain times of the year. This represents an additional constraint on the utilisation of the asset compared to a pure-play energy-only asset such as a battery storage device. Making the economics of residential and commercial DSR work will require keeping investment costs low and utilisation high.

A further challenge of a wider roll out of residential and commercial DSR is the diminishing marginal value (at system level) of additional flexibility assets. Greater levels of deployment of DSR will lead to lower levels of utilisation per asset, and diminishing returns on the value of the services provided (all other things being held constant). This has already been seen in proactive markets; the value for frequency response in the United Kingdom has fallen by two thirds in 3 years because batteries have become the price setter in this ancillary market, which is very small relative to wholesale electricity markets (e.g. day ahead and future markets). A similar dynamic applies to (the admittedly much larger) wholesale energy market. Putting aggregated DSR into operation at a large scale up to 2030 will require significant innovation in terms of technology and business models as well as policy reform to provide an adequate regulatory framework (BEIS, 2017).

This study addresses these multiple challenges for DSR, across power system configuration, DSR asset availability, consumer behaviour, and economics of DSR deployment. It combines a new technical assessment of DSR potential in Turkey with an economic assessment of DSR utilisation when deployed alongside, and sometimes in competition with, other flexibility options available to the power system, when integrating high levels of VRES deployment at lowest system cost.

The following section describes the motivation for the development of the scenarios which have been used to represent possible configurations of a 2030 Turkish power system with different degrees of electrification and application of DSR.

1.5 Scenario development

The starting point for this assessment is the Tripling scenario as set out in the SHURA grid (SHURA, 2018) and flexibility (SHURA, 2019 b) studies with a total capacity of wind and solar of 60GW, supplying 30% of Turkey's electricity demand by 2026. This scenario is also closely aligned with the Balanced Policy scenario of the recent SHURA report on an optimal capacity mix in Turkey (SHURA, 2020 b), in which wind and solar deployment rises to reach 63.6 GW by 2030, representing a 30% share in Turkey's total electricity demand.

Many power systems worldwide are working to accommodate high levels of VRES. There is consensus that this will require deployment of flexible assets on the system to balance supply and demand, to limit peaks of electricity demand and to reduce renewable curtailment. When considering the capability of DSR assets to contribute to meeting this integration challenge, two important dimensions arise:

Capability of demand side to provide flexibility: The growth in electrification of heating and transport increases the potential to provide demand flexibility. This is because many space heating (and cooling) demands have a level of inherent flexibility due to thermal mass, while most EV charging events can be shifted/delayed to provide flexibility.

More efficient buildings have more flexibility to adjust energy demand, in response to the needs of the power system.

Energy efficiency, which is vital to cost effective decarbonisation, can also support flexibility. More efficient buildings can store heat for longer, and if these have heat pumps for heating, these more efficient buildings have more flexibility to adjust energy demand, in response to the needs of the power system.

The adjustments to the demand side to account for electrification and efficiency gains, is given in chapter 2.

Source of flexibility - supply or demand side: Traditionally, power systems acquire nearly all their flexibility from the supply side: part loaded thermal generators, pumped hydro storage, interconnectors etc[2]. While some industrial demand sectors may provide flexibility via demand interruptions, these are costly and thus utilised only in extremis and for limited hours per year[3]. The capacity and type of flexible resources already available to the power system are important in determining the remaining technical and economic opportunity for demand assets to provide flexibility to the system.

Our starting point therefore is to represent the power system with the supply side flexibility assets expected in 2030. These are aligned with those specified in the Tripling scenario without flexibility in the SHURA study where the share of redispatch in total electricity demand is twice higher, curtailment increases and the grid investments are 40% higher compared to the business as usual (SHURA, 2018), and comprise system friendly location of renewable energy capacity, storage, increasing thermal power plant flexibility and DSR.

The current study's deep dive exploration of DSR can be seen as a complementary technical and economic option to these supply side solutions. Further information on the supply side generation assets is given in chapter 4.

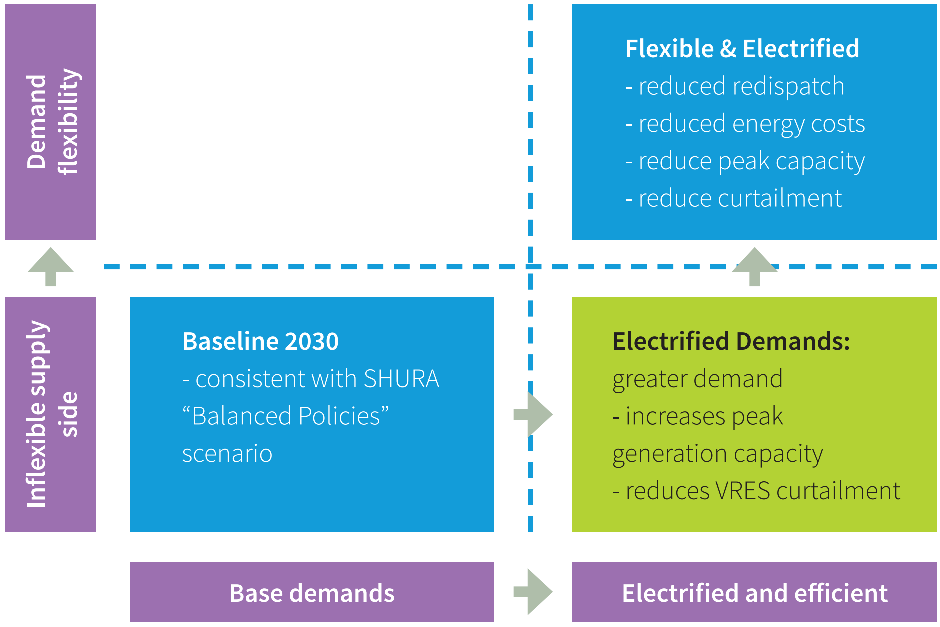
Figure 1 illustrates the development of the scenarios explored in this assessment along the dimensions described above.

- A Baseline 2030 scenario establishes the system costs of meeting 30% VRES penetration by 2030.
- The Electrified Demand scenario establishes how changes to the demand side can support 30% VRES share and reduce system costs of integration.
- The Flexible and Electrified scenario then activates DSR up to its technical and economic threshold, to establish how DSR can reduce overall system costs when achieving the 30% VRES share.

[2] We are including utility scale storage and interconnectors under supply side as they don't interact with the demand side.
[3] For example, interrupting large industrial consumers such as iron and steel manufacturers occurred on 15 days for 15 minutes up to 8 hours in 2018 in Germany with a total utilization of about 5 GWh compared to a total electricity demand of 574 TWh (Bundesnetzagentur, 2019).

The analysis of these scenarios aims to help identify the least-cost approach to increase VRES penetration in Turkey's power system as well as to increase electrification of heat and transport. . The core scenarios are Baseline and Flexible & Electrified.

***Figure 5:** Scenarios explored in this study*



1.6 Guide to the structure of this report

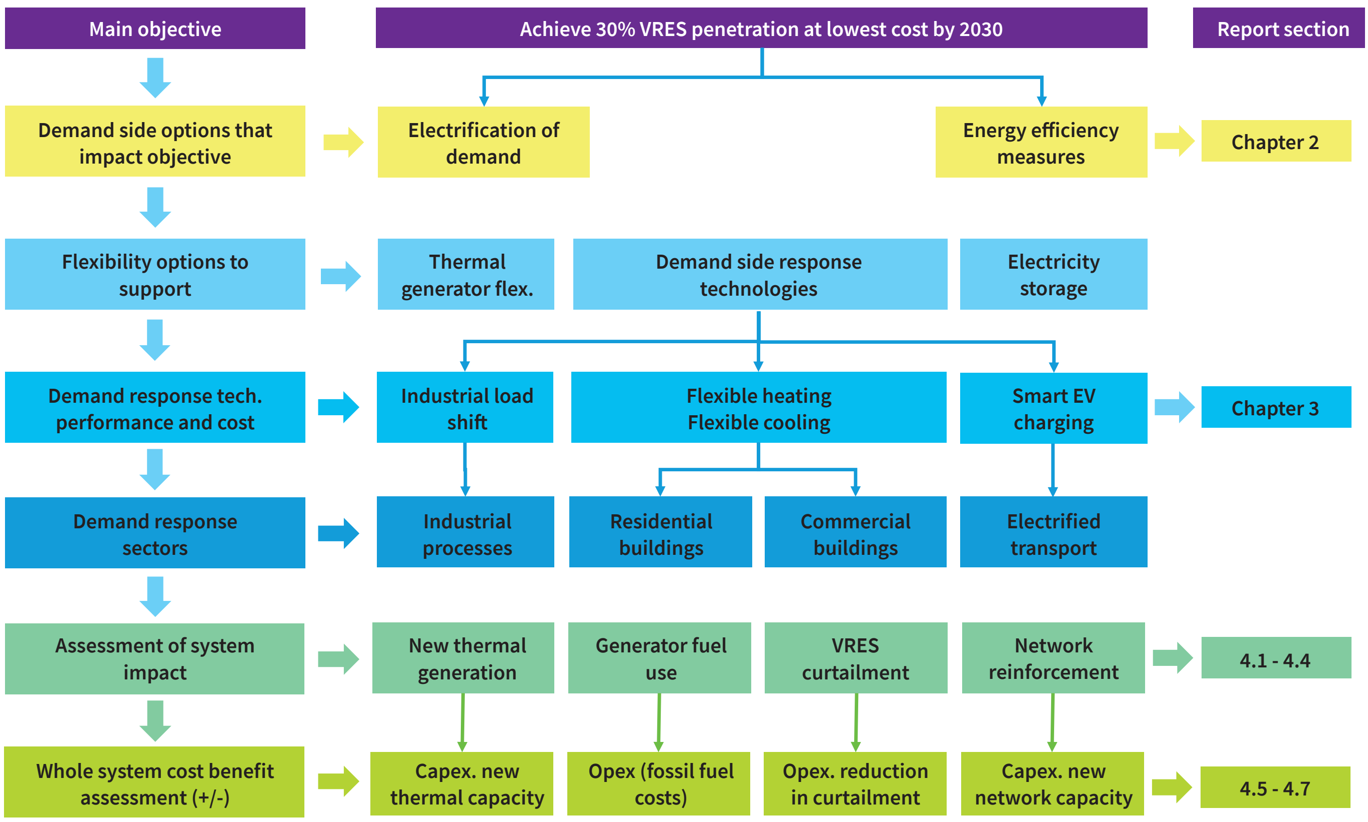
This study considers achieving 30% VRES penetration in Turkey by 2030, and doing this at lowest system cost. The diagram here illustrates the process used to determine the potential for DSR to support VRES and deliver system cost savings.

- As decarbonisation drives greater electrification of demand, this increased demand can reduce curtailment of VRES. In addition, new electrified demands increase potential for flexibility. Energy efficiency measures are important for cost effective CO_2 reductions but they reduce demand. Prior studies often make important assumptions of DSR capacity, i.e. that 5% or 10% of demand is DSR flexible. These "top down" estimates do not reflect the actual DSR availability at times of system need, nor their capital and operational costs, and therefore cannot provide sufficient evidence that policy makers need to target and focus on high performing DSR sectors. The first step in assessing the flexibility potential in key demand sectors in the power system is to estimate their future demand, which is done in chapter 2.

- Greater power system flexibility is required to accommodate VRES. Previous work by SHURA examined the potential for the supply side to achieve this (e.g. enhanced generator flexibility), while this study focuses on DSR. The current study represents variability of availability of DSR resources across the day and seasons, using a bottom-up approach. This provides evidence to how much of the energy being used in these assets correlates with times that are useful to balancing the energy system. The potential for various end-use sectors to provide DSR is assessed in chapter 3.

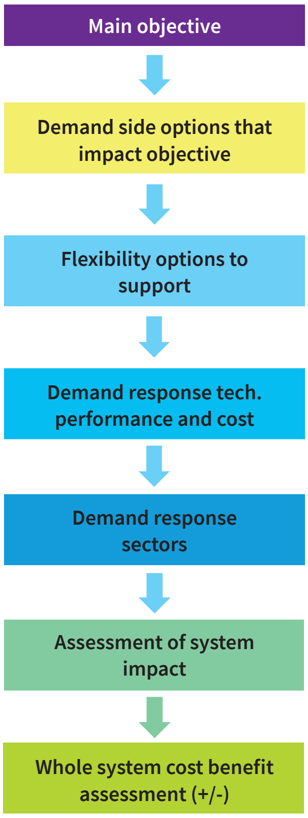
- DSR has the potential to support VRES while reducing system cost, including reducing VRES curtailment, reduced generator fuel use, and reducing or eliminating additional dispatchable generation capacity, or additional network capacity, required to accommodate the VRES target and the electrified demands. DSR assets may never be employed by the power system if they are more expensive to exploit compared to other sources of power system flexibility. We introduce our DSR assets in a whole power system model of renewable integration, with supply-side flexibility, to represent accurately the technical and economic opportunity for DSR utilisation. A whole system model approach is used to determine these costs and benefits, and this is reported in chapter 4.

- The study furthermore determines priorities for technical, regulatory and commercial development required to enable a scale up of DSR, in chapter 5.



At the start of main sections, it is identified which stage of the process the section relates to.

2. Assessment of 2030 electricity demand by sector



This chapter identifies the electricity demand sectors that are the focus for DSR, and for each determines the annual energy demand in 2030, adjusting the baseline to reflect an increase in electrification of space heating and transport. Within each demand sector, it then determines what proportion could provide flexibility to the system, for example in buildings which have the capability to store heat energy in the structure and fabric of the building, allowing the heating system to be turned off but still providing (for a time) acceptable internal temperature. The first sections of the chapter cover the development of electricity demand from buildings (section 2.1 and section 2.2), industry (section 2.3), and transport (section 2.4). Note that the "bottom-up" modelling of flexibility provision within these sectors, is explained in chapter 3. The final section (2.5) discusses the development of total electricity demand.

2.1 Method: Determining 2030 demand from buildings

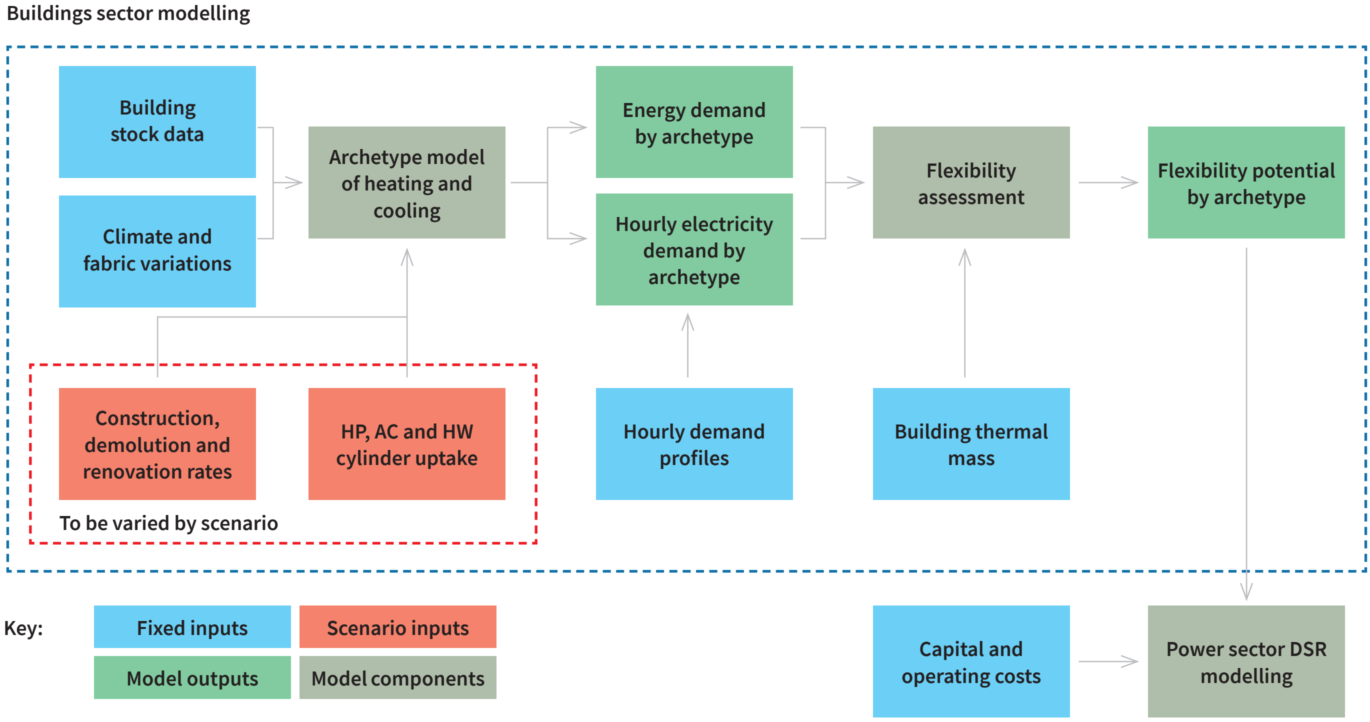
Accurately modelling electricity demand from buildings is important to estimate the potential for DSR. Space heating and hot water, space cooling, and ventilation have the potential to be flexible and to provide value to the wider electricity system. A bottom-up model of the demand for these end-uses has been developed based on the make-up of Turkey's buildings and current levels of demand (SHURA, 2020 a) and how the demand may change under the scenarios described in Section 1.6. The building sector demand for these end-uses contributes 13% of the total electricity demand in the Electrified & Efficient scenario, compared with about 7% of demand today. These sectors also add to the seasonal variability in overall electricity demand due to weather dependence. Indeed, space heating and cooling are responsible for the annual system peaks in winter and summer respectively and so are key determinants in sizing the required electricity generation capacity.

Other electricity demands from the buildings include lighting, appliances, and electric cooking. These are not modelled with the same granularity as space heating and hot water, space cooling and ventilation due to their lower potential to provide cost-effective flexibility. These other demand sectors are captured in the remaining electricity demand assumed to be inflexible (cp. section 2.5 below).

2.1.1 Archetype model

To estimate the potential for DSR in Turkey's buildings, the electricity demand from space heating and hot water, space cooling and ventilation is modelled in detail across Turkey's building stock and in high temporal resolution using an archetype model. Figure 6 presents a schematic of the modelling process.

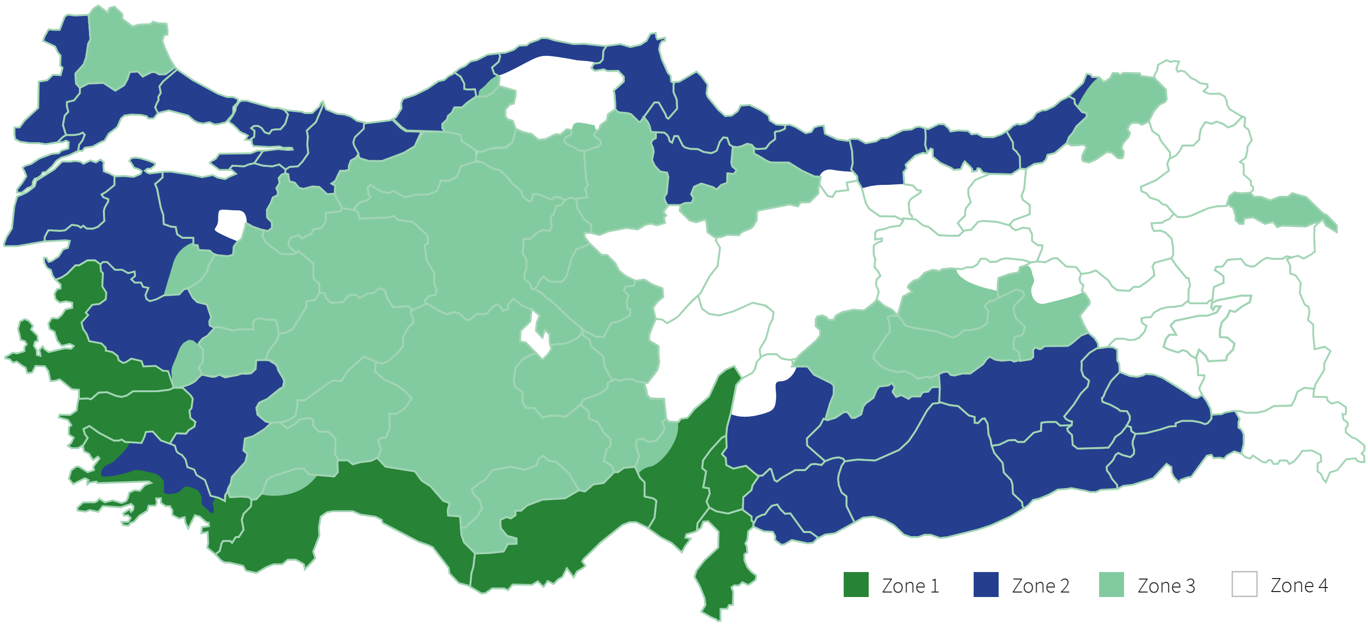
Figure 6: Schematic of the buildings modelling process



We have adopted an archetypal approach to accurately reflect the diverse Turkish building stock and the energy demand (and its flexible portion) from space heating and hot water, space cooling and ventilation. The archetype model captures the variation in demand across the building stock due to three key dimensions: building type, building age and climate zone.

Turkey is a large country with many different geographies, which give rise to a wide range of climates. Representing this variation is therefore especially important in comparison to smaller countries with more uniform climates. Turkey's buildings have been divided into four categories according to the four climate zones defined in TS 825 Thermal Insulation Requirements for Buildings (Turkish Standards Institute, 2008), which are shown in Figure 7. Zone 1 has a hot Mediterranean climate, zone 2 is mild with rains throughout the year, while zones 3 and 4 have continental climates although zone 4 is significantly colder than zone 3. Heating demand in zone 4 is over twice that of zone 1, and conversely demand for cooling in zone 1 is significantly more than in zone 4 (SHURA, 2020 a). The heating and cooling demand in the four climate zones is presented in Appendix.

Figure 7: *To represent climatic variation in the archetype model, Turkey was split into 4 climate zones following TS 825*



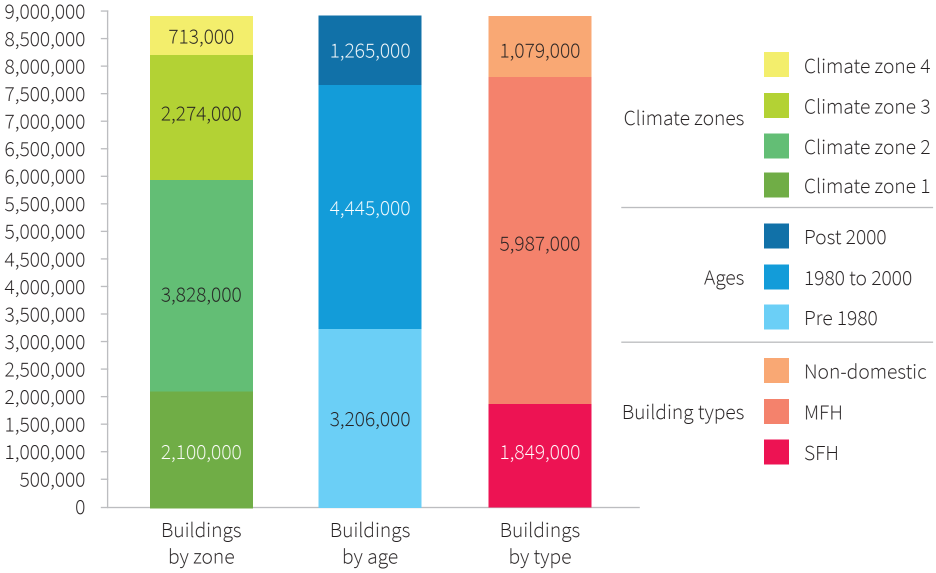
Building type and building age also strongly affect the energy demand in buildings. Single-family homes consume more energy per dwelling than multi-family homes and there is a wide range of consumption between non-domestic building types. For example, the energy demand per floor area in the health sector is about twice that of the commercial and education sectors (SHURA, 2020 a). Building age is used to indicate the level of thermal efficiency. The oldest buildings with poor energy efficiency can have heating and cooling demands up to three times those of new, efficient buildings (ENTRANZE Project, 2013). In Turkey, energy efficiency standards were first introduced in 2000 and updated in 2008 (Ministry of Energy and Natural Resources, 2008). The assumptions on building energy efficiency and age, and resulting impact on heating and cooling demand, are discussed in Appendix.

The archetype model divides Turkey's housing stock into the categories shown in Table 2 below, for a total of 160 archetypes. Archetypes that are unheated are not considered further, leaving 140 archetypes for the following analysis.

Table 2: *Categories of the archetype model*

Building type	Age	Climate zone
Single family home (SFH)	Pre 1980	1
Multi-family home (MFH)	1980 to 2000	2
Health	Post 2000	3
Education	New built	4
Hotels	Renovated	
Commercial and Other		
Public		
Unheated		

Figure 8: *Turkish building stock in 2017*



Source: (SHURA, 2020 a)

The archetype model was populated using data from the 2017 Turkish building stock (SHURA, 2020 a). The demand for space heating and hot water, space cooling and ventilation in each archetype was developed using data on the total energy consumption in each building type and in each zone (SHURA, 2020 a). System efficiencies and uptake rates were used to determine the demand for each end-use from the final energy consumed. Because Turkish-specific data on the variation of building efficiency with age was not available, data from other countries selected to match each climate zone was used to estimate the differences in heating and cooling demand of buildings within the age categories shown in Table 2. Further details on the development of the archetype model are provided in Appendix.

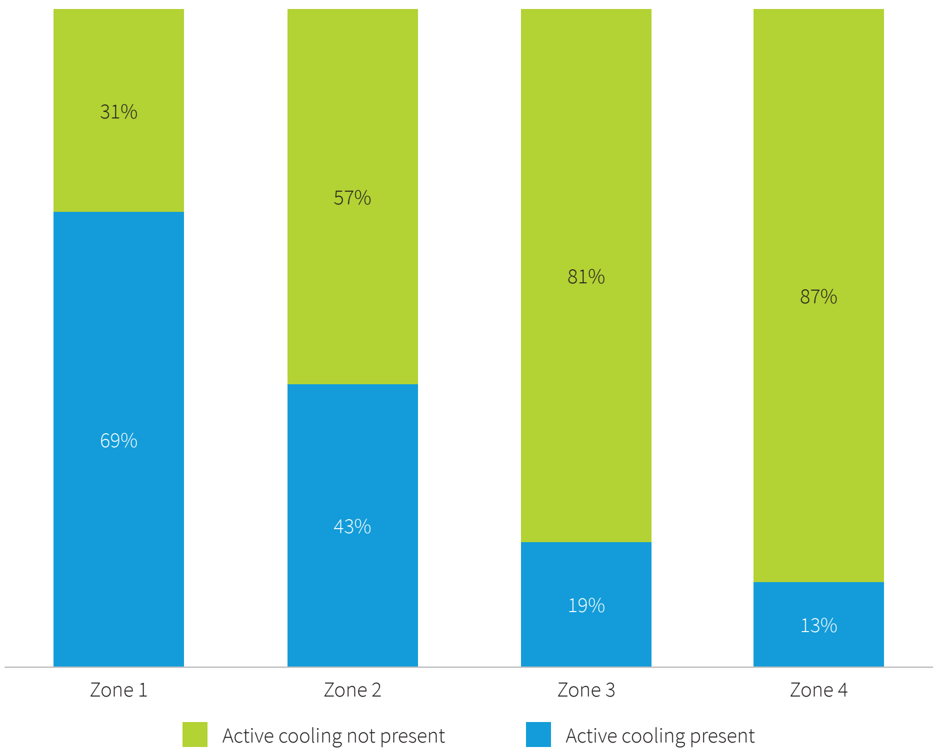
2.1.2 Scenario assumptions for buildings

As outlined in chapter 1, the impact of increased energy efficiency and of higher electrification measures is determined as an adjustment to the Baseline scenario for 2030. The rate of building fabric efficiency renovations and technology uptake rates are varied to reflect the impact of each scenario on the electricity demand for space heating and cooling. The demand for hot water and for ventilation are unchanged between the scenarios.

Baseline scenario

The 2017 building stock is adjusted using construction, demolition and renovation rates to predict the building stock in 2030. A construction rate of 3.5% per year (SHURA, 2020 a) and demolition rate of 1.5% (Ecofys, 2016) per year are applied across all scenarios. The Baseline scenario applies a building renovation rate of 0.45% per year, in line with Turkey's current rate of efficiency renovations (Ecofys, 2016).

Figure 9: *The uptake of air conditioning in the climate zones in 2030*



The number and type of electric heating and cooling systems operating in 2030 must be projected for each scenario. In the Baseline scenario, the share of electric resistive heating is kept constant at the level present in 2017. A slow but steady uptake of heat pumps is assumed. The total number of heat pumps doubles from the 30,000 present in 2017 (GIZ and Turkish Ministry of Environment and Urbanisation, 2018) to 60,000 in 2030. These are concentrated in climate zones 1 and 2, reflecting the current distribution.

The share of buildings with active cooling is anticipated to increase across all climate zones to the levels shown in Figure 9 (SHURA, 2020 c). In all scenarios, 80% of the non-domestic building archetypes are assumed to have mechanical ventilation systems.

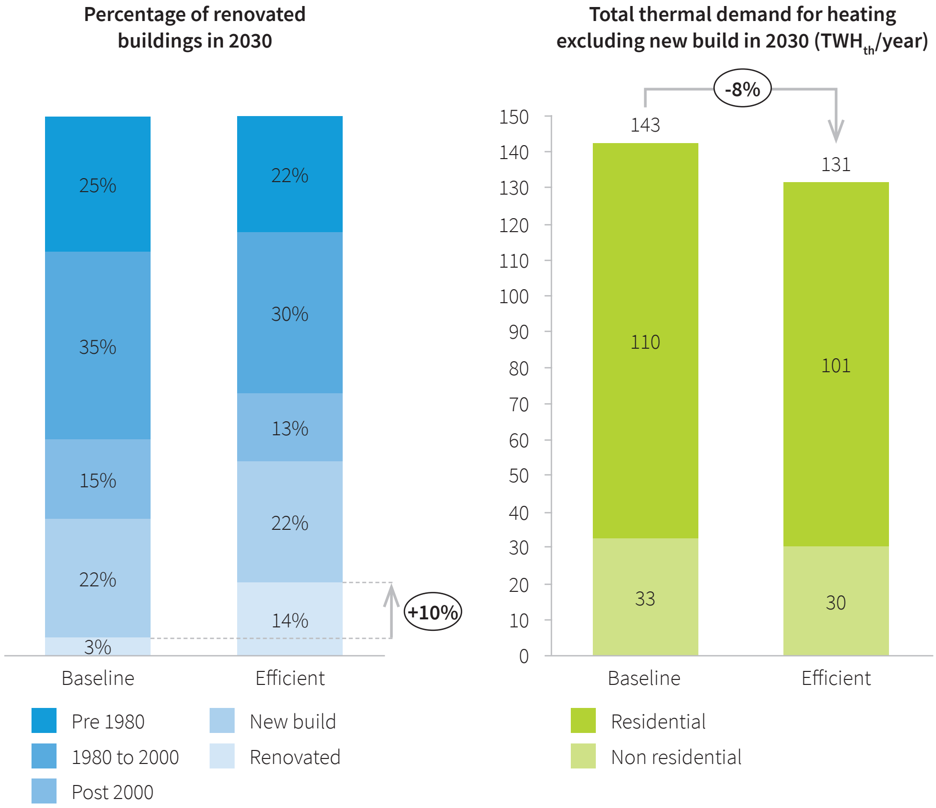
Efficient scenario

To separate the impacts of efficiency from those of electrification, each is considered in isolation before being combined in the Electrified & Efficient scenario below. The Efficient scenario applies a higher rate of energy efficiency renovations which improve building thermal performance. The rate is increased to 2% of existing building stock per year (SHURA, 2020 c), matching international frontrunners in building efficiency renovations (New Climate Institute and Climate Analytics, 2019). This renovation rate increases the number of renovated buildings in 2030 from 3% of the building stock in the Baseline scenario to 14% (Figure 10, left).

The thermal efficiency of renovated buildings is increased to match the TS 825 building standard used in new buildings, which results in a decrease in space heating and cooling demand of around 50% compared to the average existing building (see Appendix). The increased renovation rate results in an 8% decrease from 143 TWh to 131 TWh in the demand for heating for all buildings in 2030 relative to the Baseline scenario, as shown in Figure 10[4]. Turkish buildings consumed 158 TWh for heating in 2015. Given the existing mix of heating systems with an average efficiency between 80% and 90%, this implies a demand for useful energy for heating of around 140 TWh (SHURA and BPIE, 2019). This is consistent with the values projected for 2030 given the assumed growth in the building stock.

A continuation of this renovation rate beyond 2030 would result in an accumulation of benefit and a more significant decrease by 2050. Note that the heating demand shown in Figure 10 (right) is for the entire existing building stock; only buildings with electric heating are considered in the following analysis.

Figure 10: *There is a 10% increase in the renovated building stock in the Efficient scenario; this causes a corresponding 8% decrease in the total thermal heating demand for the existing stock*

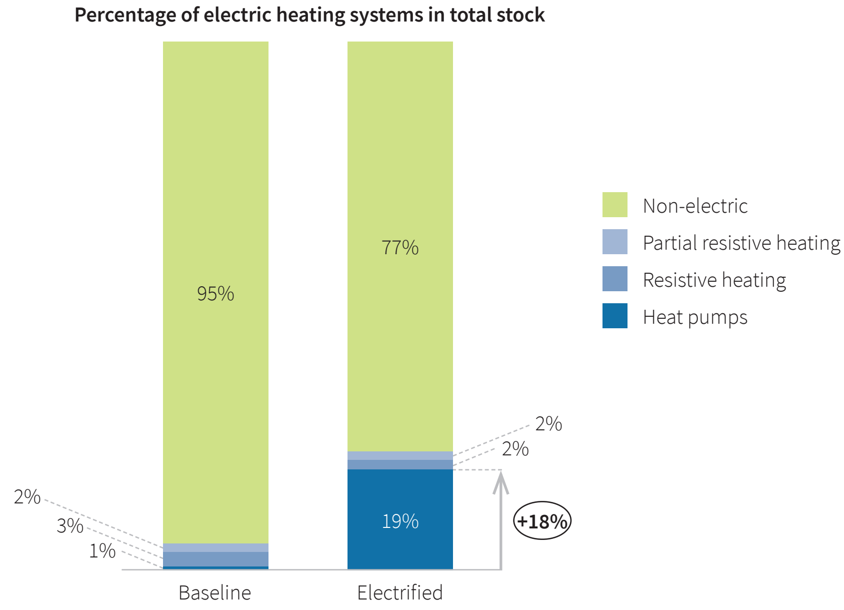


Electrified scenario

The uptake rate of heat pumps is increased in the Electrified scenario. 50% of new buildings and 10% of the existing stock, across all climate zones, adopt heat pumps. Approximately 1.9 million heat pumps are deployed across Turkey in this scenario (SHURA, 2020 c), increasing their share from 1% to 19% of the stock by 2030 (Figure 11). The uptake of electric vehicles is discussed in Section 2.4 below.

[4] Note that this is the demand for useful heat, not final energy consumption, which will vary with the heating technology and fuel used.

Figure 11: *There is an 18% increase in the use of heat pumps in the electrified scenario relative to the baseline*



Electrified & Efficient scenario

The Electrified & Efficient scenario combines the increased rate of renovation in the Efficient scenario with the increased rate of heat pump uptake in the Electrified scenario. This scenario is applied in the system-wide analysis in the following chapters. The scenario assumptions for buildings are summarised in Table 3, and the electricity demand from space heating and hot water, space cooling and ventilation in all scenarios is shown in Figure 12 below.

Table 3: *Summary of scenario assumptions for buildings in 2030*

	Baseline	Efficient	Electrified	Electrified & Efficient
Construction rate	3.5%			
Demolition rate	1.5%			
Commercial active ventilation	80% of stock			
Energy efficiency renovation rate	0.45%	2%	0.45%	2%
2030 HP uptake	60,000	60,000	1.9 million	1.9 million
2030 AC uptake	See Figure 9			

2.2 Results: Electricity demand from buildings

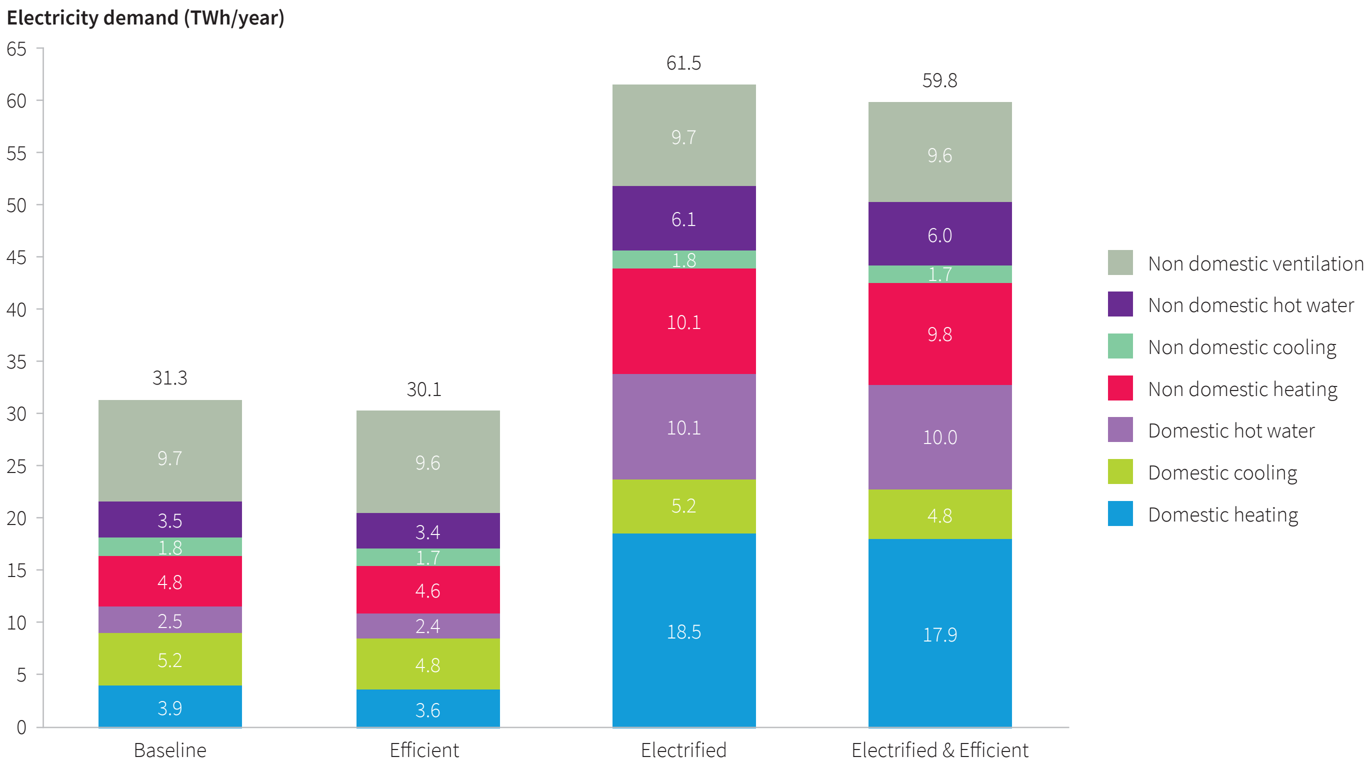
The demands for space heating, hot water, space cooling and ventilation in domestic and non-domestic buildings calculated in the archetype model are combined with the renovation and system uptake rates in each scenario to calculate future electricity demand, shown in Figure 12. The end-uses considered here contribute approximately 30 TWh to Turkish electricity demand per year in 2030 in the Baseline scenario, which was 27 TWh in 2020 (SHURA, 2020 d). These end-uses demand approximately 60 TWh of electricity per year in the Efficient & Electrified scenario. The demands for space heating and hot water, space cooling and ventilation contribute 7% and 13% of total annual electricity demand in Turkey in 2030 in the Baseline scenario and the Electrified

& Efficient scenario, respectively. Note that the hot water demand included here is only for buildings with electric heating systems (heat pumps and electric resistive heating). There is additional electricity demand for hot water in buildings that use other fuel sources for their primary heating fuel (Aydin, 2018). This additional demand is included in the total national demand for Turkey in 2030 (see Section 2.5 below).

In this analysis, the increase in electricity demand over the baseline in 2030 is about three times higher than in SHURA's earlier analysis on the role of energy efficiency for power system transformation (30 TWh versus 8 TWh per year) (SHURA, 2020 d). A higher electrification was deliberately introduced to the model to assess the impact of electrification on the DSR potential since at low electrification level these impacts would have otherwise been insignificant.

As evident in Figure 12, the addition of the Electrified scenario has a greater effect on yearly demand than the Efficient scenario. The increased uptake of heat pumps in the Electrified scenario is directly proportional to electricity demand, while the increased efficiency measures deployed in the Efficient scenario are applied across the whole stock and reduce demand also in buildings without electric heating. In addition, the majority of the heat pumps installed in the Electrified scenario are in new buildings which are not affected by the choice of efficiency level. The temporal resolution of this demand over the year is considered in Section 3.1 below where the DSR potential is also discussed.

Figure 12: *Electricity demand from heating, cooling, hot water and ventilation in 2030, by scenario. The scale of change in demand due to the modelled electrification of heat outweighs the change due to modelled increase in efficiency of the stock*



2.3 Electricity demand from flexible industrial processes

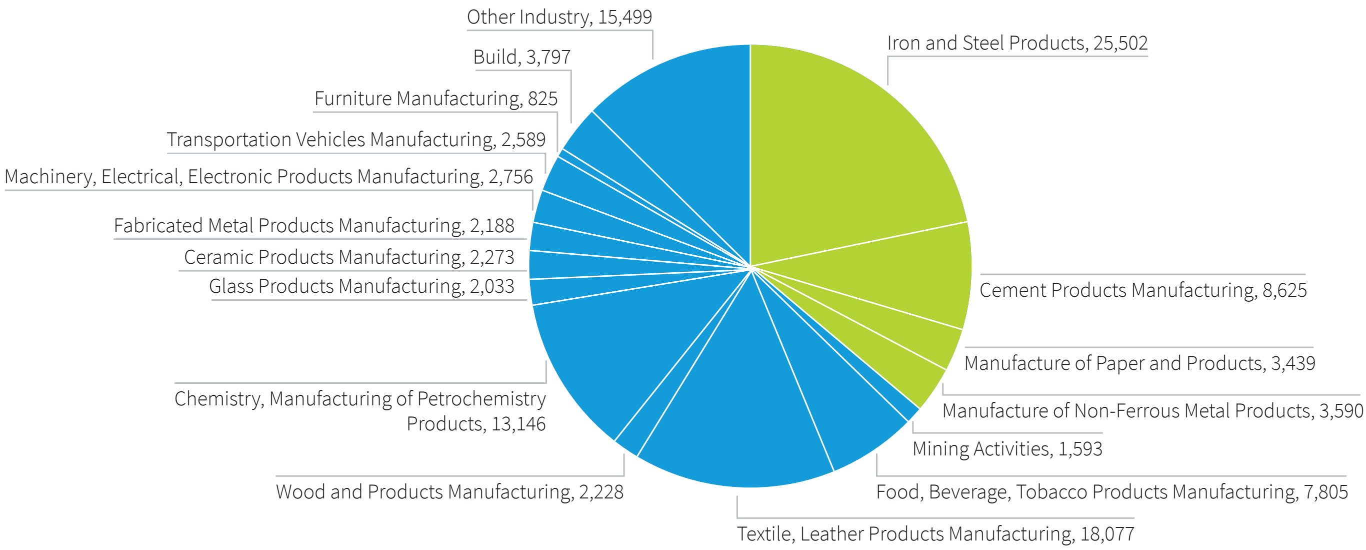
In addition to electricity demand from buildings for heating and cooling, we have assessed industrial electricity demand as a significant potential source for DSR. The Turkish government publishes detailed data on annual electricity consumption per economic sector (General Directorate of Energy Affairs, 2019). We estimate the 2030 industrial electricity demand by extrapolating the published 2018 industrial demand using the 2009-2018 average growth rate of value added by industry as published by the World Bank (World Bank, 2020), which is in line with the SHURA energy efficiency report (SHURA, 2020 d). The breakdown of industrial demand into sectors is shown in Figure 13.

We explore those industrial sectors with high techno-economic potential to provide DSR further. These are energy intensive sectors with high electricity consumption per site. Such sites are in principle able to adjust significant amounts of electricity consumption without the need to install aggregated ICT across multiple assets. On the other hand, aggregation across multiple assets and sites might be necessary in the case of non-energy intensive industry to achieve system relevant amounts of electricity demand. Installation and operation of ICT to manage aggregation can add significant costs in these cases.

The most relevant industrial sectors which have been identified as capable of DSR are steel, non-ferrous metal products, cement and paper.

The main techno-economic assumptions on industrial DSR are taken from (Gils, 2014), (Gils, 2016) and (Umweltbundesamt, 2015), which are comprehensive studies on DSR. In Turkey, the majority of electricity consumed by all industrial sectors is used for power motor systems[6]. The most relevant industrial sectors, which have been identified as capable of DSR are steel (via EAF - electric arc furnace), non-ferrous metal products (aluminium, zinc, and copper), cement and paper. These flexible industrial processes make up about 35% of all industrial electricity demand (orange in figure below). Turkey's iron & steel and cement sectors are among the largest worldwide and make up 83% of the demand of these four sectors. Flexibility can be provided by these industrial sectors in one of two forms, which will be discussed in section 3.3.1. The annual electricity consumption of steel, non-ferrous metal products, cement and paper in 2030 is estimated to be 51.4 TWh, 7.2 TWh, 17.4 TWh and 6.9 TWh respectively, adding to a total of 83.0 TWh. The full breakdown of 2030 industrial electricity demand can be found in Appendix.

Figure 13: *Breakdown of industrial electricity demand in Turkey 2018, consumption per industrial sector in GWh*



Source: (General Directorate of Energy Affairs, 2019)

[5] For a breakdown of industrial electricity demand into processes, compare Table 6 in (SHURA, 2020 d).

2.4 Transport electrification

Electrification of transport will add significant new load to the electricity system and there is a great potential to make it flexible. The main reason is that most vehicles are stationary for most of the time. Subsequently, EVs could be plugged in at charging stations at home or work for a much longer time than required to charge them. Thus, their charging could be moved into hours when it is most beneficial to the system, e.g. to times of high solar generation or low overall electricity demand. Such smart EV charging could contribute significantly to integration of VRES such as wind and solar.

Assumptions on the roll out of EVs (BEVs and PHEVs) in Turkey in the electrification scenarios and their electricity consumption are taken from the 2019 SHURA report (SHURA, 2019 a). In line with the report, it is assumed that EVs drive 10,000 km per year and consume 17 kWh of electricity per 100km. Furthermore, it is assumed that PHEVs drive half of their annual mileage powered by electricity. The assumed number of EVs in Turkey in 2030 is based on the High Growth scenario of the SHURA report, which projects a share of 65% of sales in 2030 for EVs and hybrid electric vehicles (HEVs, i.e. cars which have an electric engine to support the fossil fuelled main engine but whose electric engine is not charged by plugging into the grid). Hybrids account for 15% of the EV and hybrid sales, BEVs for 55%, and PHEVs for 30% in 2030 in this scenario. The assumed EV (BEV + PHEV) stock and the electricity consumption in 2030 are listed in Table 4 along with the corresponding values for 2018 as reported in (SHURA, 2019 a).

Table 4: *Assumed BEV, PHEV and total EV stock and electricity consumption in Turkey in 2018 and 2030*

EV category	Year	Stock	Annual electricity consumption (GWh)
BEV	2018	657	1.3
PHEV	2018	250	0.2
EV total	2018	907	1.5
BEV	2030	1,675,955	2,849
PHEV	2030	908,887	773
EV total	2030	2,584,843	3,622

2.5 Total electricity demand

To estimate the total electricity demand in Turkey in 2030, the projected demand from heating and cooling, electric vehicles, energy intensive industries with DSR potential (steel, non-ferrous metals, cement, paper) described in the previous sections are summed and the remaining electricity demand is added. This remaining electricity demand includes commercial and residential demand other than heating (e.g. lighting, appliances, cooking) as well as demand from non-energy intensive industries.
Our estimate of this remaining electricity demand is based on the 2030 Distributed Generation scenario of the ENTSO-E 2018 TYNDP (ENTSO-E, 2019). This scenario is very closely aligned with the SHURA Tripling scenario in terms of the total annual electricity demand in Turkey as well as its hourly profile. To obtain the electricity demand

excluding demand for heating, cooling, electric vehicles and energy intensive industry, the demand of these sectors is subtracted from the ENTSO-E scenario.

By adding our own projection of the demand of those sectors as derived from the modelling, a projection for the total electricity demand in Turkey is obtained. This process is illustrated in Figure 14.

Figure 14: *Synthesis of total system demand from ENTSO-E modelling of the Turkish power system and modelling of key demand sectors in this study*

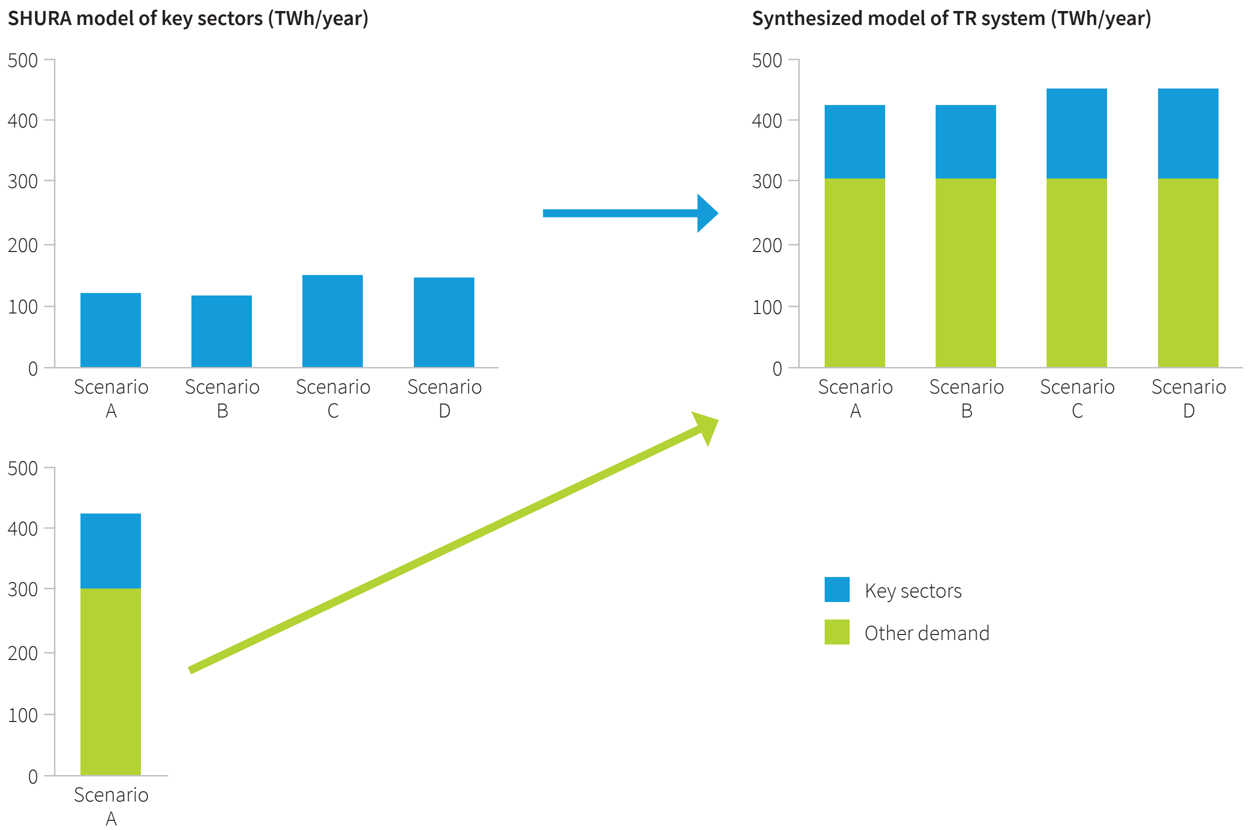
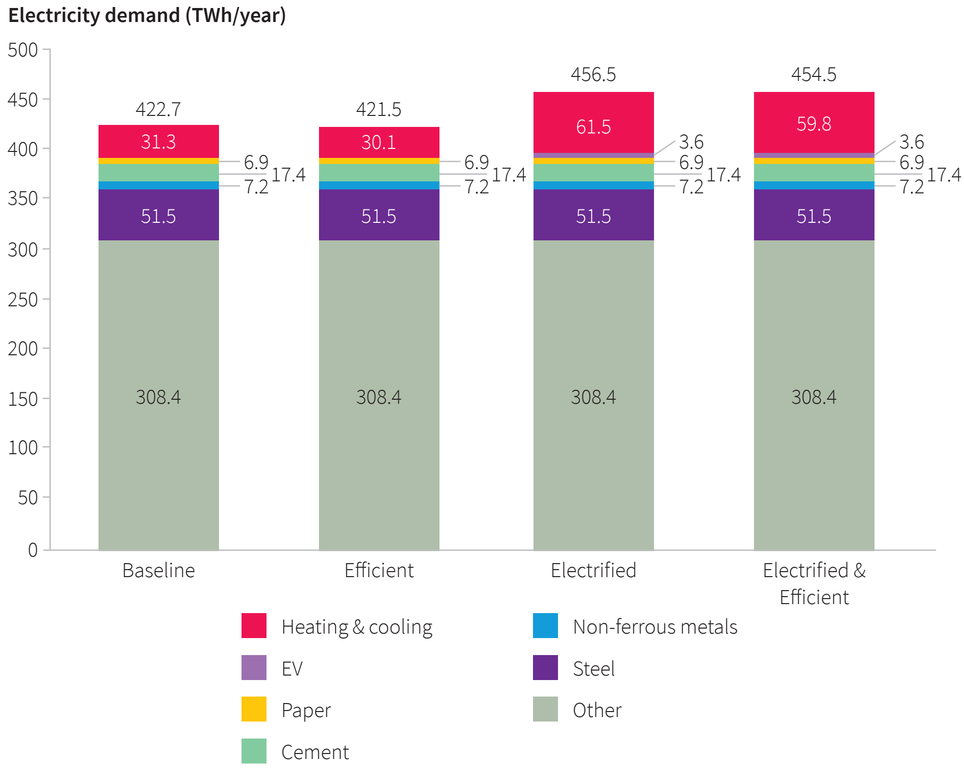
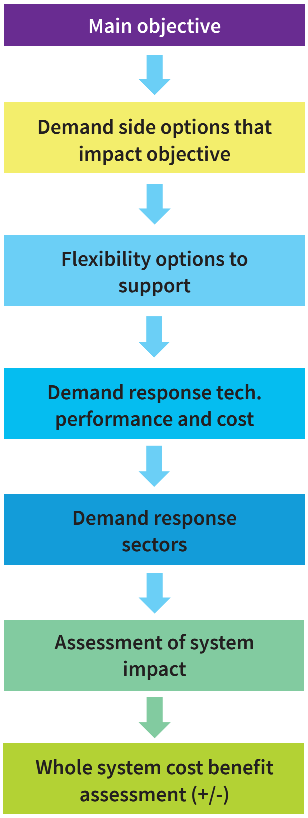


Figure 15 shows the total annual electricity demand in the four investigated demand scenarios (cp. section 2.1.2). Other demand refers to the demand other than heating and cooling, EVs and energy intensive industry. While the demand for heating and cooling is varied across the scenarios, the other demand components are held constant. Consequently, total electricity demand varies between 422 TWh and 457 TWh across the scenarios. This is closely aligned with the scenarios of the SHURA report on an optimal capacity mix in Turkey (SHURA, 2020 b), in which electricity demand varies between 421 and 461 TWh. It is also aligned with the SHURA report on flexibility (SHURA, 2019 b), which assumes a total annual demand of 440 TWh in 2030, and with the SHURA EV report (SHURA, 2019 a).

Figure 15: *Breakdown of total electricity demand in 2030 in the four investigated scenarios.*



3. Assessment of demand-side response potential



Chapter 2 determined the size of the flexible sectors in the Efficient & Electrified scenario for Turkey 2030. This chapter summarises how each of these flexible demand sectors is represented at the high level of temporal resolution required to determine their impact on the power system in 2030. In a high VRES power system, volatility and supply/demand imbalance are high and may occur frequently over each day and across the year. The capacity of flexible space heating DSR will be highest in winter but negligible in summer; space heating may be expected to have high capacity to balance wind variability in winter, but will have limited capacity to balance PV related volatility peaks in summertime.

Many prior studies on DSR assume a fixed percentage of demand can be variable, and that percentage is available to the power system at any time in the form of flexibility. The current study represents a significant advance on prior work by developing a bottom-up representation of DSR availability. To determine the extent to which DSR can contribute to integrating VRES, the power system and DSR flexibility is modelled on an hourly basis. Note that this chapter determines the technical potential for each sector to provide flexibility. Whether such potential is actually exploited is also dependent on the economic competitiveness of DSR compared to other flexibility options, and this is assessed in chapter 4.

3.1 Method: Assessing flexible demand from buildings

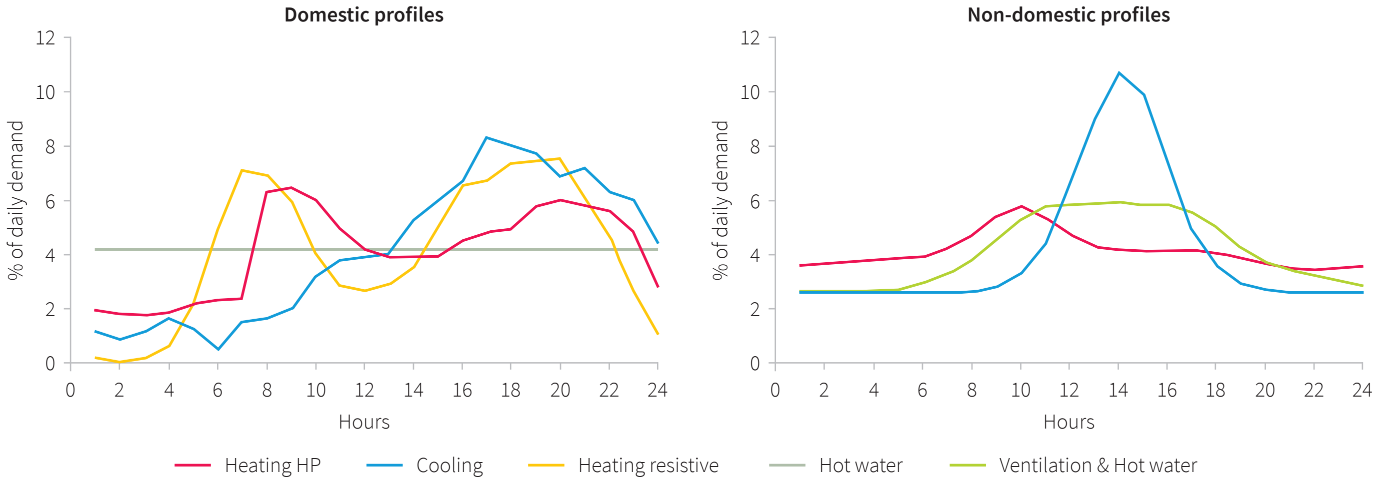
Section 2.1 presented the yearly electricity demands from space heating and hot water, space cooling and ventilation. We now consider how this demand varies over the year and how that variability impacts the flexibility potential of the sector. Note that space heating, cooling and hot water flexibility are assessed in this section.

3.1.1 Electricity demand over the day

The demand for space heating, space cooling and ventilation vary over the hours of the day. This diurnal variation impacts the passive power demand and the potential availability of the heating and cooling assets to provide DSR services. The daily demand profiles for each end-use are plotted in Figure 16 below. Very limited data is available on the hourly consumption of different heating systems. The profiles used here are primarily based on data collected for all electric heating systems during heat pump trial projects. The profile of demand is expected to be consistent to 2030. Further information on the demand profiles is provided in Appendix.

The domestic heating profiles have two characteristic peaks, in the morning and evening, while domestic cooling increases throughout the day as indoor temperatures rise and people return from work to a warm dwelling. Domestic hot water is supplied via a hot water tank which allows the electricity demand for hot water to be made flat over the day. Non-domestic heating, cooling and ventilation are concentrated within working hours.

Figure 16: *Profiles of domestic and non-domestic demand for space heating and hot water, space cooling and ventilation. The domestic space heating profiles show a characteristic double peak shape absent from non-domestic profiles – this raises the potential for two DSR events per day in domestic heating*



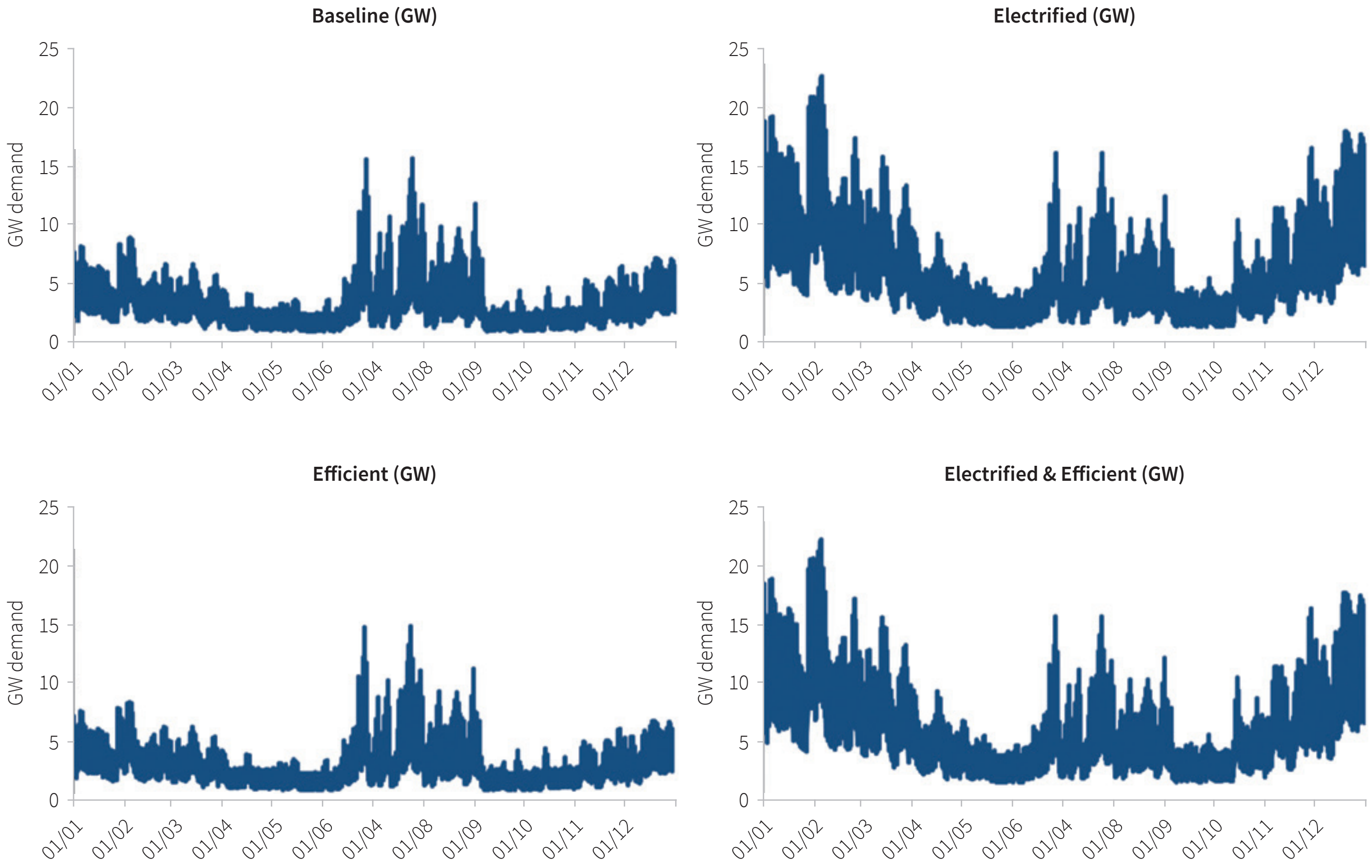
3.1.2 Electricity demand over the year

The daily demands for space heating and space cooling are calculated based on the weather in each climate zone over a representative year. This allows peaks in heating and cooling demand caused by high and low temperatures to be reflected in the model. We use the ENTSO-E 2018 TYNDP for calibrating of Turkey's 2030 energy demand, and that model was based on a 2007 weather year. We align our deep-dive heating and cooling estimates with the same weather year data. Heating and cooling degree days per day are used to apportion the annual demand to each day of the year (Gelaro, 2017). The demand for hot water and for ventilation are assumed to be constant over the days of the year.

The daily demands for space heating and cooling, hot water and ventilation are then divided over the day according to the profiles shown above. Figure 17 presents the electrical power demand in GW for these end uses in the four scenarios considered. The demand shown includes the full set of building archetypes covering different building types, ages and climate zones.

A strong summer peak is observed in all scenarios, while a large winter peak is also present in the Electrified scenario and the Electrified & Efficient scenario. The summer peak of about 15 GW is dominant in the Baseline and Efficient scenarios. The greater uptake of heat pumps in the Electrified scenario increases the winter peak to over 20 GW. The high demand in summer arises because the demand for cooling is concentrated in within a relatively low number of hot summer days in July and August, predominately in climate zones 1 and 2. The winter heating demand is spread over about four months, with peaks greater than the summer maximum occurring from November to February in the scenarios with greater uptake of heat pumps. Thus, both the timing and size of the yearly peak is dependent on the degree of electrification of heating.

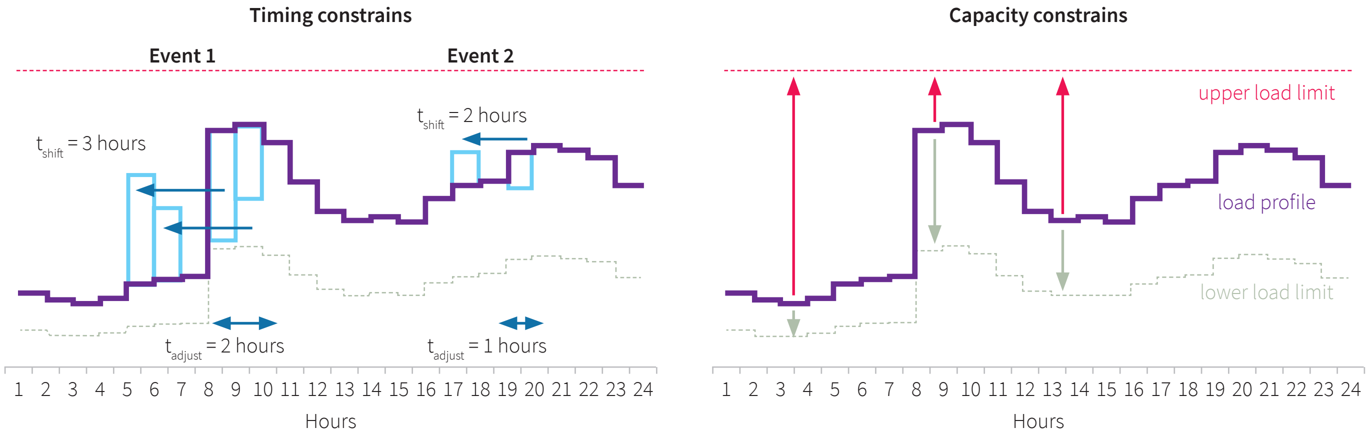
Figure 17: *The timing of the peak power demand from heating, cooling and ventilation in the buildings can be shifted from summer (cooling) to winter (heating) depending on the degree of electrification. Forecast for 2030 based on 2007 weather patterns*



3.1.3 Constraints on flexibility for space heating and cooling, hot water and ventilation

The passive profiles shown above in Figure 17 are altered when a building provides DSR services. The adjustment of the profiles must comply with several constraints which depend on the type of system supplying DSR (heating, cooling, etc). There are time-based constraints which are determined by how long a building can maintain comfortable indoor conditions when the heating and cooling systems are not in use. Demand within a time window of length t_{adjust} can be shifted earlier by the number of hours t_{shift}. No restriction is placed on how many DSR interventions may occur each day, but no DSR event may shift demand into another event's period of adjustment.

Figure 18: *DSR events are constrained in time and in magnitude according to the physical characteristics of the technology and building in which it is installed*



There are also capacity constraints which limit the amount that demand may be increased or decreased. The upper limit is set by the installed capacity of the system providing DSR. The lower load limit is a fraction of the current load and may be equal to zero. These limits are demonstrated using the discretised daily heat pump profile in Figure 18.

Heating, cooling and hot water DSR constraints

For space heating and cooling to provide DSR, a building must have sufficient thermal efficiency to maintain comfortable indoor conditions during DSR periods when the heating and cooling systems are not in use. We assume that building occupants will tolerate a temperature drop or rise of 1°C. This places a limit on the amount of time that the use of heating and cooling systems can be shifted, i.e. a limit on how much DSR can be provided. The time taken for the internal temperature of the building to drop or rise 1°C has been estimated for each archetype based on the thermal efficiency and standard assumptions for building materials and geometry.

Space heating and space cooling are modelled with this time constraint and are both limited to shifting energy demand earlier in time. For example, a building can be heated or cooled in advance of when the occupants require thermal comfort, but cannot delay operation of the systems and fail to provide thermal comfort when desired. We have set both time constraints t_adjust and t_shift to 4 hours based on the shape of the hot water, heating and cooling demand profiles (see Figure 16 and Figure 18). The peak demand in each profile occurs within 4-hour windows in the morning and evening, and a time constraint of this length allows those peaks to be reduced. Buildings which can shift their energy use by at least 4 hours are therefore considered suitable for provision of DSR.

The ability to provide DSR varies across the building archetypes presented previously. More efficient buildings are able to maintain comfortable conditions for periods of time greater than the threshold of 4 hours without operating their heating and cooling systems. Although a longer time constraint would allow greater flexibility, fewer buildings would meet the threshold for participation and the total flexible demand would be reduced. The maximum number of consecutive hours of demand that can be adjusted is set at 4, and each hour of demand can be shifted up to 4 hours earlier. It is recognised that electric hot water tanks could be operated even more flexibly, but we judged that the majority of the system benefit from hot water will be captured with this approximation. Around 2 million electric hot water tanks are present in Turkey in 2030 for the Electrified & Efficient scenario.

The power may not be increased above the installed capacity of the system and may be decreased to zero if desired during a DSR event (see Figure 18).

Ventilation DSR constraints
The constraints on flexibility from non-domestic ventilation are taken following (Gils, 2014). One hour of demand may be shifted 1 hour earlier or later than it previously occurred. The power may not be increased above the installed capacity of the ventilation system and may not be decreased below 70% of the initial power. As will be shown, these constraints make non-domestic ventilation considerably more expensive per MWh than the other sources of flexibility from the buildings. This is demonstrated by the lack of deployment projects on interruptible ventilation in the non-domestic sector.

3.2 Results: Flexible demand from space heating and cooling, hot water and ventilation

3.2.1 Proportion of systems that are flexible

The maximum number of consecutive hours of demand that can be adjusted is set at 4, and each hour of demand can be shifted up to 4 hours earlier.

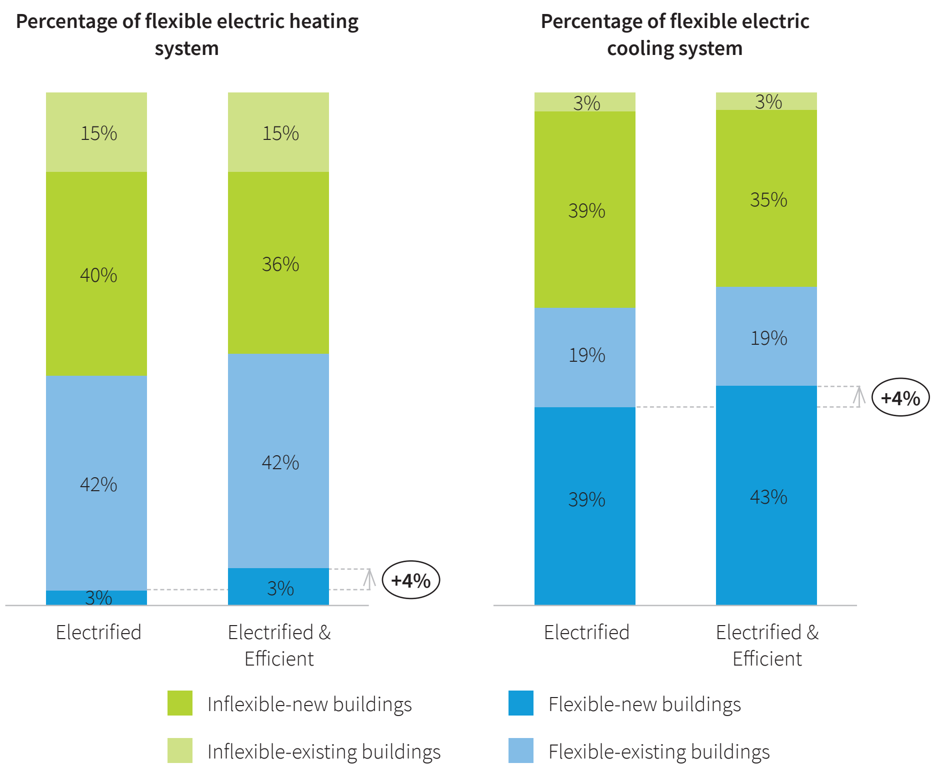
Figure 8 above presented the total electricity demand for space heating and hot water, space cooling and ventilation. However, only a subset of this demand is sufficiently flexible to be suitable to participate in DSR.

The proportion of electric heating and cooling systems in Turkey in 2030 that can be operated flexibly to provide DSR services are shown in Figure 19 for the Electrified scenario and the Electrified & Efficient scenario. In the Electrified scenario, only 3% of the electric heating systems installed in existing buildings are of value to DSR. This increases to 7% in the Electrified & Efficient scenario due to the increased renovation rate and this would increase further by 2050 if the higher renovation rate were maintained. Although the renovation rate has increased by a factor of 4, some renovated buildings remain unsuitable for space heating DSR as they are still unable to shift heat demand by 4 hours due to their location in the colder climate zones.

The lower difference between internal and external temperatures when cooling rather than heating means that buildings will take a longer time to increase temperature by 1°C. Therefore a significant proportion of the existing stock qualifies as flexible (i.e. is able to shift the demand for cooling by at least 4 hours) with or without energy efficiency renovation. Hot water storage cylinders are assumed to be present in all buildings with flexible electric heating systems, allowing hot water to be provided flexibly in addition to space heating.

We assume that 70% of mechanical ventilation systems in non-domestic buildings can be operated flexibly, subject to the constraints described in the previous section.

Figure 19: *Efficiency renovations allow a greater fraction of the electric systems in Turkey's existing stock to partake in DSR. There are about 2 million electric heating systems and about 4 million electric cooling systems in Turkey, both scenarios shown*

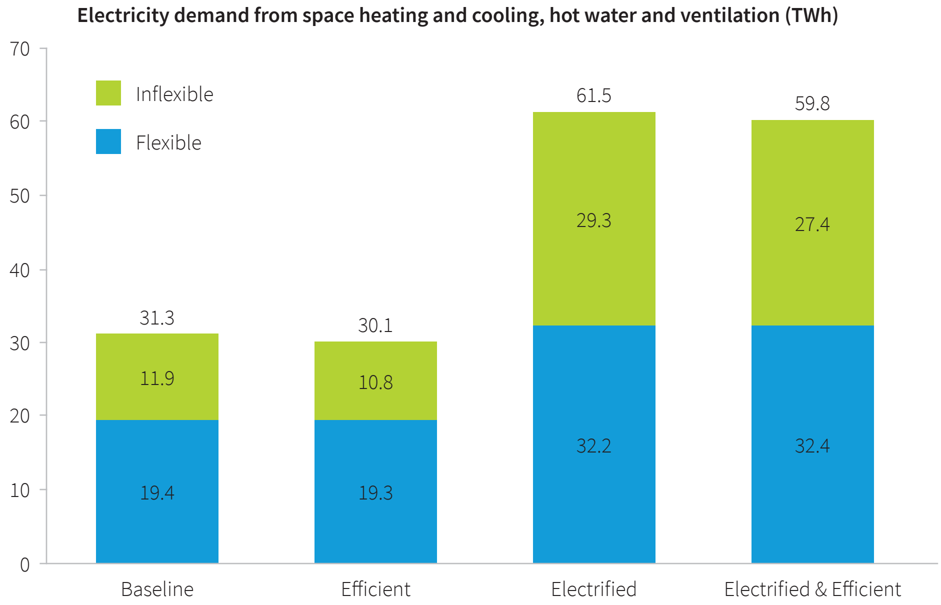


3.2.2 Proportion of electricity demand that is flexible

Figure 20 presents the proportion of the electricity demand for space heating and hot water, space cooling and ventilation that can be operated flexibly in each of the four scenarios. The amount of flexible demand increases with electrification although the flexible proportion is reduced as a fraction of the total. This is due to the uptake of heat pumps in existing buildings which are not thermally efficient enough to offer flexible heat pump operation.

Approximately 19 TWh of the electricity demand from the end uses in buildings considered here is flexible per year in the Baseline and Efficient scenarios, rising to approximately 32 TWh in the Electrified and Electrified & Efficient scenarios.

Figure 20: *Total flexible and inflexible electricity demand from the buildings in 2030, by scenario*



3.3 Industrial electricity demand

3.3.1 Load shifting versus load shedding

Industrial sites already provide DSR today to some extent. The DSR potential depends on the characteristics of the involved processes. It is necessary to distinguish between **load shifting** and **load shedding**.

In the case of load shifting, a reduction (increase) of load at one point of time is compensated by an increase (reduction) of load at a later point in time. In the case of load shedding, load is being reduced without a later compensation by load increase. As many industrial processes are run at high capacity and most hours of the year – several of them in more than 90% of the hours of the year (Umweltbundesamt, 2015), their ability to increase their load is limited and thus such processes can only provide DSR in form of load shedding. As load shedding can be provided by a larger number of sites, in particular sites with large controllable loads such as EAF steel production sites, in Germany there is sizable market for industrial load reductions (to a large extent via load shedding), but not a comparable market for load increases. A total of about 1GW of load interruption is currently procured from a pool of about 30 industrial sites in weekly auctions (Bundesnetzagentur, 2019).

It has to be noted that load shedding at industrial sites in most cases comes at high variable operational costs due to loss of product and significant disruption to processes with knock on effects (higher personnel and maintenance cost, lower product quality, sub optimal setting of processes at reduced electricity consumption). Therefore, it is only used very rarely and only in extreme situations, being remunerated at very high prices of up to €6,000/MWh (Bundesnetzagentur, 2019)[6].

[6] Total costs (availability and utilisation payments) of the interruptible loads scheme were €28m, while the total utilised load interruption was approximately 5 GWh.

In contrast to this, load shifting comes at lower variable operational cost, since it has no impact on the output produced by the site. It can thus be utilised more frequently. In future, electricity systems DSR will need to be utilised on a daily basis to manage VRES output. Therefore, load shifting will play a more important role than load shedding.

3.3.2 Capability of industrial sectors to provide load shedding or load shifting

In line with Umweltbundesamt (2015) and Gils (2014), we model steel and non-ferrous metal products as being able to provide only load shedding, while paper and cement can provide load shifting. This is also aligned with the assumptions on industrial DSR in the SHURA report on energy efficiency (SHURA, 2020 c).

This is because paper and cement production involve the production of intermediate or final products which can be easily stored for longer periods of time without loss of quality. This increases the flexibility potential. Such intermediate products are pulp, produced from wood or recycled paper in the case of paper; and grinded gravel as well as raw meal (milled gravel) and cement powder in the case of cement (Umweltbundesamt, 2015; DENA, 2013; Heidelberg Cement, 2020).

On the other hand, in the case of aluminium and electric steel production, the intermediate products after the most electricity intensive production steps are liquid aluminium and steel. Both cannot be stored for longer periods of time, as they harden when exposed to room temperatures (DENA, 2013; BMWi, 2020). Thus, they have to be processed further immediately. This limits the flexibility potential in both cases. Moreover, aluminium production sites are typically run at very high utilisation and therefore have limited capability for load increases. In the case of steel production via EAF, the rigidity of the casting process following the melting process in the EAF is a further limiting factor of flexibility (Umweltbundesamt, 2015).

More detail on the sources of flexibility in the energy intensive sectors with DSR potential can be found at the text box at the end of this section.

Sources of flexibility in energy intensive sectors

- Cement: Production involves several crushing, grinding and burning processes, which are electricity intensive and flexible due to storage capacities for interim and final products. This is already utilised to some extent today, e.g. in Germany, cement production facilities are sized to allow production only during the night at times of low electricity prices.
- Paper: The production process can be divided into the production of a fibre suspension (pulp) as an interim product, from recycling of waste paper or direct processing of wood, and the further processing of the pulp to the final paper product. Production of pulp from wood can be further distinguished into chemical pulping and mechanical pulping. The production of pulp comprises about 30-50% of the total electricity requirement of a paper production site. The electricity consumption per tonne of paper in the case of mechanical pulping is much higher than in the case of chemical pulping. However, in both cases the electricity consumption provides flexibility potential due to availability of pulp storage.
- Steel: Flexible electricity consumption in electric steel production is provided by EAFs which are used to melt steel scrap. The flexibility potential is limited due to knock-on effects, potential full shut down of the plant, typically high utilisation of production equipment and low storage capacities for interim products.
- Non-ferrous metals: In primary aluminium production, aluminium oxide is reduced to aluminium via electrolysis. Temperature and magnetic fields need to be kept as constant as possible in the electrolytic furnaces to avoid solidification or overflowing of the mixture of electrolyte and metal (Norddeutsche Energiewende, 2018; BMWi, 2020). This limits flexibility of the electricity consumption . Shedding can be provided if sites are not fully utilised due to its order situation or by buying aluminium instead from the market. Similar to aluminium, zinc and copper are produced using electrolysis. For the purpose of this modelling, the same flexibility potential as in the case of aluminium electrolysis is assumed in line with the SHURA energy efficiency report (SHURA, 2020 c).

3.3.3 Consumption profiles of flexible industrial demand

Steel, non-ferrous metal and paper sites are modelled as having a constant electricity consumption profile. This is based on Gils (2014) and in line with the SHURA report on energy efficiency (SHURA, 2020 c). Cement sites are assumed to operate at a significantly lower level in the winter months (Dec – Feb) due to reduced construction activity in these months based on Umweltbundesamt (2015) and Gils (2014). In the remaining months they are assumed to run at a flat consumption profile.

While currently cement sites shift electricity consumption to night times to benefit from lower electricity prices, we assume in the base case that they will run at a flat profile in the future. This is due to the following reason: high PV output is likely to supress electricity prices during the daytime in the future, while wind output is often higher during night times. Running at a flat profile will maximise the ability of the plant to benefit from low price periods due to high renewable output.

3.3.4 Available capacity for industrial DSR

Table 5 below, summarises estimated peak demand of the four investigated energy intensive sectors in 2030, based on their annual consumption and the profile assumptions described previously. These estimates are very closely aligned with the peak demands assumed in the SHURA energy efficiency report (SHURA, 2020 c). Electric steel production via EAF has by far the highest electricity consumption, followed by cement, while the consumption of paper and non-ferrous metals is significantly lower.

The table also lists the potential for load reductions and increases as estimated in Umweltbundesamt (2015) and Gils (2016), relative to the peak demand. The maximum load reductions and increases, given the peak demand of the respective sectors in 2030, are also listed. In 2030, a maximum of about 1,500 MW of load reduction can be provided via load shifting from paper and cement. Steel and non-ferrous metals can provide additional 1,550 MW via load shedding.

Table 5: *Maximum load reduction and increase of energy intensive sectors in Turkey in 2030*

	Load shifting		Load shedding		Total
	Paper	Cement	Non-ferrous metals	Steel	
Max load reduction (% of load)	20%	50%	19%	24%	-
Max load increase (% of load)	6%	18%	-	-	-
Peak demand 2030 (MW)	792	2,648	827	5,873	10,140
Max load reduction 2030 (MW)	162	1,324	157	1,391	3,033
Max load increase 2030 (MW)	47	477	-	-	523

3.3.4.1 Cost assumptions

The table below lists the cost assumptions of industrial DSR. In the case of paper and cement, costs are based on Umweltbundesamt (2015) and Steurer (2017). In the case of aluminium and steel, variable OPEX of €6,000/MWh are assumed based on the prices paid to large industrial sites for load interruption in Germany currently (Bundesnetzagentur, 2019). In all cases, the cost is dominated by variable OPEX. The variable cost includes higher power and heat requirements when running equipment at suboptimal set points, higher personnel costs of additional production compensating reduced production levels as well as the costs of lost product in the case of load shedding. Lost product usually leads to significantly higher costs than any other impact of DSR provision. The cost of DSR provision can be extremely high in cases where this requires a full shutdown of production units for several hours, which implies significant technical, organisational and personnel efforts (Umweltbundesamt, 2015). This implies that the costs per utilised MWh of DSR are not reducing with increased utilisation of DSR from these sectors.

Table 6: *Cost assumptions of industrial DSR*

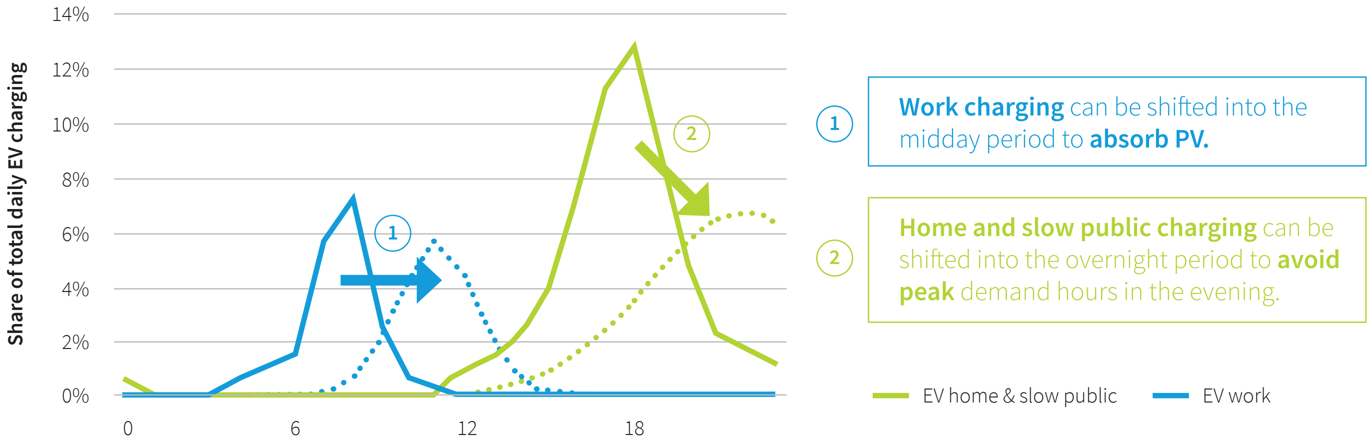
Demand type	CAPEX (€/MW)	Fixed annual OPEX (€/MW/y)	Fixed daily OPEX (€/MW/d)	Variable OPEX (€/MWh)
Paper	4,387	869	-	150
Cement	1,505	9,579	23	100
NF Metals				6,000
Steel				6,000

3.4 Flexibility from transport electrification

3.4.1 Principles of smart EV charging

As mentioned in section 2.4, the flexibility of EV charging comes from the fact that EVs are plugged in for a longer period than required for their daily charge. A typical adjustment of an EV charging profile through smart charging is illustrated in Figure 21 below.

Figure 21: *Passive vs smart charging of EVs at home & slow public chargers (where drivers plug in in the evening) and at work (drivers plug in in the morning), illustrative representation, source: Element Energy*



Charging of EVs in the morning at work can be shifted to the midday and early afternoon when PV output is high. EVs plugging-in in the evening will either charge at their own charger or slow public chargers close to their home if they do not have access to off-street parking. The charging of these EVs plugging-in in the evening can be shifted to the night period to avoid increasing peak demand of the electricity system which in many countries appears in the early evening hours, and to move charging demand into the cheap hours overnight. These benefits of smart charging were also identified in the SHURA report on transport electrification in Turkey (SHURA, 2019 a), which also includes detailed analysis on impacts of EV charging on Turkey's distribution grids.

Plug-in profiles and plug-in times set the boundaries of the flexibility of EV charging. They differ between different types of EV charging so we need to account for each. Assumptions on those are detailed in sections 3.4.3 and 3.4.4.

3.4.2 Breakdown of EV charging

The type of charging is important as it determines the flexibility potential. While charging at home and work is expected to be flexible, rapid public charging will not offer flexibility. In line with the Home Charging Support scenario in (SHURA, 2019 a), total EV electricity consumption is assumed to be broken down into 25% home charging, 25% work charging and 50% public charging. It is furthermore assumed that the public charging is broken down into 25% slow public charging and 25% rapid public charging. The share of home charging is low compared to other countries, as Turkey has a high urbanisation rate with a high share of the population living in multi-family homes without access to off-street parking (SHURA, 2019 a).

We consider rapid public charging to be fast and inflexible. Rapid public charging is included in the model as an energy demand, but it is not flexible, i.e. cannot be adjusted according to system need. Note that rapid/super chargers with buffer batteries could provide services, but these are treated as grid-level storage and outside the scope of EV flexibility.

Trials have shown that slow public charging at destination, e.g. at super markets or theaters, (plug in window length 1-2h) is negligible. Slow on-street public charging in residential areas is equivalent for our modelling purposes to home charging (mostly overnight). Home, work and slow public chargers are assumed to have 7 kW charging capacity, while rapid public chargers are assumed to have 150 kW charging capacity[7].

Rapid public charging is included in the model as an energy demand, but it is not flexible, i.e. cannot be adjusted according to system need.

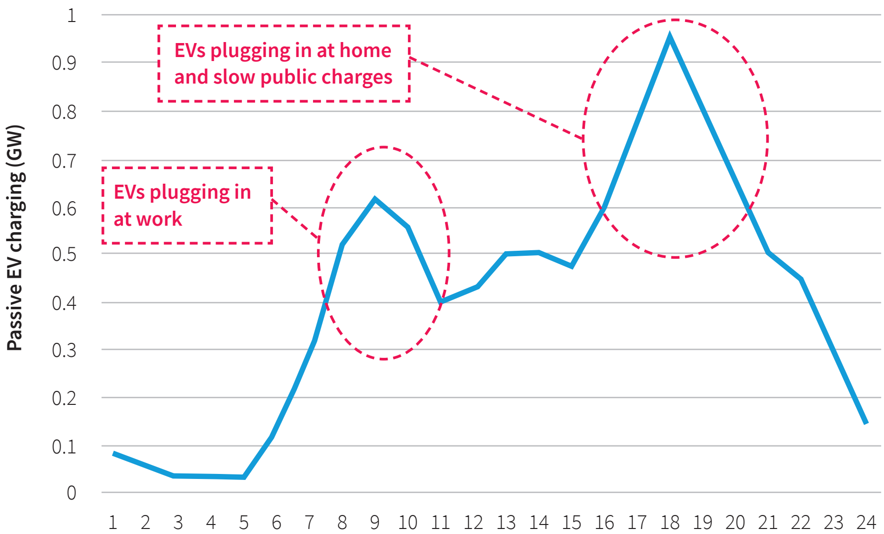
The breakdown of charging into home/work/slow and rapid public charging is the most important characteristic determining the potential and dynamics of EV DSR. It determines the energy flows into EVs which can be shifted to the midday period and the overnight period. Depending on the system characteristics (e.g. high solar penetration / low overnight demand), shifting demand to the midday or the overnight period can provide higher value.

3.4.3 Passive plug-in profiles and plug-in times

The starting point of the analysis are the unmanaged, or passive charging profiles that would be expected without smart charging. Plug-in profiles at home and work as well as at rapid public chargers are based on the recent evidence from an exhaustive literature review on EV usage profiles conducted for United Kingdom Power Networks (Element Energy, 2018).

While there is some seasonality to charging demand, daily electricity consumption of EVs is held constant throughout the year for the purpose of this modelling work. The passive EV charging profile, including inflexible rapid charging, based on the assumed plug-in profiles and charger capacities is shown Figure 22 below.

Figure 22: *Typical daily profile of passive (uncontrolled) EV charging, showing a morning and evening peak in demand*



[7] Note that whether individual EV charging is 7kW or 3kW, from a system perspective the difference in aggregate demand pattern seen over the day is in practice identical.

3.4.4 Smart EV charging flexibility

We assume home, work and slow public charging are flexible and their passive charging can thus be adapted to a smart profile according to system needs. Home, work and slow public charging represent 75% of total EV charging. The degree of flexibility of EV charging is determined to a large extent by the time for which EVs stay plugged in at EV chargers. The following assumptions, aligned with (Deporter & Assimon, 2011), have been made on plug in windows of EVs.

- EVs charging during the night, i.e. EVs charging at home and at slow public chargers, stay plugged in until 7:00 if plugged in between 18:00 and 00:00, otherwise for 8 hours.
- Work EVs stay plugged in until 17:00 if plugged in between 8:00 and 13:00, otherwise for 4 hours.
- The smart charging algorithm of the dispatch model ensures that all vehicles are fully charged at the end of their plug-in window.

3.5 Total electricity demand over the year

The construction of the hourly profile of total electricity demand is analogous to the construction of overall annual electricity demand as illustrated in Figure 16. We use our own dedicated models of heating and cooling in buildings, electric vehicles, and energy intensive industry to produce hourly profiles for these sectors with high DSR potential.

The hourly profile of the remaining demand (such as for lighting, appliances, cooking in residential and commercial premises) is obtained from the profile of total Turkish electricity demand in the ENTSO-E 2018 TYNDP by subtracting the profiles of the high DSR potential sectors as included in the ENTSO-E 2018 TYNDP.

By adding the hourly profile of remaining demand and the profiles of the sectors with high DSR potential as produced from our models, we derive the hourly profile of total electricity demand in Turkey.

Figure 23 below shows the total electricity demand in GW in each hour of the year in all four investigated scenarios. The overall peak demand appears in the summer months in all scenarios. However, in the electrification scenarios the winter peak demand gets very close to the summer peak demand (73.5 GW vs 73.7 GW in the electrification scenarios). Minimum demand is higher than 32 GW in all scenarios and thus the relative volatility of the profile is less pronounced than in the case of heating and cooling alone (cp. Figure 17, where e.g. in the Electrified scenario, the profile oscillates between 1.6 GW and 23.0 GW).

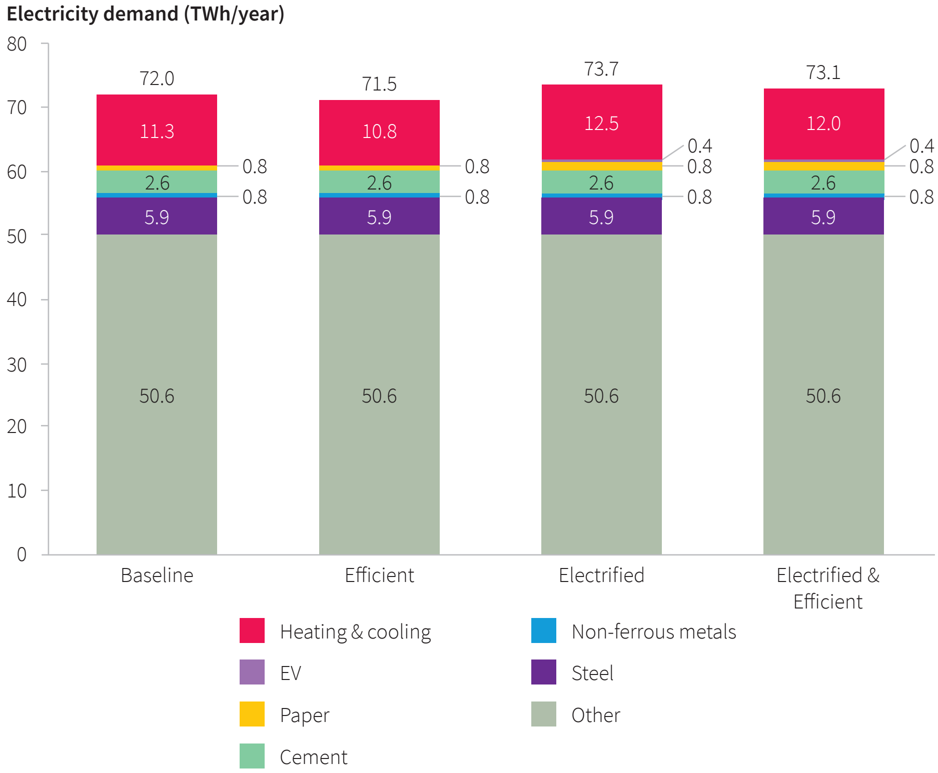
Figure 23: *Total electricity demand over the year in the four investigated scenarios. Electrification scenarios show significantly higher demand in the winter*

Figure 24 shows the breakdown of the peak electricity demand in the four investigated scenarios into demand for heating and cooling versus demand for other end uses. The peak demand appears in summer (July) near midday[8]. In all scenarios, heating and cooling contribute significantly to the peak demand. In fact, the contribution of heating and cooling to the peak demand is higher than their share of total electricity demand (cp. Figure 12).

Although the annual electricity consumption of heating and cooling in the electrification scenarios is roughly twice as high as the consumption in the non-electrification scenarios, the contribution to peak demand is only less than 20% higher. This is due to the fact that electricity consumption is increased mostly in the winter months in the electrification scenarios compared to the non-electrification scenarios (cp. Figure 17).

[8] In Turkey electricity consumption is significantly reduced during religious holidays (SHURA, 2018). The day of peak demand as calculated in the model falls outside any period of scheduled holidays to 2030.

Figure 24: *Breakdown of system peak demand, the peak appears in the summer during midday*



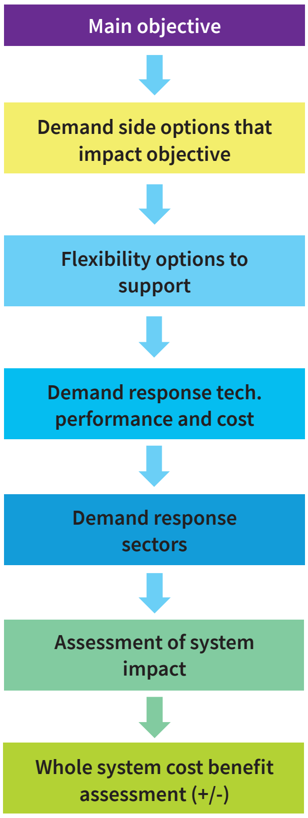
3.6 Technical potential of DSR sectors in Turkey

The table below shows the potential for each DSR sector to provide flexibility to the Electrified & Efficient 2030 scenario of the power system. For example, reducing the net peak load (the remaining demand after VRES supply is taken into account) is achieved by space heating and EV, but space cooling contributes nothing to this. The reason is that there is a large VRES supply in the heating season, and flexible heating can be used to absorb renewable input. We further see that this correlation between flexible heating demand and VRES supply means that flexible heating energy is utilised far more than flexible space cooling. Frequent DSR provision from the steel and non-ferrous metals sectors are prohibitively expensive (cp. section 3.3.4.1) in comparison to the other DSR options available and the system benefit achieved. Therefore, regular DSR provision by these sectors has not been simulated as for the other sectors.

Table 7: *Maximum technical potentials of each DSR sector when each used as only source of demand flexibility*

DSR sector	Reduction at net peak (GW)	TWh/year activated
Res. space heating	3	2.83
Res. space cooling	0	0.9
Comm. space heating	2.35	2.77
Comm. space cooling	0	0.25
Cement	0.99	0.97
Paper	0.38	0.16
EV	0.77	1.84

4. Sector-coupled energy system modelling and cost-benefit analysis



4.1 Method for establishing DSR contribution to VRES target

To establish how DSR is able to contribute to the VRES integration target at lowest system cost, it is first needed to evaluate the performance of the baseline energy system which operates without DSR.

As stated in section 1.5, the baseline is represented by the Inflexible 2030 scenario, which achieves the high VRES integration, and with supply side flexibility from thermal plant, hydro etc. Flexibility is provided by thermal generators operating at part load, highly responsive hydro power plants, and dispatch down of renewable generation where necessary, either by network capacity limits or to meet system security requirements.

DSR flexibility is then added to this scenario, and the resulting system performance and system cost savings can be evaluated. If the cost of the additional DSR deployment is lower than the system benefits, then the DSR deployment represents a net benefit to the system accommodating high levels of VRES integration.

As these characteristics of the system vary from hour to hour in response to the balance between supply and demand, in order to determine these system costs/savings we use a whole system power market model which operates at hourly resolution. We use Element Energy's Integrated Supply Demand Model (ISDM), and this is a fundamental model which is capable of reproducing all the relevant system dynamics to capture the main costs and benefits. Further details can be found in the Appendix.

4.2 How demand-side response can reduce system costs

The components of system flexibility costs, and how DSR can reduce these, is shown below. Note that each of these costs, whether CAPEX or OPEX, will need to be paid for by an energy customer. Savings on these cost items can be passed, at least in part, to customers who will see savings in their energy bills.

Table 8: *DSR contribution to system components*

Item	Description	DSR contribution
Generator fuel consumption (OPEX)	Electricity demand at peak times may require increased use of fuel in low efficiency peaking plants.	DSR can move demand out of peak times, reducing use of inefficient plant, and so reducing fuel consumption in thermal generators.
Thermal generator redispatch and part load operation (OPEX)	Thermal generators (often coal) may not be capable of responding to rapid changes in supply/demand imbalance, requiring the scheduling of more flexible generators (often gas) which results in higher electricity costs.	DSR can reduce the ramp rate of demand or net demand (GW/hr). In doing so, DSR can reduce thermal generator redispatch energy OPEX cost.
VRES curtailment (OPEX)	To balance energy supply/demand and to keep within security limits, VRES output may need to be curtailed.	DSR can move demand into times of high VRES supply to reduce curtailment levels.
Reduced peak system demand (CAPEX)	With increased electrification of demands, network capacity may need to increase to accommodate increase in peak demands.	DSR can move load out of peak times and to limit or avoid investments in additional network capacity.
Reduced peak system net demand (CAPEX)	A deficit between the supply of renewable energy, and energy demand, needs to be made up with dispatchable (thermal) plant. The peak net deficit may require additional peaking plant capacity (as might be procured via a capacity market).	DSR can move demand out of peak net demand hours, thus reducing the net deficit, which reduces or avoids additional investments in thermal generator (peaker plant) capacity.

4.3 Baseline (inflexible) system results

The performance of the baseline system is summarised in the table below. All figures are outputs from the power market model ISDM.

Table 9: *Performance of the baseline system*

Baseline system flexibility	Value	Unit
System peak demand	73	GW
Annual Energy demand	423	TWh/yr
Annual generator fuel costs	5,071	(€m/year)
Redispatch volume	8.54%	of annual demand
Redispatch fuel costs	328*	(€m/year)
VRES Curtailment	3	GWh/year

*Assumptions on the SRMC ranges of different generation technologies are in line with the ones in the Shura Tripling scenario of SHURA flexibility report (SHURA, 2019 b).

Generator redispatch volumes and fuel costs are aligned with the SHURA flexibility study (SHURA, 2018). ISDM can operate in two modes; where there are no hour-to-hour constraints on thermal generator output, and a second mode where these constraints are active. The difference in generator fuel costs between the two modes is the redispatch cost. See Appendix for more details. The cost of merit order redispatch is estimated at 328 €m per year, which could be reduced with DSR.

Note that the peak system demand in the Electrified & Efficient scenario is 73 GW. This is higher than the peak load assumed in the above SHURA study and is due to the additional electrification of heating and cooling and transport, which raises peak demand by about 2 GW in the baseline inflexible case (where there is no DSR). The system cost of this additional capacity is very significant. For example, if new generation capacity were required to meet all of this additional electricity demand[9], the cost of this would amount to 140€m/year due to new, additional capacity requirements arising from electrification of heating and transport. DSR can work to move demands out of these peak times and reduce additional capacity requirements.

4.4 Visualising examples of DSR flexibility

DSR can work to move demands out of the peak times and reduce additional capacity requirements.

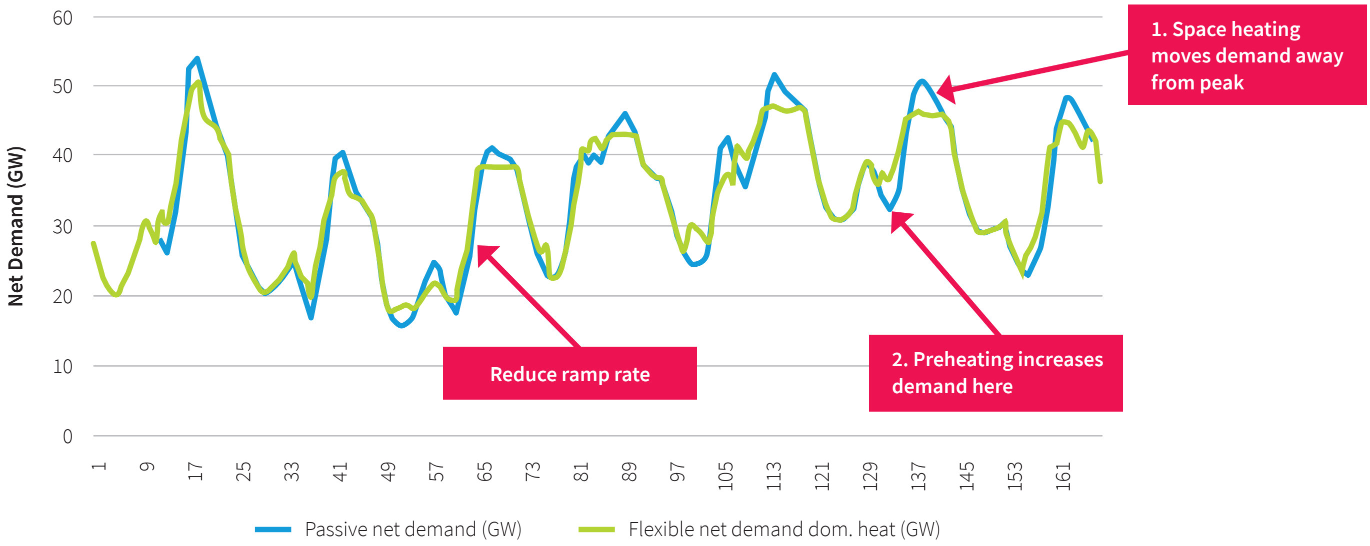
While tables of performance data are vital in summarising the achieved performance of DSR, to aid interpretation, it can be helpful to see a graphical example; a period of time when DSR is operating. This also shows how vital it is to use an hourly modelling approach to capture these aspects.

Figure 25 shows a week of space heating operating in flexible mode, showing how space heating (one of a number of DSR sectors) provides useful services to the power system. The figure shows three separate ways in which this asset is reducing system costs over this hypothetical two-week period:

1. Peak demands (or net demands) on the system are reduced by pre-heating spaces and moving heating demand out of peak times. As thermal generators are required to provide residual net demand capacity, a reduction of net demand reduces the dispatchable capacity that is required on the system. It can also reduce any investment required in network extension/reinforcement.
2. Pre-heating (utilising flexibility of heating by turning on the heating system earlier than scheduled) moves demand into system “troughs” where more baseload plant can provide electricity more efficiently than peaker or mid-merit plants. This results in savings in generator fuel.
3. Flexible demand also reduces the ramp rate of demand, i.e. the change in GW/hr. As mentioned above, dispatchable generators must provide flexibility to ramp up or down in response to changes in demand, and this will have a cost to the system.

[9] The Net Cost of New Entrant (Net-CONE) is the cost of new generation capacity that would need to be procured. In this study we use a figure of 70€/kW.year. Note that capacity markets can produce a lower figure (in the UK, ca. 20€/kW.year) because existing - rather than new - capacity can bid into these capacity mechanisms.

Figure 25: *Seven days of residential space heating in Turkey. The blue line represents the overall system net demand, with inflexible space heating. The orange line shows the system net demand with flexible space heating. By pre-heating, DSR automatically moves demand from peaks, and reduces ramp rates on the system*



4.5 Demand-side costs and deployment order

4.5.1 Levelised cost of response (LCOR)

Although DSR is typically regarded as a "free" source of flexibility as its investments are generally outside the boundaries of the power system, there could be costs associated to its deployment. While heating systems have the potential to provide flexibility, unlocking that flexibility will require investments. For example, to allow smart charging of an EV may require a smart charge point (more costly compared to a passive charger) and it will require control by a 3rd party (usually called an aggregator) to determine when to charge. Similarly, a grid responsive heating system will require some additional hardware in the home, connected to the internet and controlling the heating system. As with smart EV charging, grid-responsive heating will require an aggregator, which will charge for its services in controlling the device, billing etc.

In the above examples, the hardware represents a capital investment (CAPEX) and the aggregator service is an operational expenditure (OPEX). For the load shifting DSR assets that we assess in this report, the CAPEX component dominates (see Table 10). To pay for itself, a DSR asset has to be utilised at least to a level that the benefits exceed the cost of DSR activation. If it achieves high utilisation, it can spread its capital cost across many hours of use, and so can charge less for each hour of service. But if it is utilised only rarely, then to be economic, it must charge a high price per utilisation hour, to recoup its capital cost.

The resulting €/MWh is called the Levelised Cost of Response (LCOR) and is a way of capturing the costs of DSR assets. The LCOR is the minimum cost of providing one unit of flexible energy to the system. If the LCOR for a DSR device is lower than the cost of other flexibility assets, then it will be utilised first. But if the LCOR is too high, it may never be used at all.

4.5.2 Utilisation estimates to determine LCOR

To determine the LCOR, a realistic estimate of utilisation is required. This is where many DSR studies need to make large (and often unrealistic) assumptions. But in this report, our detailed power system model can help us identify what those utilisation rates could be, and therefore the LCOR.

The capital cost of each DSR asset can be spread over these annual utilisation rates, across the asset lifetime, and using economic discount rates, the effective cost to the system of each unit of flexible energy can be calculated.

By adding each DSR resource individually into the baseline ISDM model for Turkey, we are able to estimate the utilisation rate of each asset, and this is included in the table below. The table shows that between 20%-25% of the energy in space heating occurs at a time that could usefully be shifted by the power system. This is contrasted to EV charging, where nearly two-thirds of charging energy can be usefully shifted by the power system.

Between 20-25% of the energy in space heating occurs at a time that could usefully be shifted by the power system.

The LCOR also requires an estimate of capital costs. These costs are taken from prior Element Energy projects, discussions with EV manufacturers, and a number of aggregators. Figures for industrial processes are taken from the research by Gils (2014) as referenced elsewhere in this report. For DSR equipment in commercial and industrial applications, a lifetime of 20 years has been assumed. In residential applications, a 10 year lifetime is assumed. Furthermore, an interest rate of 10% is used to annualise the capital investments in the case of residential application, while a 6% rate is used in the case of commercial and industrial applications.

The combination of these relatively high utilisation rates, and the low CAPEX, results in the lowest LCOR for space heating and EV charging (up to 50 €/MWh). This is followed by cement and paper with a LCOR of 100-150 €/MWh. The cost of flexible response from the space cooling sector is about 350-450 €/MWh, because there is a smaller amount of annual energy utilised for cooling, compared to heating.

Table 10: *Total cost, utilisation and levelised cost of response (LCOR) for different demand sectors*

Sector	CAPEX (€m)	Aggregation cost (€m/y)	OPEX (€m/y)	Utilisation (GWh/y)	Utilisation (%)	LCOR (€/MWh)
Commercial heating	440	42	11	2,348	21%	39
Residential heating	449	58	13	2,829	26%	51
Work EV	97	19	0	615	68%	53
Home EV	194	39	0	1,231	68%	57
Cement	1	0	100	906	5%	110
Paper	1	0	58	385	6%	150
Commercial cooling	460	44	9	254	19%	368
Residential cooling	1,325	170	28	903	34%	458
White goods	172	206	0	300	5%	780
Commercial ventilation	1,160	110	23	74	1%	3,161
Non-ferrous metals	0	0	0	0	0%	6,000
Steel	0	0	0	0	0%	6,000

4.5.3 DSR deployment order and marginal value

The above table, ordered from lowest LCOR to highest, gives an indication of the economic proposition represented by each DSR sector. Assuming that future DSR assets will be in competition with other sources of flexibility, then the lowest cost assets will be dispatched first, followed by the more expensive assets.

The order of economic DSR deployment is important because the market for flexibility is a finite size with supply and demand dynamics. The introduction of DSR onto the system reduces problems associated with peak loads, redispatch etc., and that reduces the marginal demand for DSR. Note that this reducing marginal value also occurs with other flexibility sources, where excess capacity of interconnectors, or batteries etc. can depress prices.

DSR sectors which are relatively low cost to implement, and are effective in providing flexibility to the system, would be expected to be deployed first.

Those DSR sectors which are relatively low cost to implement, and are effective in providing flexibility to the system, would be expected to be deployed first. As a result, the remaining (marginal) flexibility needs of the system are lower, and this can adversely impact the utilisation and therefore economic viability of deploying subsequent DSR sectors.

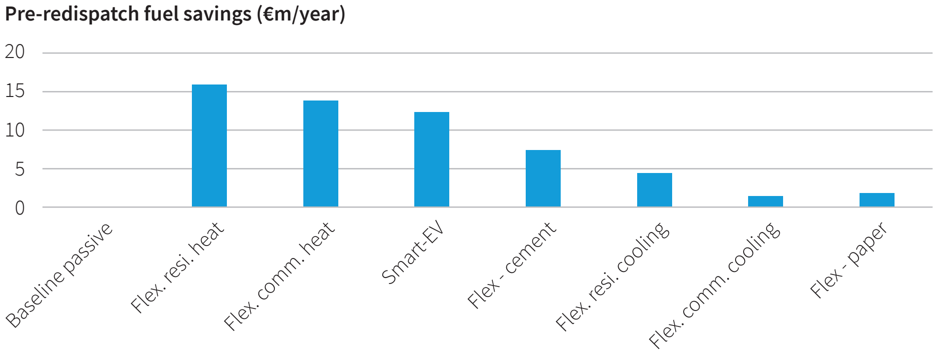
To represent this marginal value effect, each DSR sector is deployed individually, from cheapest to most expensive. The next DSR asset type is then added to the system model. We cycle through all DSR sources in turn, adding each to the power system model in sequence. The cost and system benefit of each DSR asset is calculated at each step, and in this way we capture the marginal value of deploying each DSR. Note that in terms of interaction between DSR sectors (which may have the effect of reducing utilisation of one DSR source), this looks to be relatively low. Most heating happens in the morning, while most charging happens in the evening. There is also very limited interaction between heating and cooling as rarely are required at the same time.

4.6 System performance with demand-side flexibility

Generator fuel savings

DSR can move load out of peak times, reducing use of low-efficiency thermal plant and therefore reducing generator fuel use. The contribution of each DSR sector to reducing generator fuel use by moving demand away from peak times is shown below. Flexible space heating could save €30 million/year in avoided fuel use, while smart EV charging could save over €10 million/year. Note that these are savings from each sector deployed alone, and that cumulative savings may be less than the sum of the parts. This interaction is not explicitly researched in the literature, but is incorporated into the whole-system approach that we use in this study (cumulative impact, see section 4.7).

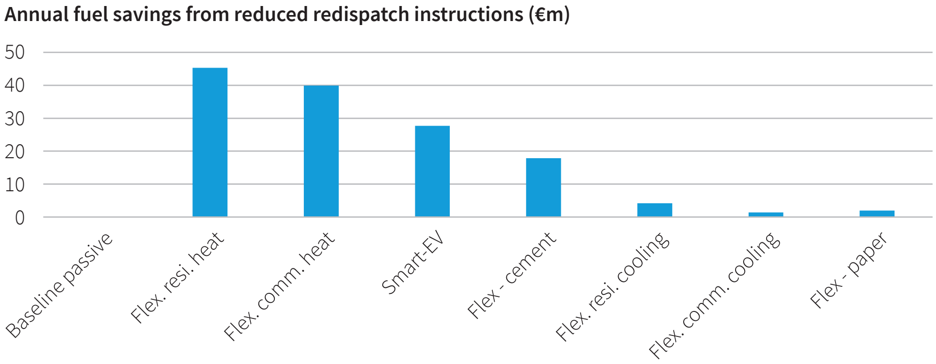
Figure 26: *Contribution of each DSR sector to reducing generator fuel use by moving demand away from peak times*



Redispatch savings

By reducing the ramp rate of demand, DSR is able to reduce redispatch costs. The capability of each DSR sector to reduce annual redispatch volumes is shown in the figure below. For example, the highest performing DSR sector is flexible space heating. This alone could save over €85 million/year in generator fuel savings.

Figure 27: *Annual fuel savings due to each DSR sector reducing thermal generator redispatch*



System capacity savings

DSR assets can provide flexibility to the power system, to reduce peaks in demand, and thereby reduce capacity requirements. There are two ways in which DSR can provide system savings, and while these often overlap, they are not identical.

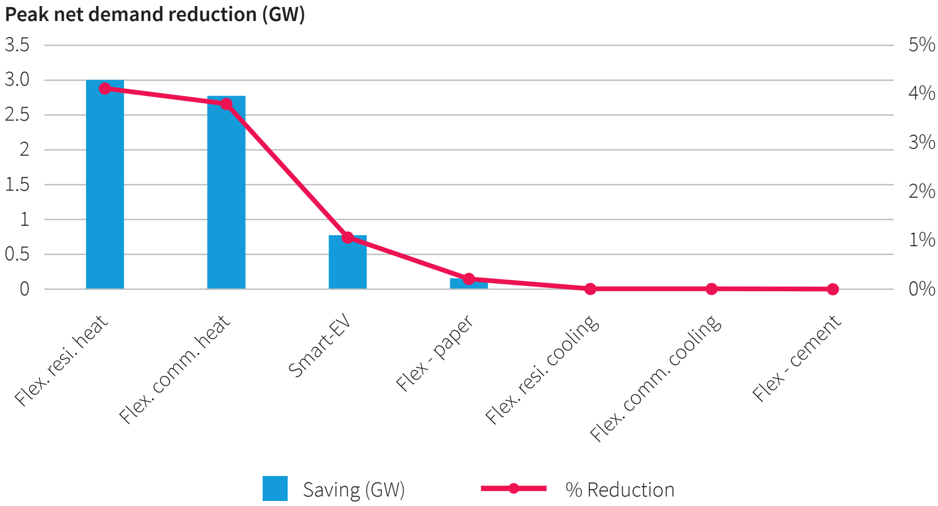
With a high amount of VRES on a power system, the residual demand (or net demand) must be supplied by a dispatchable power source. If a DSR asset can reduce the peak net demand, then that translates into a reduction in the peak dispatchable power that the system requires. Separately, if DSR can reduce the peak demand on the system, then it can contribute to reducing network investments through reduced capacity extension (network reinforcement).

DSR assets can provide flexibility to the power system, to reduce peaks in demand, and thereby reduce capacity requirements.

Reducing generation capacity (net demand reduction)

The graph below shows the potential contribution of each flexible demand sector to reduce net-peak capacity and thus reduce dispatchable generation requirements. It is notable that only space heating and smart EV charging make any form of significant contribution. This is because these demand sectors, when operating passively, add to peak demand, as well as having the capacity to move that demand away from peak times. This is especially the case with smart EV charging; despite a relatively small amount of annual energy in EV charging compared to space heating, the greater flexibility of smart EV charging means nearly all of the EV demand can be displaced away from peak times.

Figure 28: *Contribution of each DSR sector to reduction in peak net demand.*

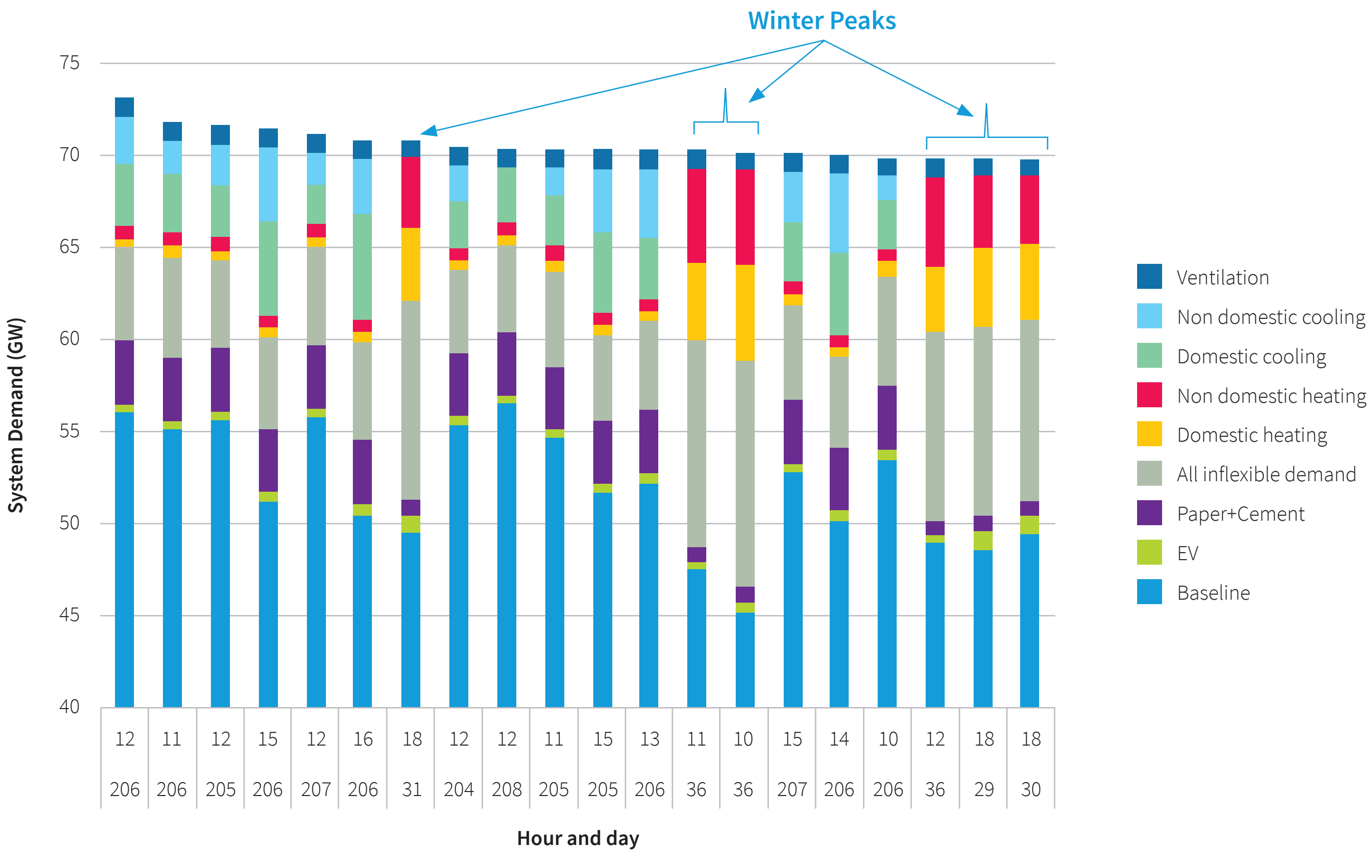


Reduction in peak system demand (reduced network reinforcement)

To determine how each DSR sector can contribute to reduce peak demand, below we show the top 20 demand hours of the year, and the contribution of each sector to that demand. Note that the order of assets is arbitrary, and for clarity the graph begins at 40 GW.

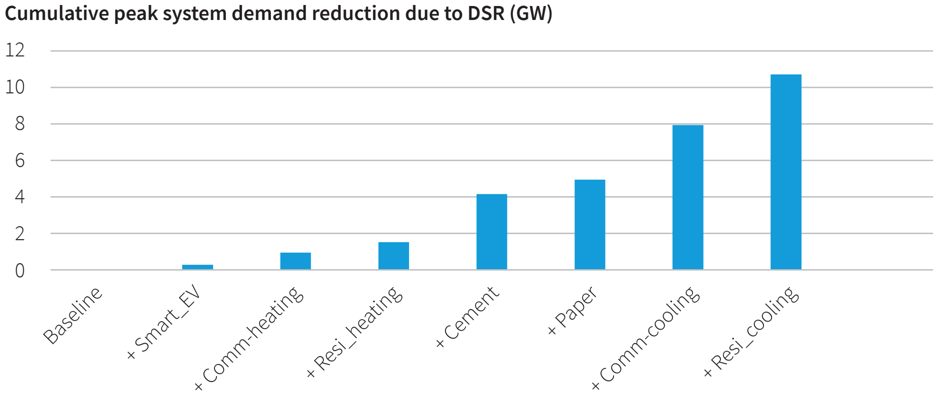
We can see that the peak day is in summer (73 GW, day 206) and that six of the peak hours are in summer-time. While flexible space cooling (light blue colours) could save over 10 GW during these peak times, peak system demand would remain high in winter (end January) driven by heating demands. To achieve the full benefit of flexible space cooling, it needs to be combined with flexible space heating, so that peak demands are driven down on all days. The same applies to other flexible sectors, such as EV charging: deploying one flexible sector on its own can achieve peak demand reductions, but to realise the full savings, it needs to be deployed alongside other technologies.

Figure 29: *Contribution of demand sectors to top 20 system demand hours*



The cumulative reduction in system peak demand is shown in the graph below. It is important to note that the reduction at each step is the result of all of the DSR technologies applied up to that point. For example, while flexible space heating on its own would seem to save about 2 GW, actually more of its flexible potential is released when flexible space cooling is deployed. As various demand sectors contribute to the peak, the greatest effect is achieved by a combination of technologies that work in concert to reduce peaks across many hours. The impressive performance when cooling is added, is not due to cooling alone, but to a combination of cooling, heating and smart EV charging.

Figure 30: *Cumulative peak system demand reduction due to DSR deployment. Note that the savings are cumulative: for example, the savings generated when cooling is deployed, are mainly due to the latent potential of cooling, heating and EV charging being realised*



4.7 Cumulative net system impact of DSR

The contribution of DSR to accommodating the high VRES at lowest system cost, is shown in figures 31 and 32 below.

The graph shows the cumulative whole system savings arising from cumulative DSR deployment (positive y-axis), which is offset by the cumulative costs of the DSR sectors being deployed (negative y-axis). As explained above, the system savings arise from a combination of electricity generation efficiency and reduction in VRES curtailment (operational savings) and savings due to avoided network and generator capacity. The cost of DSR is represented by the LCOR.

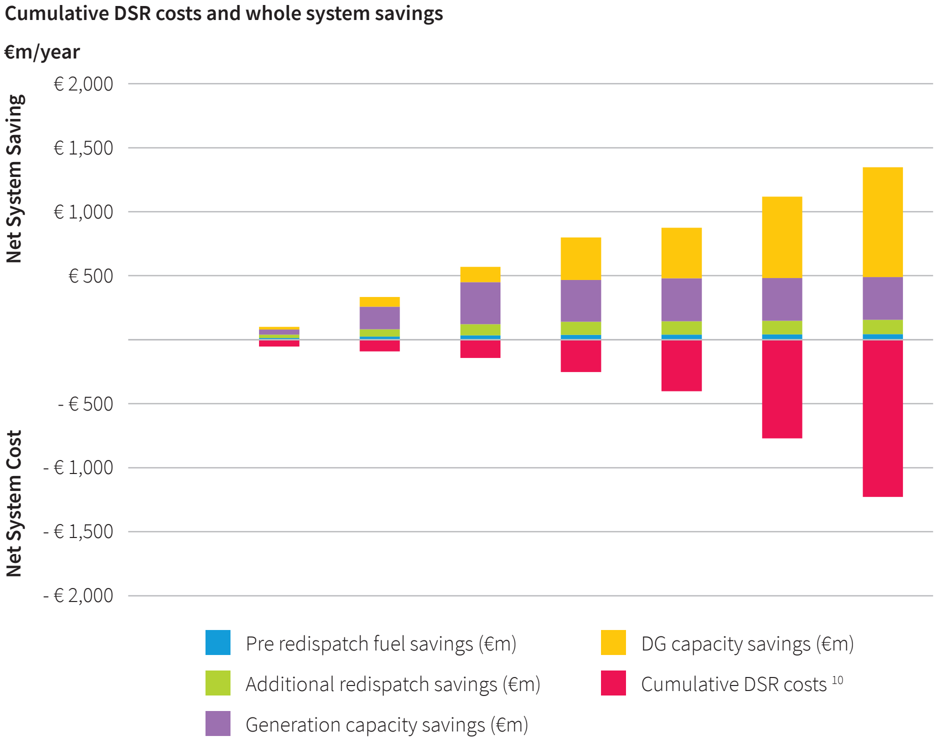
The graph shows that the system benefit increases significantly as flexible space heating + hot water and smart EV charging is deployed, and that the costs of activating these DSR sectors is lower than the system value, so there is a net economic benefit of deploying these sectors.

The capacity related benefits comprise the great majority of system value for DSR.

After heating, hot water and EV, cement and paper can deliver useful savings particularly in avoided network capacity. However, system savings in other areas are very low – this shows the reducing marginal value of cumulative DSR deployment. Beyond paper, the deployment of smart cooling does bring system benefits (avoided network capacity) but the cost is high. The system benefits for smart cooling do not outweigh the costs of smart cooling.

An important point to observe from the results graph is that most of the system value is derived from avoiding capacity investments, both across generation and distribution infrastructure. There are also savings from reduced fuel use and reduced generator redispatch costs, but they are small in comparison when compared to the potential capacity benefits. As can be seen in the graph, these capacity related benefits comprise the great majority of system value for DSR. If these system capacity benefits do not flow down to the DSR owner/operator, then the economic viability of any DSR investment is at best marginal and typically it would mean DSR deployment would be uneconomic for the asset owner/operator. It will be important to ensure there are mechanisms in place for such small (kW) scale DSR assets to be allowed fair and non-discriminatory access to capacity and congestion avoidance markets.

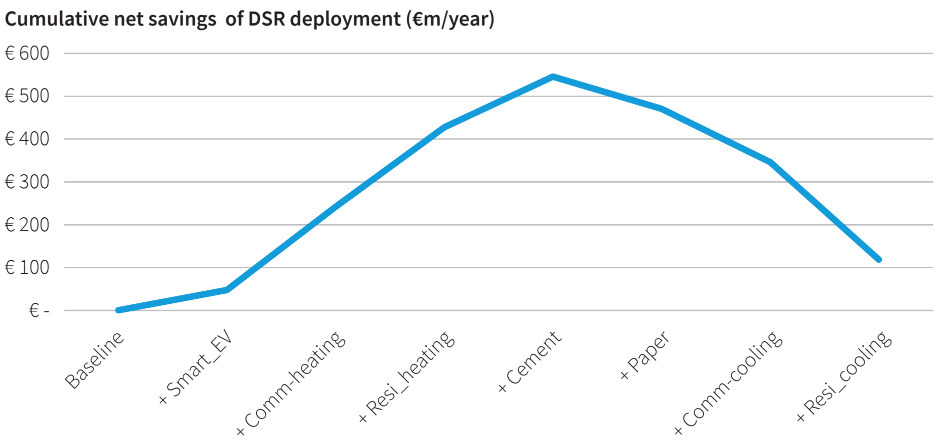
Figure 31: *Cumulative DSR costs and whole system savings. System savings are positive (above the x-axis) while costs are shown as negative (below the x-axis)*



The graph below shows the cumulative net cost/saving arising from DSR deployment. The maximum net system saving value could rise to €550 million/year due to smart EV, flexible space heating and flexible cement. Subsequent deployments still generate system savings, but their costs are greater and so the net benefit decreases.

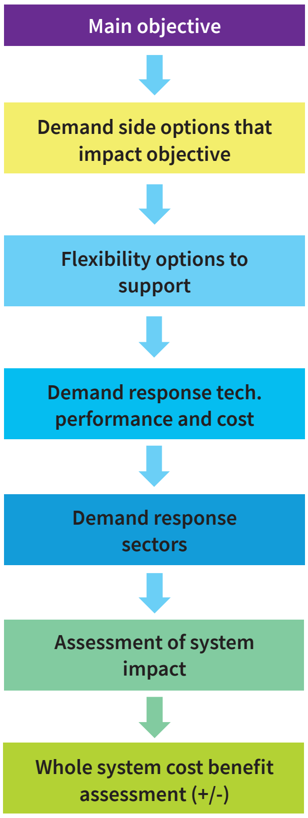
It should be noted that the cost estimates we have used are conservative. In particular, it may be possible to activate flexible cooling at low capital cost in houses or buildings which already have smart heating infrastructure. Such savings would reduce or eliminate the additional cost of smart cooling while delivering the system benefits.

Figure 32: *Cumulative system savings of up to €550 million are possible with smart EV charging and smart space heating*



[10] DG and generation capacity CAPEX is based on Element Energy's model which uses data from the average of the European situation.

5. Conclusions and recommendations for a DSR strategy for Turkey



5.1 Conclusions from the DSR evaluation

Technical capability of DSR in Turkey

The electrification of demand sectors such as space heating and transport will be an important component of a decarbonisation strategy in Turkey. However, the impact of unmanaged electrification could add significantly to peak demand of the system by 2030. This could require an expansion in peak generation and in capacity (distribution lines, transformers) of the distribution grid, and in low efficiency power production in peaking plants. This increase in demand at peak times would be expected to increase wholesale electricity prices at those times, as well as increase CO_2 intensity due to the use of lower efficiency peaking plants. This will increase suppliers' costs and have an impact on tariffs and electricity prices to customers.

DSR has the potential to make this electrification "smart", which can avoid investments in the power system (from generation to distribution), improve efficiency of electricity generation, and improve the capability of the system to accommodate high levels of VRES penetration. The combination of space heating, space cooling and smart EV charging could reduce peak demands in summer and winter by up to 10 GW by 2030 in Turkey according to the findings of this study.

The analysis explored in detail the potential of flexibility from space heating (1.9 million heat pumps) and domestic hot water, space cooling (ACs in 80% of buildings) and smart EV charging of 2.5 million cars. In addition, several flexible industrial processes have also been evaluated such as cement, paper and steel. It shows that space heating and smart EV charging have a relatively high technical potential in net peak reduction to support a more flexible power system of over 6 GW by 2030. This is due to a combination of large sector size (reflected in the peak GW capacity to move demand) as well as the annual level of utilisation (reflected in the annual amount of energy moved via DSR). In particular, smart EV charging can offer the system a high level of flexibility, allowing charging demand to respond to system needs, affirming SHURA's earlier study findings from December 2019 that the integration of 2.5 million EVs to Turkey's distribution grid is technically and economically feasible. Following the potential of space heating and EV charging, utilising the potential of flexibility in electricity-intensive production process of cement making can be utilised for over 900 GWh/year (equivalent to 1 GW). The technical potential of flexible space cooling is somewhat marginal: it does have a high potential to reduce peak demands (over 7 GW demand reduction) together with space heating, but the commercial utilisation offered to the system (energy per year) is low – close to 200 GWh/year for flexible cooling compared to over 2000 GWh/year for flexible heating.

Costs and benefits of deploying DSR in Turkey by 2030

To be economically viable, the cost of activating DSR must be offset by system savings that arise from the deployment of DSR. We find that for distribution-connected DSR like space heating, hot water, space cooling and smart charging, operational costs are small in comparison to capital costs. The capital investment of enabling DSR is affordable when spread across many hours of utilisation (equivalent to over 2000 GWh/year annually), and we find that space heating and hot water have the potential to deliver flexibility at a cost of 40-60 €/MWh. This means they are the cheapest sources of DSR to enable.

When deployed to provide flexibility to the system, DSR can reduce system costs through several mechanisms comprising operational efficiencies as well as investment avoidance (reduced capacity required for generation and distribution infrastructure). System modelling of DSR in Turkey in 2030 showed that DSR can economically:

- Move loads out of peak times, allowing more electricity to be generated by efficient baseload plants, leading to €10-15 million/year saving from each of residential space heating, commercial space heating, smart EV charging and responsive cement production.
- Reduce the redispatch of thermal plants, leading to €35-45 million/year saving from each of residential space heating, commercial space heating and smart EV charging.
- Avoid capacity investments (in generation and the distribution grid),
  - o Around €100 million/year saving from smart EV
  - o Around €300-400 million/year saving from residential space heating and commercial space heating.

In total, DSR can lead to efficiency savings amount to €122 million/year from space heating and smart EV charging combined, while capacity avoidance amounts to savings of approximately €500 million/year from space heating and smart EV charging combined. The savings in total are €622 million/year, which is not the net savings. The CAPEX of the DSR comes at a cost of €72 million/year, and the net system savings are €550 million/year. As all system costs are ultimately borne by the consumer (commodity costs via wholesale markets, and non-commodity costs such as network and generation capacity investments via tariffs), this represents a significant saving on bills to the consumer.

Over €550 million/year of net system benefit can arise from the deployment of smart charging, space heating and flexibility in the cement sector.

Implications for technical and economic viability of DSR in Turkey

Overall, over €550 million/year of net system benefit can arise from the deployment of smart charging, space heating and flexibility in the cement sector. Flexibility in other sectors comes at an excessive cost such that the marginal system benefits are less than the cost of exploiting DSR.

The main reason for the high performance of the flexible space heating and smart EV sectors is their ability to contribute to demand avoidance at peak and contribute to system savings from avoided generation capacity. When combined with flexibility from other sectors such as space cooling, additional system savings from avoided network investment are also significant.

Without monetising these system capacity benefits, the net benefit of DSR is close to zero (i.e. the efficiency savings arising from DSR deployment are offset by the costs of DSR activation). To underpin the economic viability of DSR it is vital to monetise the system value of capacity avoidance. Mechanisms to account for capacity avoidance include capacity markets and virtual power plants in the UK, and PJM (a regional transmission organisation) in the USA. Operational efficiency savings such as redispatch are easier to monetise as these could be recovered through wholesale markets, with energy supplier passing these savings on to the DSR provider (either the end user, or an aggregator), via dynamic TOU tariffs.

5.2 Prerequisites for deploying DSR

The analysis presented in this study shows that DSR could add significant technical value to a power system requiring flexibility and that a proportion of such flexibility could be provided economically, with the costs of enabling key DSR assets far less than the system value they generate.

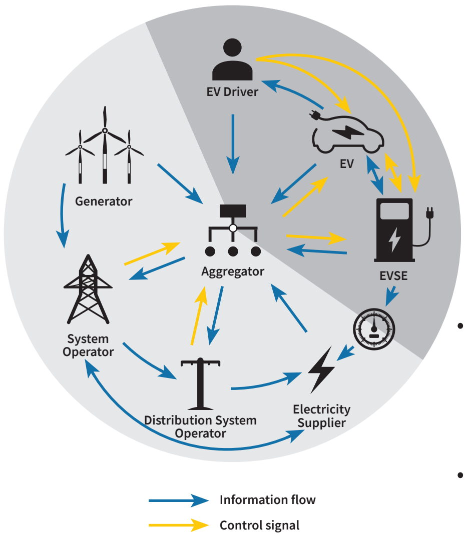
Despite these assets, the participation of large scale DSR to provide flexibility to a future decarbonised power grid in Turkey is not fully assured, and there are several prerequisites that need to be in place to support the development of this nascent sector. These are set out below.

5.2.1 Prerequisites (technical, system, VRES support focussed)

Activating DSR to provide a benefit to the system, is a novel approach to managing the power system, particularly if such demands are small (kW scale) and connected to the system at the lowest voltage level. Various distinct components are required to make this work:

A reliable and rapid communication system is required to send dispatch or control instructions from one stakeholder in the energy system down to the flexible asset.

- A reliable and rapid communication system: This is required to send dispatch or control instructions from one stakeholder in the energy system (either the TSO, DSO, supplier, or an intermediary aggregator) down to the flexible asset, and also to send data such as power or energy metering, back up to verify the action was taken as instructed and to support billing. The frequency of data transfer should respond to the technical requirements of the system service being provided. This report has focussed on energy and peak power/congestion services, which may require 15-, 30-, or 60-minute reporting intervals. The provision of ancillary services, and ultimately frequency response, sets the highest requirement for measurement and data transfer, and many TSOs are evaluating the technical basis for how such services could be provided in practice (Smarter Networks, 2019).
- Smart metering infrastructure with hourly/half hourly resolution to reward reprofiling of demand: Energy/power metering is required to verify that the DSR asset "flexed" in response to the instruction sent. As mentioned above, for energy markets and capacity related services, hourly or half hourly resolution is typically sufficient, while the provision of ancillary services will require higher specification of meter.
- Public buildings in Turkey: They could be required to include smart meters and the electricity consumption lower limit to be decreased for the duty of smart meter deployment, which would have the benefit of identifying opportunities for decreasing electricity consumption (SHURA, 2020 d). Defining standards for privacy and data analytics is also important to establish a secure infrastructure.
- Solution to the issue of baselining: As DSR needs to reward an asset for a change in demand following an instruction, it is important to establish a baseline demand profile which reflects the consumption expected without intervention. This is emerging as a challenging problem, in part because large datasets on demand assets are not yet available.
- A form of efficient aggregator service to dispatch/control: An agent is required to determine what action is desired of each DSR asset, and to send and receive data with each asset.



As the move to smaller (kW) scale assets means a huge increase in the number of assets under control, then a key function is the ability to schedule the position of all assets in the portfolio, and to communicate with them effectively. This requirement is novel, and so the role of the aggregator has emerged as being an important and novel enabler in the system. Successful aggregators understand the requirements of service provision of the assets, understand energy markets, have predictive capabilities on market prices, asset use, temperatures etc., and have contractual access to the markets for which they provide services.

- Definition of consumers and aggregators in the regulations as market stakeholders: Particular licensing of the stakeholders to participate in the market is required. Eligibility criteria for DSR mechanisms to participate in balancing reserves and in capacity mechanisms through aggregators should also be defined.
- A financial reward mechanism: The customer or DSR asset owner needs to be incentivised to provide flexibility to the system. A form of electricity tariff can link the use of the asset to the system benefit, for example:
  - A simple static TOU tariff can be timed to avoid demand peaks and increase demand during supply peaks. To be effective, these peaks need to occur regularly.
  - A dynamic TOU tariff can reward consumption based on instantaneous net demand, which is more fit for purpose in highly decarbonised grids with higher proportion of VRES supply.
  - Grid responsive tariffs can have high load factors on grids such as the case with some transmission network tariffs, as well as avoid congestion, being explored by some distribution companies such as United Kingdom Power Networks.

The customer or DSR asset owner needs to be incentivised to provide flexibility to the system.

Note that this study identified DSR capacity benefits as being most valuable. DSR customers would need to access to this revenue stream. Because capacity is usually contracted and paid for but not always utilised, the tariff, or payment to the customer would need to reflect this, such as with an annual payment per asset.

In this study, the system generation capacity benefits are derived from representative CONE (cost of new entrant) values. If there is an oversupply of existing generation, then that could be exploited at lower cost and put downward pressure on capacity values available for DSR suppliers.

5.2.2 Challenges (DSR sector/customer focussed)

DSR at kW scale is a nascent sector but is emerging as a key enabler of high penetration of VRES into power networks. There are a number of challenges which need to be overcome in order to encourage or require DSR to become more widespread:

- Regulation to prohibit passive demand: Increasingly the value of smart charging and the system penalty of passive EV charging is becoming more understood. In some jurisdictions, the sale of passive (unmanaged) charging assets is discouraged. While such steps do not guarantee that smart charging infrastructure will be utilised “smartly”, they indicate there is greater acceptance of the need for smart charging to be adopted by legislation, and avoid a problematic capacity of unmanaged passive electrification. Such regulation can also provide the framework for DSR rules, potentially providing a solution to challenges such as baselining. Turkey is working on this issue with revisions in directives related to the efficient use of energy and this is mentioned in the 11th Development Plan (Eleventh Development Plan, 2019).

- Incentivising consumers to install equipment: The provision of services to the power system is hitherto not the primary reason for electrification of demand. There are real concerns amongst customers that flexible operation should not prejudice the provision of the energy service (such as keeping a home at the required temperature or making sure an EV is charged and ready). The greater deployment of smart home technologies such as thermostats (with customers paying for these), indicates that more customers are willing to give up control over such key functions to 3rd parties. Increased familiarity with such technologies as they reach greater deployment, will support a networking effect of accelerating deployment (Smart Energy, 2020).
- Clarity on revenues from DSR: Deploying DSR purely on economics is challenging because the utilisation rate of the assets is fundamentally unclear. Yet the utilisation is important in determining the price of DSR that can be offered to the system. To overcome this barrier, large scale trials will be required, where customers are protected against the downsides of low utilisation, with some form of price floor to guarantee the investment can be recouped. By adding such costs to suppliers, they can be encouraged to make maximum use of the assets. Innovative electricity suppliers also see the value in offering such up front guarantees to customers, as a way of encouraging smart demand, branding and recruiting new customers.

The greater deployment of smart home technologies such as thermostats indicates that more customers are willing to give up control over such key functions to third parties.

5.3 Deploying DSR to support wind and solar energy integration

The results of this study show a significant potential for DSR for Turkey to enable integration of higher shares of VRES such as wind and solar energy. The role of the DSR is already set out in the National Energy Efficiency Action Plan – Action E10 - Build a Market Infrastructure for Demand-Side Response, thereby highlighting the multiple role DSR can contribute to transformation of Turkey's energy system.

A synergistic national strategy of wind and solar energy integration enabled with DSR deployment will be crucial: Accommodating greater levels of VRES, will require a more flexible, agile transmission and distribution grid if uneconomic levels of energy curtailment is to be avoided. DSR can contribute to that flexibility in an economic manner and can support wind and solar energy integration. Additionally, to avoid erosion of marginal value as greater levels of DSR are deployed, it is important to continue to increase VRES deployment, so that the system demand for flexibility is maintained. What is required is a synergistic strategy of VRES and DSR deployment for Turkey that builds on Turkey's 11th Development Plan (2019-2023), which mentions the establishment of a market infrastructure to ensure demand-side participation in the power system.

Colocation of wind and solar energy integration with DSR demand should be encouraged: The capability of DSR to match and support wind and solar energy deployment, is limited by the capacity of the network between the two. Colocation of wind and solar energy supply and flexible demand should be encouraged where possible, to avoid such constraints. Examples of colocation should include:

- Offsetting summertime cooling demand with rooftop solar PV systems where at least a total potential of 15 GW exists (SHURA, 2020 a).
- Offsetting peak PV generation with daytime (workplace) EV charging of 2.5 million EVs by 2030 (SHURA, 2019 a).

Develop smart power purchase agreements: PV developers can increase the value of their energy by matching time of generation with time of consumption. Power purchase agreements deals with flexible customers enhancing the correlation of supply and demand. Developing local markets for energy (PV specific) is important.

Dynamic TOU tariffs: As daily volatility will increase due to wind and solar energy penetration, and the net demand becomes more variable, there needs to be increased access to dynamic TOU tariffs, linking consumption to wind and solar energy supply.

A regulatory framework for DSR and aggregation in Turkey is necessary, which is currently worked on: In the short-term, DSR should be allowed to participate in the ancillary services market, to resolve congestions, followed by the intra-day and day-ahead markets. On the other hand, dynamic pricing should be implemented as the market gets fully liberalised. The first step might be to establish both static and dynamic TOU tariffs together in Turkey. In addition to industrial loads, commercial and residential loads might be a good developing point to implement DSR in Turkey. This later can be extended to lower level of loads.

References

AA, 2019. Available at: https://www.aa.com.tr/en/economy/turkey-expects-1-million-electric-cars-on-roads-by-2030/1704467

Aydin, E., 2018. An Assessment of Residential Energy Efficiency in Turkey. IICEC Energy And Climate Research Paper.

BEIS, 2017. Realising the Potential of DSR to 2025. [Online]

Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/657140/DSR_ressearch_Executive_Summary.pdf

BMWi, 2020. Industrie als Partner der Energiewende. [Online]

Available at: https://www.bmwi-energiewende.de/EWD/Redaktion/Newsletter/2020/02/Meldung/News1.html

Bundesnetzagentur, 2019. Monitoring Report 2019. [Online]

Available at: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/Monitoring/Monitoringberichte/Monitoring_Berichte_node.html

DENA, 2013. Handbuch Lastmanagement. [Online]

Available at: https://www.dena.de/fileadmin/dena/Dokumente/Pdf/1408_Lastmanagement_Handbuch.pdf

Deporter, S. & Assimon, P. M., 2011. Les Véhicules Electriques en Perspective. [Online]

Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/43/001/43001305.pdf

Ecofys, 2016. U-value Maps Turkey, s.l.: s.n.

Element Energy, 2018. Charger Use Study - Recharge The Future. [Online]

Available at: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/02/20180921_UKPN-Recharge-the-Future_Charger-Use-Study_FINAL.pdf

Eleventh Development Plan, 2019. Presidency of Strategy and Budget. [Online]

Available at: https://sbb.gov.tr/wp-content/uploads/2020/06/Eleventh_Development_Plan-2019-2023.pdf

Energy Affairs General Directorate, 2019. Balance Chart 2018. [Online]

Available at: https://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari

ENTRANZE Project, 2013. Data Mapping Tool. [Online]

Available at: https://entranze.enerdata.net/

ENTSO-E, 2019. 2018 TYNDP Data and Expertise as Key Ingredients. [Online]

Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/tyndp-documents/TYNDP2018/consultation/Technical/DataExpertise.pdf

Gelaro, R, 2017. The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). Journal of Climate.

Gils, H. C., 2014. Assessment of the Theoretical DSR Potential in Europe. Energy.

Gils, H. C., 2016. Economic Potential for Future DSR in Germany – Modeling. Applied Energy, pp. 401-415.

GIZ and Turkish Ministry of Environment and Urbanisation, 2018. Energy Efficiency Technology Atlas: Executive summary, s.l.: s.n.

Heidelberg Cement, 2020. Herstellung von Zement. [Online]

Available at: https://www.heidelbergcement.com/de/herstellung-von-zement

IRENA, 2018. Power System Flexibility. [Online]

Available at: https://www.irena.org//media/Files/IRENA/Agency/Publication/2018/Nov/IRENA_Power_system_flexibility_1_2018.pdf

IRENA, 2019. Demand-side Flexibility for Power Sector Transformation. [Online]

Available at: https://www.irena.org/publications/2019/Dec/Demand-side-flexibility-for-power-sector-transformation

Ministry of Energy and Natural Resources, 2008. National Standard for Thermal Insulation Requirements for Buildings, s.l.: s.n.

Münster et al, 2020. Sector Coupling State of the Art and Perspectives. [Online]

Available at: https://www.researchgate.net/publication/339365854_Sector_Coupling_Concepts_State-of-the-art_and_Perspectives

NEEAP, 2017. National Energy Efficiency Action Plan 2017-2023. [Online]

Available at: https://policy.asiapacificenergy.org/sites/default/files/National%20Energy%20Efficiency%20Action%20Plan%20

%28NEEAP%29%202017-2023%20%28EN%29.pdf

New Climate Institute and Climate Analytics, 2019. Scaling up Climate Action: Turkey, s.l.: s.n.

Norddeutsche Energiewende, 2018. Trimet investiert in Flexibilisierung. [Online]

Available at: https://new4-0.erneuerbare-energien-hamburg.de/de/new-40-blog/details/trimet-investiert-in-flexibilisierung.html

Nursimulu, A., 2016. Demand-Side Flexibility for Energy Transitions: Policy Recommendations for Developing. [Online]

Available at: https://irgc.org/wp-content/uploads/2018/09/Demand-side-Flexibility-for-Energy-Transitions-Policy-Brief-2016.pdf

SHURA and BPIE, 2019. Enhancing Turkey's Policy Framework for Energy Efficiency of Buildings, and Recommendations for the Way Forward Based on International Experiences, s.l.: s.n.

SHURA, 2018. Increasing the Share of Renewables in Turkey's Power System: Options for Transmission Expansion and Flexibility. [Online]

Available at: https://www.agora-energiewende.de/fileadmin2/Partnerpublikationen/2018/SHURA_Partnerpublikationen/SHURA_Increasing-the-Share-of-Renewables-in-Turkeys-Power-System_Report.pdf

SHURA, 2019 a. Transport Sector Transformation: Integrating Electric Vehicles into Turkey's Distribution Grids, s.l.: s.n.

Available at: https://www.shura.org.tr/wp-content/uploads/2019/12/Transport-sector-transformation.Integrating-electric-vehicles-into-Turkey%E2%80%99s-distribution-grids.pdf

SHURA, 2019 b. Costs and Benefits of Options to Increase System Flexibility. [Online]

Available at: https://www.agora-energiewende.de/fileadmin2/Partnerpublikationen/2019/SHURA_Partnerpublikationen/SHURA_Costs-and-benefits-of-options-to-increase-system-flexibility.pdf

SHURA, 2019 c. Enerji ve Ulaştırma Sektörleri Dönüşümünde Batarya Teknolojilerinin Rolü: Eğilimler, Fırsatlar ve Yenilikçi Uygulamalar. [Online]

Available at: https://www.SHURA.org.tr/wp-content/uploads/2020/01/Enerji-ve-

Ulastirma-Sektorleri-Donusumunde-Batarya-Teknolojilerinin-Rolu-Egilimler-Firsatlar-ve-Yenilikci-Uygulamalar-.pdf

SHURA, 2020 a. The Potential for Rooftop PV Systems in Buildings in Turkey – Necessary Financing Models and Policies for the Implementation of Rooftop PV Systems, s.l.: s.n.

SHURA, 2020 b. Optimum Electricity Generation Capacity Mix for Turkey towards 2030. [Online]

Available at: https://www.SHURA.org.tr/wp-content/uploads/2020/08/ExecutiveSum.pdf

SHURA, 2020 c. The Role of Energy Efficiency in Turkey's Energy Transition. [Online]

Available at: https://www.SHURA.org.tr/wp-content/uploads/2020/10/SHURA_Ana-Rapor-1.pdf

SHURA, 2020 d. Türkiye Elektrik Sistemi için En Ekonomik Katkı: Enerji Verimliliği ve Yeni İş Modelleri. [Online]

Available at: https://www.SHURA.org.tr/turkiye-elektrik-sistemi-icin-en-ekonomik-katki-enerji-verimliligi-ve-yeni-is-modelleri/

Smart Energy, 2020. [Online]

Available at: https://www.smart-energy.com/industry-sectors/iot/smart-thermostats-dominate-european-connected-home-market/

Steurer, M., 2017. Analysis of Demand Side Integration for an Efficient and Environmentally Friendly Energy Supply. [Online]

Available at: https://elib.uni-stuttgart.de/handle/11682/9198

Technology, P., 2014. Electricity DSR. [Online]

Available at: http://researchbriefings.files.parliament.uk/documents/POST-PN-452/POST-PN-452.pdf

TÜBİTAK, 2020. Technology Office. Available at: https://ee.mam.tubitak.gov.tr/en/laboratories/batteryenergy-storage-technologies-laboratory

Turkish Standards Institute, 2008. TS 825 Thermal Insulation Requirements for Buildings. Ankara: s.n.

UK Parliamentary Office of Science & Technology, 2014. Electricity DSR. [Online]

Available at: http://researchbriefings.files.parliament.uk/documents/POST-PN-452/POST-PN-452.pdf

Umweltbundesamt, 2015. Potentiale Regelbarer Lasten in Einem Energieversorgungssystem mit Wachsendem Anteil Erneuerbarer Energien, s.l.: s.n.

World Bank, 2020. Country Profile Turkey. [Online]

Available at: https://data.worldbank.org/country/turkey

Flexible industrial processes

Electricity demand as reported for 2018 in (General Directorate of Energy Affairs, 2019) and as projected for 2030 using the method described in 2.3 is listed in Table 11.

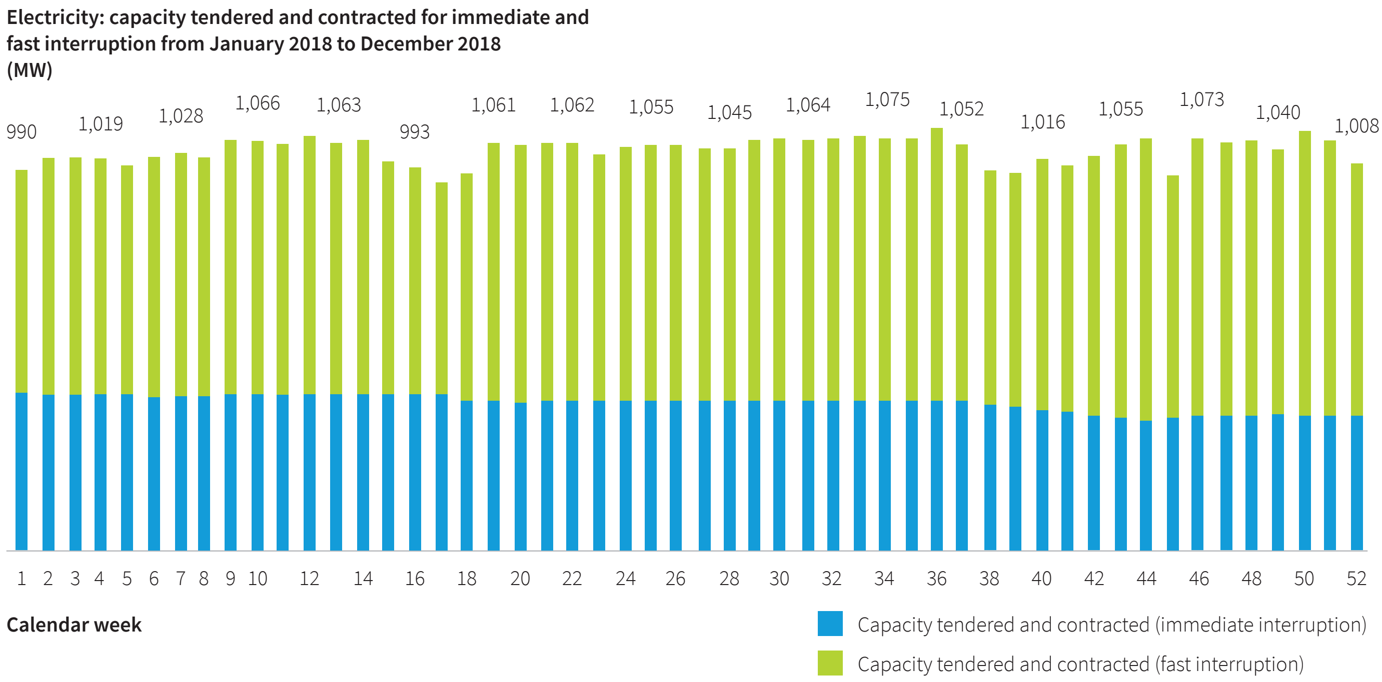
Table 11: *Industrial electricity demand as reported for 2018 and as projected for 2030 (baseline)*

Industrial sector	Electricity demand 2018 (GWh)	Electricity demand 2030 (GWh)
Manufacture of paper and products	3,439	6,938
Iron and steel products production	25,502	51,445
Manufacture of non-ferrous metal products	3,590	7,242
Fabricated metal products manufacturing	2,188	4,413
Cement products manufacturing	8,625	17,398
Glass products manufacturing	2,033	4,102
Ceramic products manufacturing	2,273	4,585
Food, beverage, tobacco products manufacturing	7,805	15,744
Textile, leather products manufacturing	18,077	36,466
Wood and products manufacturing	2,228	4,495
Chemistry, manufacturing of petro-chemistry products	13,146	26,519
Machinery, electrical, electronic products manufacturing	2,756	5,559
Transportation vehicles manufacturing	2,589	5,224
Furniture manufacturing	825	1,663
Build	3,797	7,659
Other industry	15,499	31,266

Industrial load reduction in Germany currently

- In Germany, 1 GW of load reduction from industrial DSR is procured from a pool of 30 industrial sites by the TSOs in weekly auctions (cp. Graph below).
- However this DSR was only utilised on 13 days of the year in 2018 with a total of 5 GWh of utilised demand reduction.
- Sites are remunerated with availability and utilisation payments.
- The 5 GWh of utilised DSR correspond to a cost of €6,000/MWh per MWh of utilised DSR in 2018.
- This type of rare event DSR is different from the dominant form of DSR in high VRES systems, which require DSR on a daily basis to manage volatile VRES output.

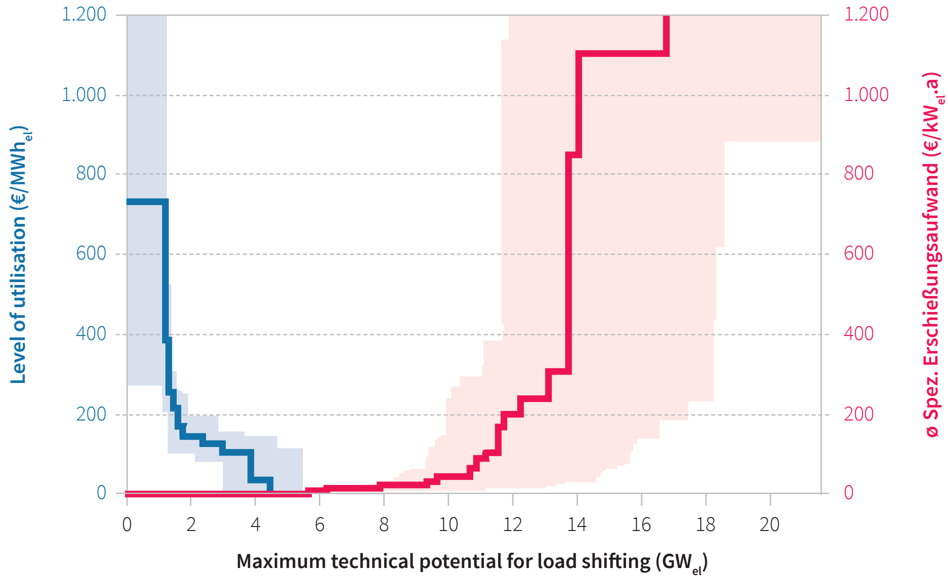
Figure 33: *Load interruption capacity procured in Germany per week in 2018*



Cost comparison of industrial vs. residential DSR

- As mentioned, energy intensive processes allow provision of DSR without capital investment in aggregation ICT infrastructure, however the utilisation of such DSR comes at high variable cost.
- The below figure from (Steurer, 2017) shows variable (blue) vs fixed (red) cost of different DSR potentials in Germany.
- Industrial production processes are shown on the left with very high variable cost, while residential and small commercial assets are shown towards the right side of the chart with high capital cost.

Figure 34: *Variable OPEX in €/MWh (left axis) and CAPEX in €/kW/y (right axis) of different DSR sectors*



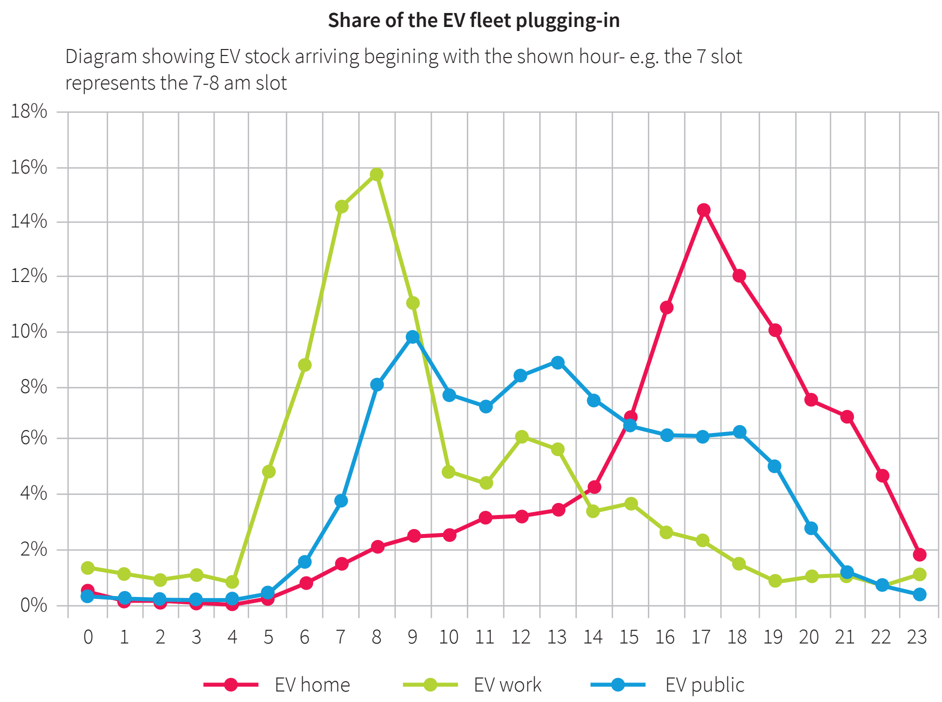
Source: (Steurer, 2017).

Electric vehicles

EV plug in profiles

The assumed profiles are based on based on the recent evidence from an exhaustive literature review on EV usage profiles conducted for UKPN (Element Energy, 2018) and are shown in Figure 31. Slow on-street public charging in residential areas is equivalent for our modelling purposes to home charging (mostly overnight) and thus already captured in the 'home charging' category.

Figure 35: *EV plug in profiles at home, work and public chargers*



Background on charging capacities

- Home: 3 kW and 7 kW are most common in the UK. While 3 kW would be sufficient for overnight charging, it is to be expected that people will want 7 kW in future just in case they need to charge quickly occasionally.
- Work: 7 kW and 22 kW are most common capacities currently for workplace charging. However currently only the Renault ZOE is able to charge at 22 kW whereas most EVs limit the charging to capacities below 22 kW, e.g. Tesla to 11 kW and many EVs to 7 kW (Smart Home, 2020).
- Slow public charging: 7 kW charge points are the most common public charge points currently in the UK.
- Rapid public charging: 150 kW is already available today and along with a trend to larger battery capacities there is a trend to higher rapid charger capacities (350 kW and possibly higher) according to an IRENA report (IRENA, 2019). 150 kW is a good average value for 2030.

Plug in windows

The following assumptions, aligned with (Deporter & Assimon, 2011), have been made on plug in windows of EVs.

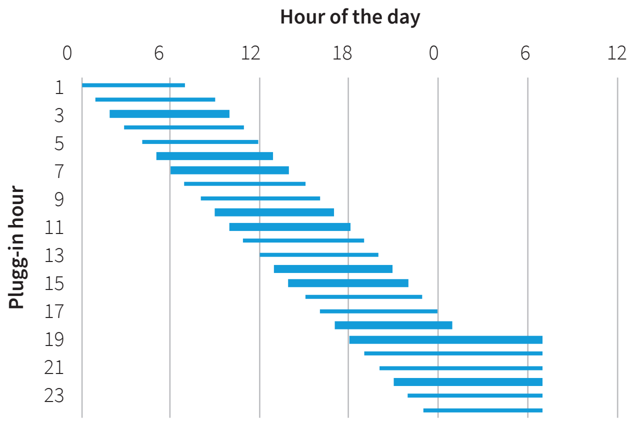
- EVs charging during the night, i.e. EVs charging at home and at slow public chargers, stay plugged in until 7:00 if plugged in between 18:00 and 00:00, otherwise for 8 hours.
- Work EVs stay plugged in until 17:00 if plugged in between 8:00 and 13:00, otherwise for 4 hours.

These assumptions are illustrated in Figure 36.

Figure 36: *Assumptions on plug in windows of EVs plugging in at various times during the day determine EV charging flexibility*

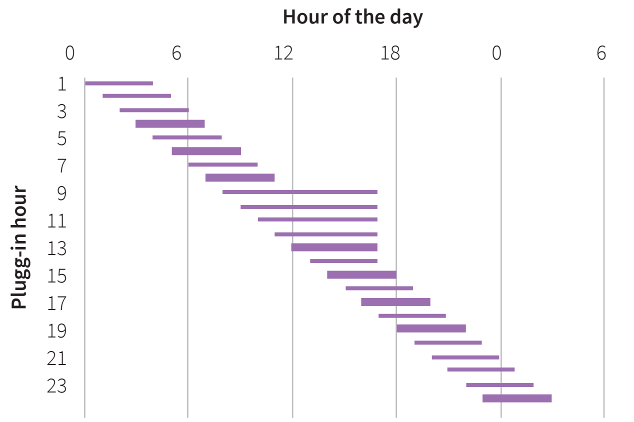
Home EV plugg-in time

It is assumed that at home EVs stay plugged in until 7:00 if plugged in between 18:00 and 00:00, otherwise for 8 hours.



Work EV plugg-in time

Our modelling assumes that at work EVs stay plugged in until 17:00 if plugged in between 8:00 and 13:00, otherwise for 4 hours.



Baseline electricity demand

The estimate for the baseline electricity demand, comprising all electricity demand besides heating and cooling, electric vehicles and energy intensive industry, is based on the demand data of the ENTSO-E 2018 TYNDP. It is estimated by removing the demand for heating and cooling, EVs, and energy intensive industry from the electricity demand of Turkey in the Distributed Generation 2030 scenario of the ENTSO-E 2018 TYNDP.

The ENTSO-E TYNDP includes three annual profiles of total demand for all ENTSO-E countries in hourly resolution. The three different profiles are based on weather data of three different years – 1982, 1984, and 2007 – which are representative years for the 34 year period from 1982 to 2015 in terms of a number of characteristics such as temperatures, and wind and solar resource, cp. Figure 33 (ENTSO-E, 2019). Figure 34 shows the three demand profiles for Turkey. In all cases the peak demand occurs in the summer but it is much higher in the profile based on 2007 weather data than in the other cases (79 GW vs 64 GW). This is likely to be related to the higher temperatures in the 2007 summer compared to 1982 and 1984 (cp. Figure 35). We choose to model system operation based on 2007 weather data as it is the most representative year for the whole 34 period as well as for the second half of the period and thus potentially for the long term trend (cp. Figure 37).

Figure 37: *Mapping of 34 climate years to three representative years; source: ENTSO-E 2018 TYNDP*

__Figure 38:__ Annual profiles of total electricity demand in Turkey in 2030 in the Distributed Generation scenario of the ENTSO-E 2018 TYNDP based on three different climatic years

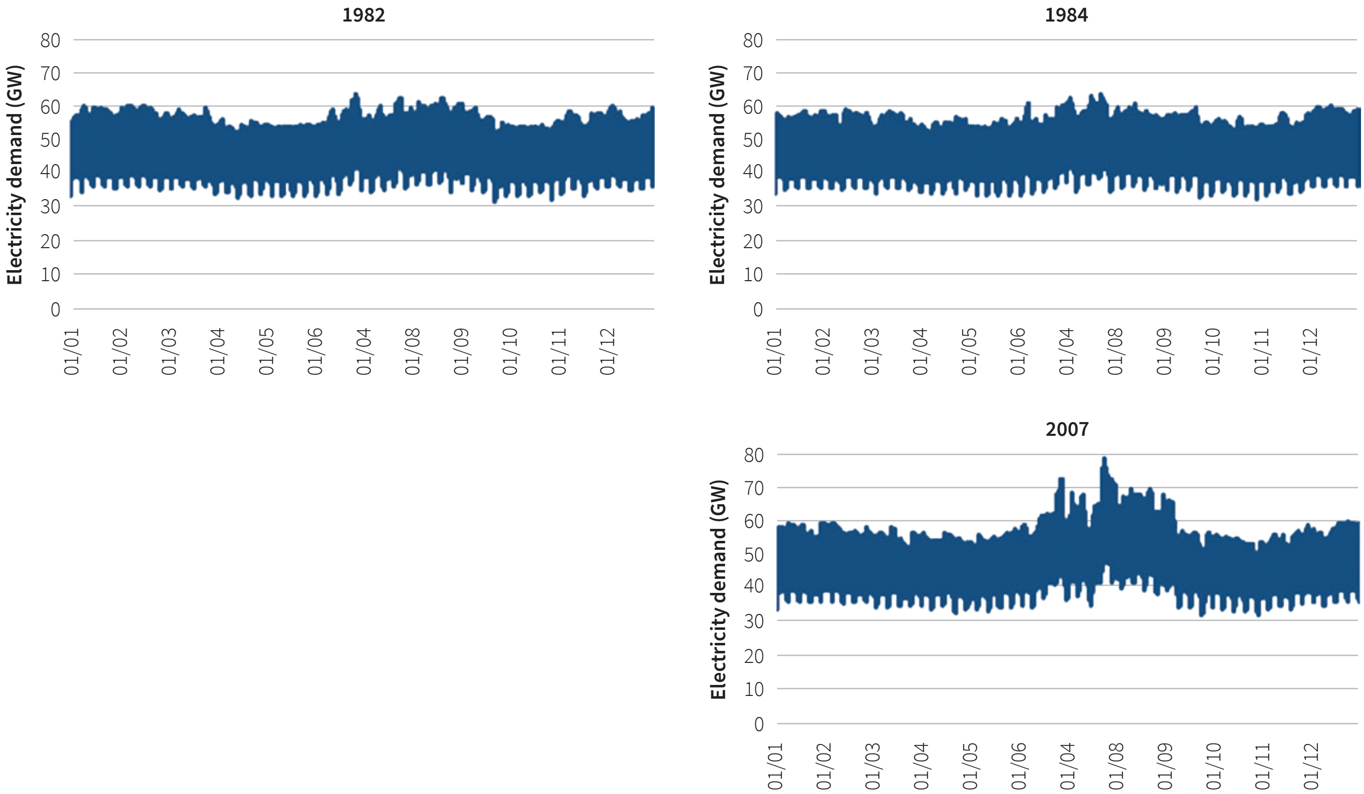
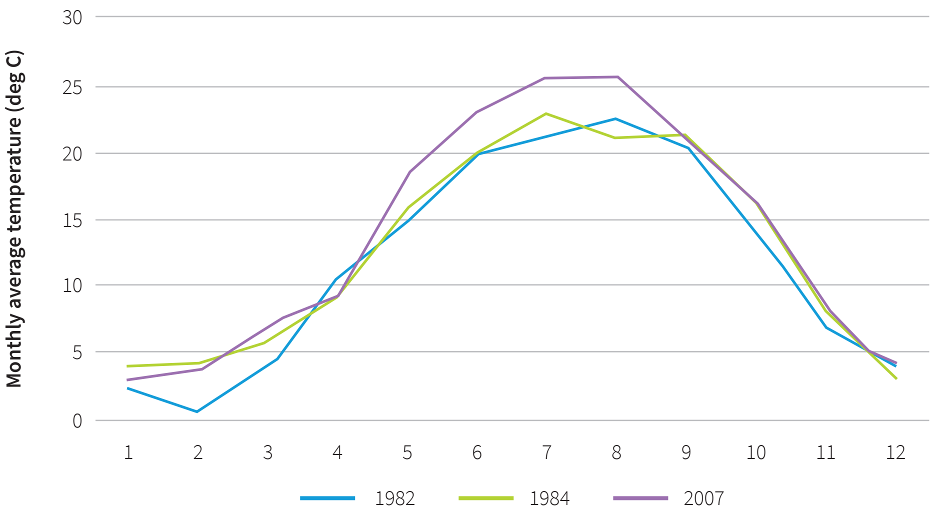


__Figure 39:__ Monthly average temperatures in Turkey in 1982, 1984, and 2007



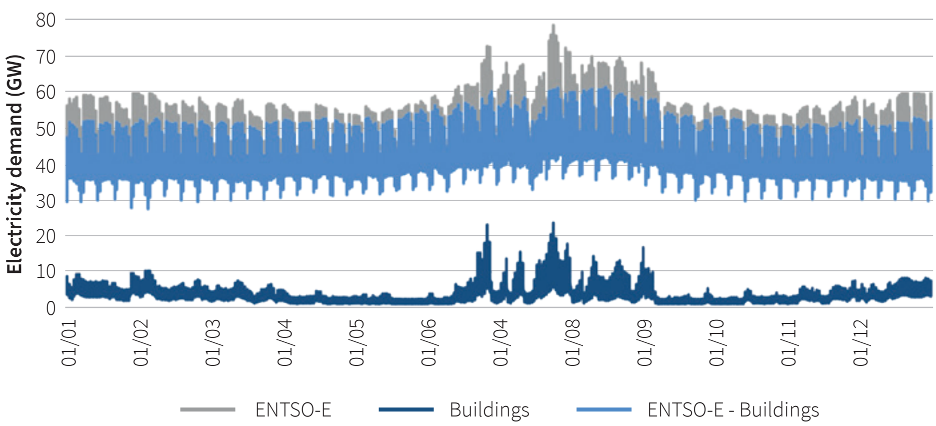
Removing demand for heating and cooling in buildings

To calculate the demand profile for heating and cooling included in the ENTSO-E profile, we run our model of heating and cooling demand of buildings with the assumptions as given by the ENTSO-E Distributed Generation scenario. The TYNDP documentation specifies the number of heat pumps but further information on heating and cooling assumptions could not be found. We therefore need to make assumptions on the amount of active cooling included in the ENTSO-E profile. The significantly higher summer peak based on the hotter 2007 temperature data compared to 1982, and 1984 temperature data, suggests an aggressive uptake of active cooling. For cooling and heating are the main electric loads sensitive to temperature (Gils, 2014) and thus likely to be responsible for the higher peak. We therefore use the following aggressive but plausible assumptions of the penetration of active cooling in the model:

- 80% in hotels and health care use active cooling (as in our baseline)
- For all other building types (SFH, MFH, education, commercial, public), we assume that the uptake is increased by another 30% compared to our baseline assumptions but never exceeds 80%. This thus leads to the following uptake across the 4 climate zones
    - Zone 1: 80% (vs 69% in baseline)
    - Zone 2: 73% (vs 43% in baseline)
    - Zone 3: 49% (vs. 19% in baseline)
    - Zone 4: 43% (vs. 13% in baseline)

Figure 40 suggests that the buildings model is able to approximate the demand for heating and cooling included in the ENTSO-E profile rather accurately when using these assumptions. For when subtracting the modelled heating and cooling demand of buildings from the ENTSO-E profile, the resulting profile shape (light blue graph in Figure 36) is much more regular and more similar to that of the demand profiles based on the less hot years 1982 and 1984. This is also the expected profile shape of electricity demand excluding demand for heating and cooling. For heating and cooling are the main temperature sensitive electricity demands and thus electricity demand excluding those is rather regular throughout the year.

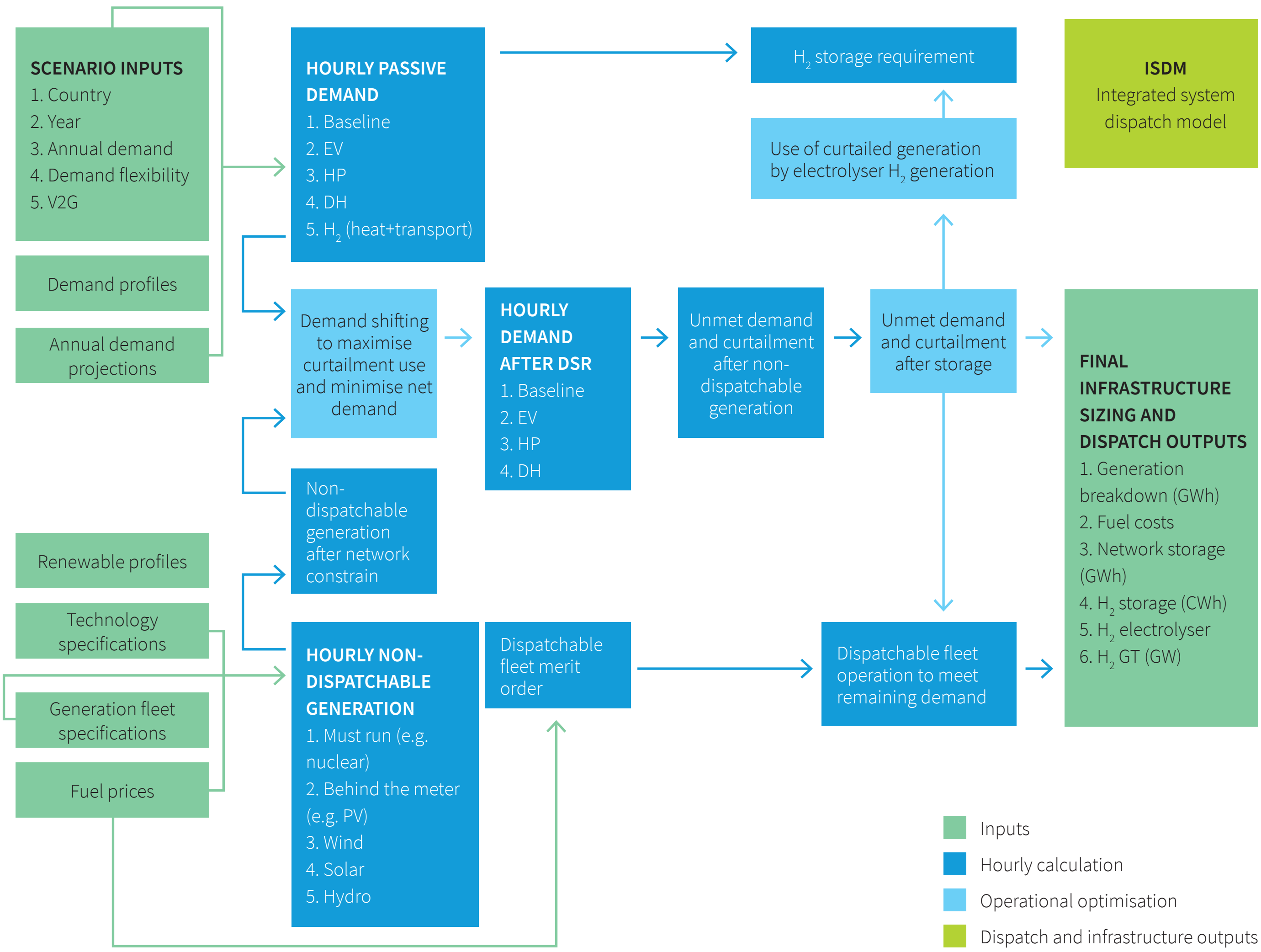
Figure 40: *ENTSO-E demand profile, demand of buildings for heating and cooling included in the ENTSO-E profile as approximated by Element Energy and difference of the two*



Removing demand for EVs and energy intensive industry
The Distributed Generation scenario of the 2018 TYNDP did not assume any electric vehicles in Turkey in 2030. Therefore no EV electricity consumption needs to be removed from the ENTSO-E profile.

As no further information on the assumptions on annual electricity consumption and consumption profiles of energy intensive industry could be found in the TYNDP documentation, we assume electricity consumption of energy intensive industry is modelled identically in the ENTSO-E profile as in our approach. We therefore subtract the consumption profile of energy intensive industry as modelled in our industry module (cp. section 3.3.3 from the ENTSO-E profile).

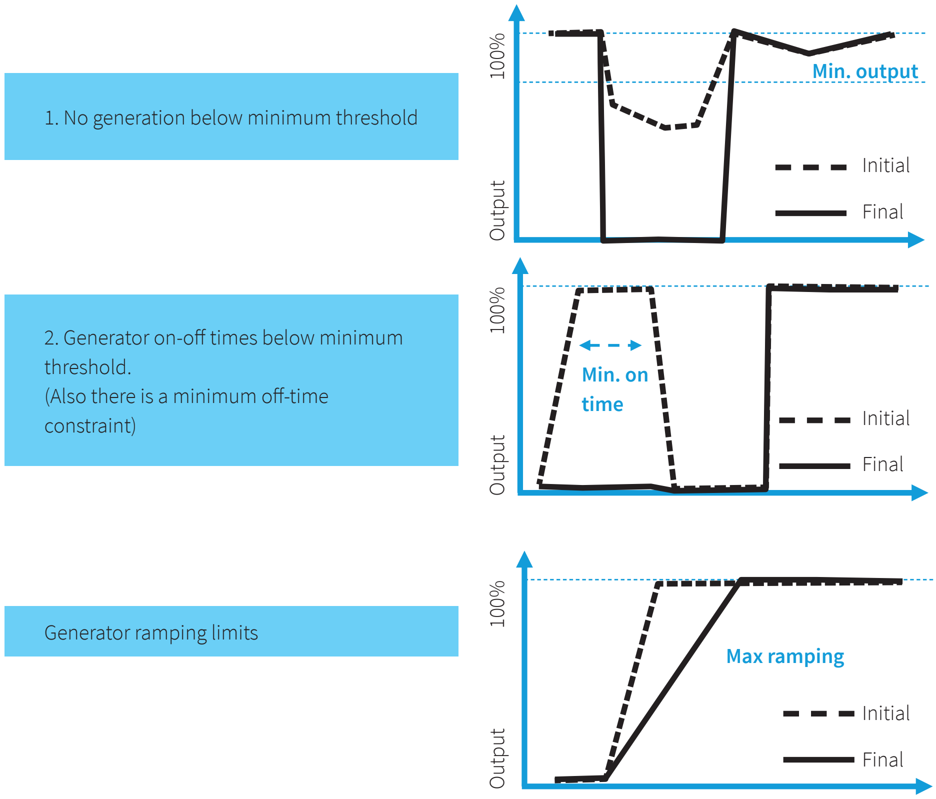
Integrated supply and demand model (ISDM)



Summarise features and key outputs

- ISDM is an in-house dispatch model developed by Element Energy to meet the demands of low/zero carbon power systems.
- The model places equal emphasis on dispatching demand side as well as supply side, to achieve required system flexibility at least cost.
- It also has optimisation models for storage at various durations, from hourly up to thermal generator redispatch.

Figure 41: *Three components of thermal generator redispatch in ISDM*

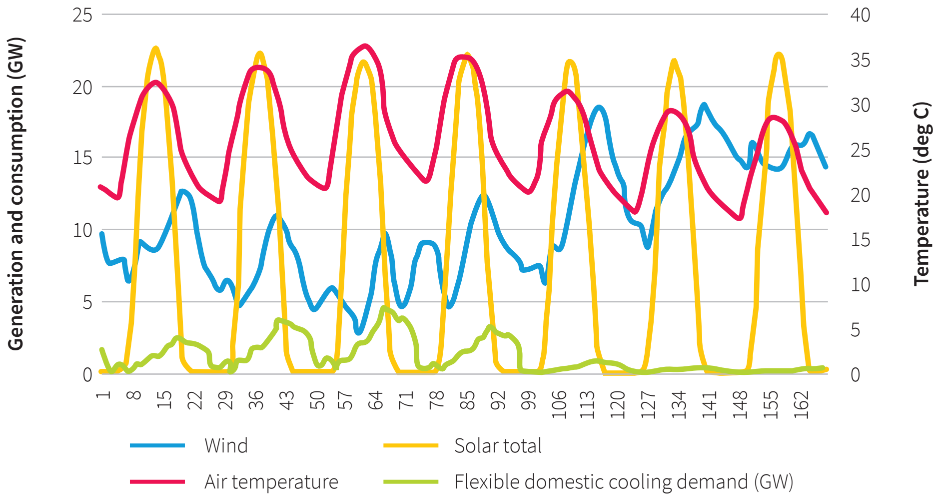


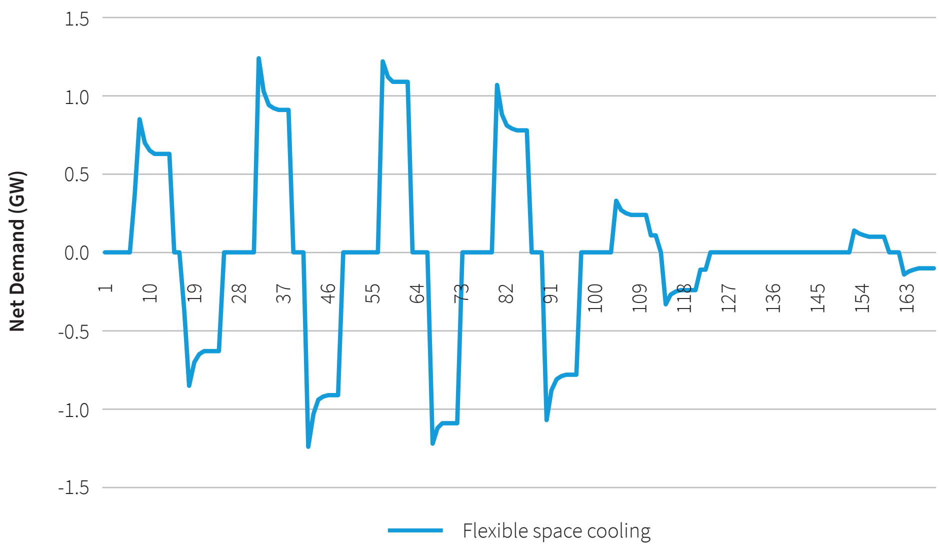
Example DSR dynamics

Purpose here is to showcase the high resolution and dynamics of our DSR implementation. Because it approaches true DSR behaviour compared to prior studies, this underpins our recommendations.

Example of flexible cooling. Initially high due to high air temperatures and low wind, but then cooling demand drops.

Figure 42: *The availability of flexible cooling for week 25 for the SHURA Tripling scenario (top) and resulting utilisation of flexible cooling (bottom) showing demand reduction near system peaks*





NOTES

About Istanbul Policy Center at the Sabancı University

Istanbul Policy Center (IPC) is a global policy research institution that specializes in key social and political issues ranging from democratization to climate change, transatlantic relations to conflict resolution and mediation. IPC organizes and conducts its research under three main clusters: The Istanbul Policy Center–Sabancı University–Stiftung Mercator Initiative, Democratization and Institutional Reform, and Conflict Resolution and Mediation. Since 2001, IPC has provided decision makers, opinion leaders, and other major stakeholders with objective analyses and innovative policy recommendations.

About European Climate Foundation

The European Climate Foundation (ECF) was established as a major philanthropic initiative to help Europe foster the development of a low-carbon society and play an even stronger international leadership role to mitigate climate change. The ECF seeks to address the "how" of the low-carbon transition in a non-ideological manner. In collaboration with its partners, the ECF contributes to the debate by highlighting key path dependencies and the implications of different options in this transition.

About Agora Energiewende

Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests, but rather to its commitment to confronting climate change.

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