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Citation (APA)
Chauhan, S., Donkervoort, W., Hers, S., Cvetkovic, M., & de Vries, L. (2027). Understanding demand-side flexibility characterisation and barriers to effective deployment: A Dutch case study. *Energy Policy*, *220*, Article 115670. https://doi.org/10.1016/j.enpol.2026.115670

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Energy Policy 220 (2027) 115670

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/jepo

Understanding demand-side flexibility characterisation and barriers to effective deployment: A Dutch case study

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HIGHLIGHTS

- Barriers to demand response lack systematic definition and classification.
- A comprehensive framework is built to classify barriers based on their primary nature.
- The framework is validated on the Dutch energy sector using literature and stakeholder interviews.
- Grid constraints, taxes and tariffs and policy ambiguity are key barriers.
- The framework can inform targeted interventions and incentives for demand response.

ARTICLE INFO

Keywords:
Demand response
Flexibility
Barriers
Energy markets
Policy analysis

ABSTRACT

Demand response is a critical component of future energy systems, as it provides a significant contribution to the cost-optimal integration of renewable energy. However, a variety of barriers inhibit its deployment and utilisation. While the research on barriers to demand response is wide and varied, it is often unsystematic and incomplete, with studies focusing on parts of the demand response ecosystem such as specific sectors, technologies or stakeholders. To bridge this gap, this study builds upon existing literature to develop a consistent and comprehensive framework for systematically identifying, classifying and analysing barriers across the demand response ecosystem, with the aim of providing input for the design of policy incentives. We develop an integrated framework that is based on the underlying nature of the identified barriers. We identify four overarching categories: technical, economic, regulatory and behavioural, along with multiple sub-categories and elements. This framework is tested on the Dutch energy system. We find that the most significant technical barriers faced by the Dutch energy sector are process and operational constraints and network limitations; the main economic barriers are financial uncertainty and distorted market signals due to taxes and tariffs; the main regulatory barriers are policy ambiguity and information insufficiency; and the main behavioural barriers are lack of expertise and incompatible individual preferences.

1. Introduction

Demand-side flexibility is expected to play a critical role in resolving energy system challenges arising from increased dependence on variable renewable energy, but current markets pose a variety of barriers to its development. While a number of studies describe barriers, e.g., technical barriers such as process and operational dependencies and lack of suitable technology, economic barriers such as investment and operation costs, regulatory barriers such as market entry parameters, and behavioural barriers such as aversion to external control (Lashmar et al., 2022; Alcázar-Ortega et al., 2015), a consistent framework for characterising and regulating flexibility is lacking. Identification of barriers and analyses of their causes are critical to the design of incentives and interventions for supporting demand-side flexibility (Moreno et al., 2025;

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https://doi.org/10.1016/j.enpol.2026.115670
Received 26 March 2026; Received in revised form 16 October 2026; Accepted 17 October 2026
Available online 29 October 2026
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Stampatori et al., 2026). Effectively regulating and incentivising flexibility presents a classic chicken-and-egg problem, as sustainable, long-term flexibility deployment requires supportive regulation that addresses perceived and practical barriers, while the barriers are often not revealed without a regulatory framework that stimulates them adequately.

Demand-side flexibility has been studied extensively in recent years, both within academia and in real-world experiments with demand response, flexible and distributed generation, and market coupling (Lund et al., 2015; Anaya and Pollitt, 2020a,b; Boisvert et al., 2002). In many studies, demand flexibility is modelled and assessed as a tool for easing grid congestion, reducing system peaks, integrating higher shares of renewable energy and mitigating imbalances (Cappers et al., 2012; Spiliotis et al., 2016). At the same time, given the interdisciplinary nature of electricity market research, this topic has also been studied through the lens of market performance and efficiency and economic benefits to both the flexible resources and system operators (O'Connell et al., 2014; Koliou et al., 2014; Sridhar et al., 2023).

The main objective of this paper is to develop a framework for the analysis of barriers to flexibility and to test it on the Dutch energy sector. The study adopts a qualitative approach, focusing on the construction and application of a systematic framework for analysing barriers to demand-side flexibility rather than their quantitative evaluation. To achieve this, we first conduct a thorough literature review to examine how demand flexibility is characterised in academic studies, including its definition, parametrisation, methods of studying and market participation in Section 2. Next, we discuss barriers to demand flexibility identified in literature in Section 3. We use this to construct a framework for classifying and analysing barriers in Section 4. We apply this framework to the Dutch energy system in Section 5 to test its robustness and validity using a mixed-methods research design combining literature review with semi-structured, multi-stakeholder interviews. Sections 2 and 3 are based entirely on literature review. Section 5 combines this with interviews with stakeholders in the Dutch energy sector. Thus, this paper contributes to academic discourse by synthesising a wide range of literature on demand-side flexibility, proposing a framework for studying barriers and validating the framework with a case study.

The scope of this paper includes all major consumer sectors – residential, commercial, transport, and industrial. The barriers framework is developed for the intended use of a broad range of energy-sector stakeholders from consumers to network operators and regulators. Finally, the case study and discussion sections, Sections 5 and 6, include findings from both academic and grey literature on different demand sectors and interviews with stakeholders from a variety of Dutch organisations.

2. Characterising demand-side flexibility

Flexibility, and the attributes that characterise it, are defined in many different ways (Degefa et al., 2021; Kara et al., 2022). A similar diversity characterises the parameters that are studied and the methods for studying them. In this section's synthesis of the literature on demand-side flexibility, we start by examining how flexibility and, more specifically, demand response are defined. Next, we review the parameters commonly associated with demand response. We then review the markets that facilitate demand response participation, followed by a brief overview of the methods that are used for studying it. Finally, in Table 2, we enumerate a set of studies that illustrate these elements of research. Going forward, we will use the terms demand response and demand-side flexibility interchangeably.

2.1. Defining flexibility and demand response

The definition and characterisation of flexibility have been the subjects of considerable research (Degefa et al., 2021; Mathieu et al., 2025; Kara et al., 2022; Villar et al., 2018). While some studies consider flexibility arising from all sources, others focus on demand response. Degefa et al. (2021) performed an extensive review of the definitions and characteristics of flexibility. Mathieu et al. (2025) reviewed the definitions of demand response in the context of regulation. Both these studies remarked on the variability in the degree of specificity of the definitions, highlighting the non-standard nature of these terms. Commonly included elements in demand response definitions are as follows (Degefa et al., 2021; Kara et al., 2022; Villar et al., 2018; Mathieu et al., 2025):

Source	:	change (increase or decrease) in power withdrawal or injection by end user
Activation	:	voluntary (self-controlled), involuntary (controlled by aggregator, DSO, etc.)
Period	:	real-time (seconds), short-term (minutes, hours), long-term (months, years)
Purpose	:	maintaining system balance, reliability, stability, avoiding VRE curtailment
Stimuli	:	grid imbalance, network congestion, market signals, and other external factors

The above-mentioned elements are illustrated in the definitions of demand response used in the European Union Directive 2019/944 and the Dutch Energy Act[1] (European Parliament, Council of the European Union, 2019; Ministerie van Klimaat en Groene Groei, 2024) (Figs. 1 and 2).

The literature does not agree on whether flexibility is a (tradeable) product or a property of the electricity system and/or of parts of it, like generation, storage and demand. A common thread in the definitions of flexibility is the reliance on external stimuli for triggering flexibility, which aligns with the view of flexibility as a product or service, to be triggered by external signals such as imbalance, congestion, prices, etc. However, we consider this to be a restrictive view of flexibility as i) consumers possess an inherent degree of flexibility arising from operational and behavioural factors and ii) flexible behaviour can be triggered by stimuli outside the power sector such as demand and supply of substitute energy carriers. These factors are particularly important from the perspective of policy design, as we will discuss in the following sections. Therefore, we side with Zhao et al. (2016), who regard flexibility as '*an inherent property of the system*'. Focusing on demand flexibility, we apply a broad definition as *the ability of a consumer to modify its load in response to external stimuli*. This definition expands the view of demand flexibility from merely a product to an inherent techno-economic characteristic of the consumer independent of the system and the market. Fundamentally, demand-side flexibility can be manifested as load shifting and load shedding, both of which essentially alter the demand profile of a consumer. Both actions can be triggered with the purpose of mitigating grid congestion, capitalising on market conditions or accommodating behavioural preferences.

2.2. Parametrising flexible demand

Parameters associated with flexibility vary according to the type of demand response. While there are several ways to categorise demand response, we choose a categorisation based on economic drivers, as the literature indicates a clear distinction between parameters used to characterise flexibility under implicit and explicit demand response. Below, we describe the two main types of demand response based on incentive structure and provide the parameters used to analyse them:

i *Implicit or price-based demand response*: implicit DR is defined as change in consumer behaviour triggered by price signals such as time-of-use, critical peak or real-time electricity prices (Paterakis

[1] "*vraagrespons: verandering van het verbruik of de invoeding van elektriciteit bij eindafnemers ten opzichte van hun normale verbruiks- of terugleverpatronen, in reactie op marktsignalen of systeembehoeften, met als doel de vraagvermindering, of -verhoging te verkopen op een energiehandelsmarkt*". Translated from Dutch to English using Google Translate.

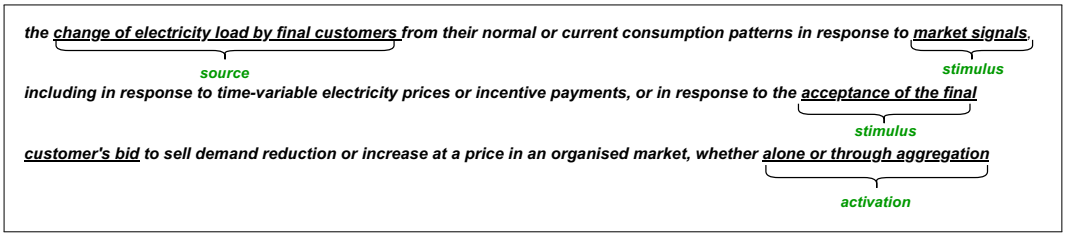


Fig. 1. Demand response as defined in EU Directive 2019/944 (European Parliament, Council of the European Union, 2019).

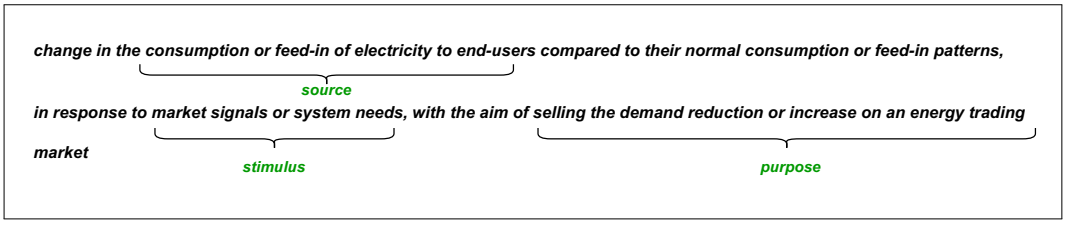


Fig. 2. Demand response as defined in the Dutch Energy Act (Ministerie van Klimaat en Groene Groei, 2024).

et al., 2017). Such a response is not offered to the market as a product but is evident in consumers' demand profiles and bidding behaviour. It is voluntary in nature and controlled entirely by the consumer. The parameters associated with this type of demand flexibility are (Su and Kirschen, 2009; Bompard et al., 2007; Aalami et al., 2010; Moghaddam et al., 2011; Venkatesan et al., 2012; Albadi and El-Saadany, 2008; Heydarian-Forushani and Golshan, 2020; Chauhan et al., 2024):

- Volume (total demand) (MWh)
- Willingness to pay or price (EUR/MWh)
- Price elasticity of demand

ii *Explicit or incentive-based demand response*: explicit DR entails direct or indirect load control (shifting and shedding) (Paterakis et al., 2017) and is triggered by a signal from an external entity such as the system operator. In this case, consumers are remunerated explicitly for the change in their consumption. The key distinctive features of explicit DR are its visibility in the market and dispatchability. The parameters associated with explicit demand response are (Kara et al., 2022; Degefa et al., 2021; Zhao et al., 2016; Ulbig and Andersson, 2015):

- Volume (change in demand) (MWh)
- Response time (seconds to hours)
- Capacity (MW)
- Availability periods (time of day)
- Ramp rate (MW/h)
- Availability duration (seconds to hours)
- Location (grid voltage, zone, node)
- Cost or bid price (EUR/MW, EUR/MWh)

2.3. Markets for flexible demand

Consumers with flexible demand, both implicit and explicit, can participate in electricity markets through a variety of available mechanisms and products. Table 1 provides an overview of market types with some examples. There is variation in the terminology used to define and describe different markets in different geographies. For the purpose of our study, we will refer to the markets as defined and utilised in the Dutch and European contexts.

- *Retail market*: market for the sale of energy to end users. In the Netherlands, consumers have the liberty to choose their retailer

Table 1
Markets for participation of flexible demand.

Type of DR	Type of market	Type of trading	Trading period	Description	Global examples
Implicit DR	Retail	Bilateral contract	Monthly, annual, etc.	Consumers enter into retail contracts with energy suppliers. Tariffs in such contracts vary from time-of-use to real-time pricing.	Retail choice offered by The Netherlands, Germany, etc. (European Union Agency for the Cooperation of Energy Regulators, 2023a)
	Wholesale	Auction-based, continuous	Term-ahead, day-ahead, intra-day, real-time, etc.	Consumers, either independently or through aggregators, trade electricity on exchange-based market platforms	EPEXSpot (Europe), Nordpool (Europe), PJM ISO (US), NYISO (US), ISONE (US) (European Union Agency for the Cooperation of Energy Regulators, 2023b; Federal Energy Regulatory Commission, 2025)
Explicit DR	Ancillary services (including balancing) market	Auction-based, continuous	Day-ahead, intra-day, real-time	Consumers respond to signals sent by system operators to increase or decrease consumption specifically for the purpose of establishing system stability	FRR and FCR procurement (Central-West Europe), FCAS (Australia) (ENTSO-E, 2024; Australian Energy Market Operator, 2025)
	Flexibility platforms	Auction-based, continuous	Term-ahead, day-ahead, intra-day, real-time	Consumers can offer flexibility on dedicated platforms that may or may not be linked with spot markets.	GOPACS (The Netherlands), Euroflex (Norway), NEBEF (France) (GOPACS, 2023; NODES, 2025; RTE, 2025)

Table 2
Select studies on demand-side flexibility.

Type of DR	Sector	Technology	Parameters analysed	Method	Market	Ref.
Explicit	Residential	Heating, appliances, EVs	Willingness to enrol in DR program, Willingness to accept for demand reduction	Empirical - survey	NA	(Sridhar et al., 2023)
Implicit	Residential	Total demand	Hourly demand, Dynamic prices	Modelling - bi-level optimisation	Retail	(Cai et al., 2022)
Implicit	Residential	Total demand	Hourly demand, Time-of-Use prices	Empirical - observed data analysis	Retail	(Enrich et al., 2024)
Implicit	Residential	Total demand	Hourly demand, Price-elasticity	Empirical - survey	Retail	(Peersman and Wauters, 2024)
Explicit	Commercial	Refrigeration	Load shifting	Empirical - interviews	NA	(Grein and Pehnt, 2011)
Explicit	Industrial	Automotive assembly	Demand reduction (kW, %)	Modelling - simulation	NA	(Li et al., 2012)
Implicit, Explicit	Industrial	Aluminium, Cement, Steel	Total demand, Load shifting, Revenue from DR	Modelling - optimisation	Day-ahead, Ancillary services	(Gerami et al., 2021)
Implicit	Transport	Passenger EVs	Hourly demand, price responsiveness	Empirical - field experiment Modelling - ABM	Day-ahead	(Pelka et al., 2024)
Implicit	Transport	Passenger EVs	Hourly demand bids (price and volume)	Modelling - optimisation	Day-ahead	(Wang et al., 2024)

and the type of contract that they prefer. Price-agnostic consumers may opt for fixed price contracts, while price-sensitive consumers may opt for dynamic or real-time price contracts (European Union Agency for the Cooperation of Energy Regulators, 2023a).

- *Wholesale market*: market for bulk trading of power. The trades may be performed bilaterally or through an exchange-based platform that offers auction-based or continuous market products (Batalla et al., 2021).
- *Ancillary services market*: market for services necessary for stable, continuous operation of the grid including balancing power, frequency response, reactive power and black start facility (TenneT, 2022a). In the Netherlands, ancillary services are classified into balancing and other (non-frequency) services (Ministerie van Klimaat en Groene Groei, 2024).
- *Flexibility platforms*: specialised platforms for offering flexible demand and supply. The platforms may be used for procuring services for congestion management, such as GOPACS in the Netherlands (GOPACS, 2025).

Although flexibility platforms and ancillary services markets overlap in their use of flexible resources, there are key differences in their scope, procurement mechanisms and applications. This distinction is evident in the regulatory framework that governs the Dutch market. In the Netherlands, flexibility platforms are used for procuring congestion management services, which are explicitly excluded from the definition of ancillary services in the Dutch Energy Act, itself based on the European Parliament Directive 2019/944 on common rules for the internal market for electricity (Ministerie van Klimaat en Groene Groei, 2024; European Parliament, Council of the European Union, 2019). Ancillary services markets are established mechanisms for the procurement of critical system services under strictly regulated mechanisms with stringent technical qualifying criteria for participants, while flexibility platforms allow for a broader range of flexibility providers (GOPACS, 2023; NODES, 2025; ENTSO-E, 2019). Thus, we have included them as separate markets for explicit demand response rather than nesting them under one category. The classification presented here is not intended to be exhaustive and other mechanisms for trading flexibility may exist across different electricity markets.

2.4. Methods for studying demand flexibility

The two main groups of methods for studying demand flexibility are modelling and empirical studies:

i Modelling: a variety of models ranging from optimisation to agent-based simulation and equilibrium models have been used to study demand flexibility. Ringkjøb et al. (2018) performed an extensive review of energy system models from the perspective of modelling variable renewable energy. While this study is somewhat dated, many of the models covered in it are still widely used. Of the 75 models assessed in that paper, 28 incorporate elastic demand, while 37 incorporate demand response in some form. This subset of models comprises optimisation-based supply/demand models such as COMPETES and MESSAGE, simulation-based models such as the Energy Transition Model (ETM) and equilibrium models such as TIMES Integrated Assessment Model (ETSAP-TIAM) (Ringkjøb et al., 2018).

ii Empirical research: studies of the implementation of demand response programs as well as analysis of observed data from the use of differential pricing constitute primary research in this area. These types of studies often employ surveys targeting specific consumer groups, statistical and econometric analytical methods and technical and behavioural interventions.

2.5. Studies on demand flexibility

In Table 2, we enumerate select studies to illustrate the breadth of research on demand flexibility covering the aspects discussed above.

3. Barriers to flexibility

Fundamentally, a barrier can be defined as an element that prevents efficient deployment of flexibility. Efficient deployment refers to the enablement and utilisation of available flexibility in an economically optimal manner to benefit consumers as well as the energy system. However, from the perspective of a consumer, providing flexibility is not the end goal of energy consumption, as also observed by Callaway and Hiskens (2011); Katz (2014) and Stede et al. (2020). Rather, energy consumption is aimed at the generation of products and services that lead to value creation for the user. Similarly, from the point of view of grid operators, the primary goal is to facilitate power transmission while maintaining grid stability and reliability. Not every element that restricts flexibility can be considered a barrier, as modifying that element to facilitate flexibility may compromise the final goal of energy use. Thus, we expand the definition of a barrier as an element that hinders the deployment of flexibility, but the resolution of which does not adversely impact the intended end use of energy.

Literature reveals a large number of barriers, divided into diverse categories including, but not limited to, technological, economic,

regulatory, and behavioural aspects (Lampropoulos et al., 2018; Barbero et al., 2020; Lashmar et al., 2022; Katz, 2014; Alcázar-Ortega et al., 2015; Good et al., 2017). While many studies cover similar barriers, there is considerable variation in their categorisation and subdivision, resulting in a lack of a consistent framework that can be utilised in future studies. For example, Cappers et al. (2013) uses the qualification of 'implicit' for technological barriers related to the required infrastructure for market participation and Olsthoorn et al. (2015) classifies barriers into internal and external factors. However, these qualifiers can overlap. In addition, the characterisation of high costs as a barrier is subjective, as it depends on the consumer's willingness to pay as well as on the availability of external financial support.

In Table 3, we identify the barriers that are mentioned in the literature by their root cause. The second column provides a description of the barrier. The third column indicates how the barrier is categorised in the literature. The table indicates the lack of precision and consistency in the literature.

Other barriers that are mentioned less frequently include cybersecurity concerns (Lashmar et al., 2022), unsuitable design and regulation of retail tariffs (Hirst, 2001), IT infrastructure insufficiency

Table 3
Barriers to demand flexibility.

Barrier	Description	Category assigned	References
Process and operational constraints	Processes, particularly in industrial and commercial sectors, may be inflexible or have limited flexibility due to upstream and/or downstream dependencies and may even conflict with energy efficiency-based goals	Technical, Regulatory	(Lashmar et al., 2022; Olsthoorn et al., 2015; Leinauer et al., 2022; Bielefeld et al., 2023)
Metering, sensing and communication equipment deployment limitations	Limited availability, affordability and utilisation of metering, sensing and communication equipment	Technological	(Good et al., 2017; Lampropoulos et al., 2018; Grein and Pehnt, 2011; Hirst, 2001; Weck et al., 2017; Cappers et al., 2013; Leinauer et al., 2022; Vallés et al., 2016)
Inconsistent standards	Lack of standardisation across energy system participants in: metering, sensing and communication technology, billing and verification, etc.	Technological, Regulatory	(Good et al., 2017; Lampropoulos et al., 2018; Annala et al., 2018; Vallés et al., 2016)
Lack of expertise	Lack of in-house knowledge and skills to undertake DR	Technological, Understanding, Social and Behavioural, Competences, Informational, Grid user maturity	(Good et al., 2017; Lashmar et al., 2022; Olsthoorn et al., 2015; Grein and Pehnt, 2011; Leinauer et al., 2022; Parrish et al., 2020; Annala et al., 2018; Mlecnik et al., 2020; Sæle et al., 2023; Thunshirn et al., 2025)
Imperfect information	Differences in quality and quantity of information available to different parties	Market failures (Economic), Market, Informational	(Good et al., 2017; Lampropoulos et al., 2018; Nolan and O'Malley, 2015; Katz, 2014; Leinauer et al., 2022; Sæle et al., 2023)
Imperfect competition	Participants with large market shares can influence prices and market outcomes	Economic, Regulatory	(Good et al., 2017; Lampropoulos et al., 2018; Cruz et al., 2018)
High investment and operation costs	Cost for retrofitting or upgrading equipment to enable DR, installing smart metering and control devices, automation, etc. can be prohibitive. There may also be competing investment avenues	Economic, Behavioural Enabling infrastructure investment	(Barbero et al., 2020; Olsthoorn et al., 2015; Cappers et al., 2013; Leinauer et al., 2022; Cruz et al., 2018)
Financial uncertainty	Lack of historical data and uncertainty in future costs and benefits of deploying DR to the DR provider as well as procurer	Market barriers (Economic), Informational, Customer, Revenue availability and revenue capture	(Good et al., 2017; Nolan and O'Malley, 2015; Katz, 2014; Lashmar et al., 2022; Olsthoorn et al., 2015; Weck et al., 2017; Cappers et al., 2013; Leinauer et al., 2022; Parrish et al., 2020; Annala et al., 2018; Mlecnik et al., 2020; Sæle et al., 2023)
Transaction costs	Monetary (fees, taxes, penalties) and non-monetary (time, expertise) costs associated with negotiating and concluding contracts, participating in markets, actively modulating load, etc.	Economic, Behavioural, Organisational, Regulatory	(Good et al., 2017; Lashmar et al., 2022; Olsthoorn et al., 2015; Leinauer et al., 2022)
Taxes and tariffs	Price signals from the market may get distorted due to the imposition of taxes, tariffs and other regulatory charges	Policy and regulatory	(Good et al., 2017; Leinauer et al., 2022; Fernqvist et al., 2023; Cruz et al., 2018)
Timing structures	Lead time from request to response, auction period, gate closure, and minimum and maximum product durations may not be suitable for some DR providers	Market design, Technical, Attributes of performance, Regulatory	(Katz, 2014; Lampropoulos et al., 2018; Barbero et al., 2020; Leinauer et al., 2022)
Market entry criteria	Minimum bid size, ramp rates and other qualifying criteria stipulated for participation balancing and ancillary services (FRR, FCR) markets may keep smaller users from participating in the market	Market design, Market access, Technical, Regulatory	(Katz, 2014; Lampropoulos et al., 2018; Barbero et al., 2020; Cappers et al., 2013; Leinauer et al., 2022; Pedro et al., 2023)
Policy ambiguity	Regulations may be vague, inconsistent, outdated, have short-term validity and low visibility on future changes	Policy and regulatory, Regulatory, Informational	(Good et al., 2017; Olsthoorn et al., 2015; Leinauer et al., 2022; Fernqvist et al., 2023; Annala et al., 2018; Knezović et al., 2017)
Network constraints	Grid congestion, limited interconnector capacity, lack of coordination between different grid operators and connected parties	Physical, Regulatory	(Good et al., 2017; Cruz et al., 2018; Knezović et al., 2017)
Individual preferences	Comfort, convenience, trust in external entities, risk aversion, indifference to energy costs, data privacy concerns etc.	Behavioural, Social, Customer, Legal	(Good et al., 2017; Nolan and O'Malley, 2015; Lampropoulos et al., 2018; Lashmar et al., 2022; Weck et al., 2017; Leinauer et al., 2022; Parrish et al., 2020; Mlecnik et al., 2020; Thunshirn et al., 2025; Cruz et al., 2018)
Division of roles and responsibilities	Role of DR providers, aggregators, balance responsible parties, grid and market operators and regulators are not clearly defined leading to conflicts	Regulatory, Informational	(Barbero et al., 2020; Cappers et al., 2013; Leinauer et al., 2022; Fernqvist et al., 2023; Annala et al., 2018; Sæle et al., 2023)
Diverging interests of stakeholders	Stakeholders may have different priorities and varying views of demand response	Institutional, Market and business models	(Weck et al., 2017; Fernqvist et al., 2023; Cruz et al., 2018)

for energy management systems (Leinauer et al., 2022), inaccuracy in establishing baseline demand (Nolan and O'Malley, 2015), restrictions on aggregators (Barbero et al., 2020), high automation requirements (Katz, 2014; Annala et al., 2018), and incomplete markets (Good et al., 2017).

A few studies include items that do not qualify as barriers according to our definition and criteria. Lashmar et al. (2022) mentions 'maintaining comfort level in buildings' in terms of temperature regulation, and 'failing to meet production targets' as barriers. In both cases, the 'barrier' actually is the very purpose for consuming energy: comfort for households, production of goods. In our view, meeting the needs of consumers is the overall objective. Similarly, we do not agree with Grein and Pehnt (2011) when they state that the temperature regulation for food refrigeration is a legal barrier to flexibility. This regulation concerns the quality of the food and, therefore, the end use objective for the consumption of energy. Thus, we do not consider it a barrier.

These examples highlight an important distinction between barriers to flexibility and the opportunity cost of load shifting and shedding. Consider the example of individual preferences in space heating and comfort. Some residential or commercial consumers can exhibit flexibility with respect to temperature changes in buildings. However, this flexibility comes at a cost: consumers will only be flexible if the financial reward is sufficient. Thus, unwillingness to change their behaviour may not constitute a barrier but may indicate that the opportunity cost of being flexible is higher than the financial reward. The purpose of market design is to provide a mechanism that incentivises consumers to be flexible if this improves social welfare, i.e., if their cost of flexibility is lower than the additional cost of providing power if they were not flexible.

4. Framework for classifying and studying barriers to flexibility

Based on the literature provided in Section 3, we have developed the following framework for the classification and analysis of barriers. The categories have been determined based on the underlying nature of the barriers. For example, barriers originating from physical constraints such as equipment operation ranges are classified as technical. Further descriptions are provided in Table 4.

We derived the categories in which we placed the barriers from the main constraints on flexibility. As an example, an industry may have the requisite technology, expertise, financial feasibility and regulatory support to be flexible, but a lack of electricity network capacity may stop it from being able to shift its load. Thus, limited network capacity is the barrier, which is categorised as a technical barrier. Similarly, a small consumer may be able and willing to offer flexibility in the market but is deterred by the administrative fees associated with using a trading platform (essentially a transaction cost). As this barrier is essentially monetary in nature, it is classified as an economic barrier.

Barriers may not necessarily be mutually independent and may influence one another, potentially enhancing their individual impacts on flexibility deployment. For example, distorted market signals due to taxes and tariffs can exacerbate financial uncertainty for consumers while also worsening network constraints by discouraging efficient grid usage. Similarly, lack of standardisation can contribute to limitations in metering, sensing and communication infrastructure. Conversely, the removal of one barrier can increase the relevance of another barrier that was previously inapplicable. For example, removal of process and operational constraints to enable flexible operation of an industrial consumer can increase its dependence on the grid and expose it to network constraints and tariffs. These interlinkages are explored in the Dutch case study in Section 5. To achieve economic efficiency, all barriers need to be removed, regardless of their interlinkages. Therefore, the framework is valid regardless of interrelations between barriers. However, if only some barriers are removed, these interrelations may lead to unexpected (and disappointing) results.

Table 4
Framework for assessing barriers to demand flexibility.

Category of barrier	Description	Barriers
Technical	Physical constraints related to availability and accessibility of suitable technology and its compatibility with existing infrastructure and operational practices	- Process and operational constraints - Metering, sensing and communication infrastructure limitations - Network constraints
Economic	Monetary limitations that prevent enabling of flexibility or increase the cost of utilising it	- High investment and operation costs - High transaction costs - Financial uncertainty - Distorted market signals due to taxes and tariffs
Regulatory	Limitations arising from gaps in regulation or incompatible and counteractive regulation	- Lack of standardisation - Policy ambiguity - Restrictive market entry criteria - Unsuitable flexibility product design - Information insufficiency
Behavioural	Constraints related to individual or organisational and institutional characteristics	- Lack of expertise - Incompatible individual preferences - Ambiguity in division of roles and responsibilities - Diverging interests of stakeholders

We have identified 16 barriers, which we consider a comprehensive set of all possible barriers within an energy system. The framework is designed to be sector- and stakeholder-agnostic to allow its application across demand sectors and utilisation by different stakeholders. Consequently, not all barriers identified in the framework will be applicable to every demand sector. This framework can serve as a practical first step to designing economically efficient incentives for flexibility and achieving its optimal utilisation. We demonstrate its application using a case study of the Netherlands in the following section.

5. Case study of the Netherlands

We applied the framework developed in Section 4 to the Dutch energy sector. We first reviewed available literature, both academic and grey, on the barriers to demand-side flexibility deployment in the Netherlands. Next, in semi-structured interviews with energy sector stakeholders, information about the identified barriers was discussed. Their responses helped us to validate, reject or qualify the findings from the literature. The interviewees were selected to represent as many actors in the Dutch energy sector as possible to capture the differences in their roles in the energy sector as well as the diversity in perspectives. The type and number of interviewees are detailed in Table 5.

A deductive interview design was used with the underlying premise that the barriers identified in the literature are existent in the Dutch energy sector. A standard questionnaire was developed to guide the initial discussion and follow-up questions were asked to gain further insights from the respondents based on their organisational role and expertise. The responses of the interviewees were analysed collectively to identify consensus and divergence of opinions.

Weck et al. (2017) conducted a similar study to understand the barriers to residential demand response in the Netherlands. We apply a broader scope, also including other consumer segments that are of key importance to the Dutch economy, such as the horticultural and industrial sectors. We present our findings for each barrier listed in Table 4 in the following subsections.

Table 5
Interviewed stakeholders overview.

Stakeholder type	Organisations	Number of interviewees
Distribution System Operator (DSO)	3 (requested to be anonymous)	3
Energy company	1. AgroEnergy (aggregator in horticulture sector) 2. Energy Management Netherlands (EBN[a]) (energy company owned by the Dutch government)	2
National Regulatory Authority	Authority for Consumers and Markets (ACM)	1
Governmental organisation	Netherlands Enterprise Agency (RVO[b]) (Dutch government agency for supporting businesses)	1
Interest organisations	1. Netbeheer Nederland (association of electricity and gas network operators) 2. Energie Nederland (trade association in energy sector) 3. VEMW (advocacy group for business consumers)	3
Transmission System Operator (TSO)	TenneT	1

[a] Energie Beheer Nederland
[b] Rijksdienst voor Ondernemend Nederland

5.1. Technical barriers

5.1.1. Process and operational constraints

For industrial consumers, process and operational dependencies as well as limitations of energy and material storage constitute major challenges to incorporating flexibility (Donkervoort, 2025). Athanasiadis (2025) and Feta et al. (2018) found that low ramp rates and continuous operational requirements of multiple processes in steel manufacturing, combined with rigid production targets lead to diminished flexibility. Further, consumers who are not heavily dependent on the grid and for whom electricity costs form a small fraction of their total operational costs are not motivated to invest in flexibility measures (Donkervoort, 2025). As an example, the current configuration of Tata Steel plant uses predominantly natural gas and waste gases from various processes for its energy needs (Athanasiadis, 2025). Thus, its ability to offer flexibility is low and it is not a major factor in its economic decisions. However, in a future configuration where blast furnaces (BF) and basic oxygen furnaces (BOF) are replaced with direct reduction plants (DRP) and electric arc furnaces (EAF), the dependence on electricity increases, exposing them to both market volatility and grid constraints. As a result, the plant will not only be more flexible on account of EAFs but also more amenable to utilising this flexibility to save energy costs (Athanasiadis, 2025).

5.1.2. Metering, sensing and communication infrastructure limitations

There is no evidence of this being a barrier in the Netherlands. As of 2023, the penetration of smart meters already stood at 90% (European Union Agency for the Cooperation of Energy Regulators, 2024). The requirements for metering infrastructure are stipulated in the Electricity Metering Code, 2016 (Autoriteit Consument en Markt, 2016). The requirements for meter installation, communication, data collection and the role of network operators and metering responsible parties in the same are stated in the new Energy Act (chapters 3 and 4 of Energiewet, 2025) (Ministerie van Klimaat en Groene Groei, 2024). The Energy Act also specifies that the new meters installed at consumer sites must have communication capability, which may be turned off at the request of the consumer (Ministerie van Klimaat en Groene Groei, 2024). Compliance with these regulations should mitigate the risk of this barrier manifesting in the future.

5.1.3. Network constraints

Limited grid capacity is a dominant technical barrier to flexibility in the Netherlands, which is also exacerbated by the regulation for network connections. As shown in the Fig. 3, the majority of the Dutch transmission and distribution grids face congestion. As load shifting could cause sharper and higher peak demand from certain consumers, particularly when in response to energy prices (Princen, 2024), it could aggravate grid congestion. In some cases, this could result in some consumers exceeding their contracted network capacity limits, necessitating an increase in contracted capacity (Donkervoort, 2025), but this may not always be available.

The electrification of several end-use categories, such as industrial heat, hydrogen production, the built environment and transport is expected to increase the demand for grid capacity. Additionally, new connection and upgrade requests are treated in a non-discriminatory manner by the system operator and are processed on a first-come, first-served basis (Article 26a of Electricity Act (Minister van Economische Zaken en Klimaat, 1998)). The delay and uncertainty in getting connected discourage consumers from undertaking technical and economic measures for enabling flexibility. In 2024, the Dutch market regulator, ACM, mandated the network operators to implement a 'social prioritisation framework' in congested areas that allows users with congestion mitigation potential to move to a higher position in the queue (Netbeheer Nederland, 2024). This may benefit flexible consumers who can reliably shift their load away from congested periods. Further discussion on network constraints and the attempts to mitigate the same is provided in Section 6.1.

5.2. Economic barriers

5.2.1. High investment and operation costs

The leading economic barrier to flexibility is the cost of incorporating flexibility measures (Donkervoort, 2025). It includes the capital expenditure for replacing old, inflexible technology with new, flexible technology along with the cost of requisite metering, security and communication equipment. These expenses are considered unnecessary by consumers who do not foresee flexibility as a significant aspect of their operations or a major financial factor (Donkervoort, 2025).

In addition, incentives from net metering and subsidies for emission reduction technologies can be counteracted by taxes and tariffs, reducing their financial attractiveness. For instance, the Sustainable Energy Production and Climate Transition Incentive Scheme (SDE + +[2]) provides operational subsidies for e-boilers, which are of interest to horticultural consumers (greenhouses), who are mandated to phase out their combined heat and power plants. However, conflicting influences of network tariffs, electricity and gas taxes and the subsidy can be challenging to model and predict, contributing to the complexity of decision making (Donkervoort, 2025; Princen, 2024; European Union Agency for the Cooperation of Energy Regulators, 2023c).

5.2.2. High transaction costs

Contractual complexity is observed as a barrier to undertaking flexibility upgrades and offering flexibility to the system. Engaging external experts to navigate the legal and administrative sides raises costs for the consumers. In addition, consumers need to invest in expertise, which may require detailed knowledge of their own operations as well as of the electricity system and markets (Donkervoort, 2025). Building a team of in-house experts or outsourcing this task again adds to the consumer's financial burden. Some municipalities have started offering 'Flex Scan' services to businesses in their area with the aim of utilising flexibility for easing grid congestion (Gameente Rotterdam, 2026). Such programs must be expanded to assist users in understanding their flexibility potential and ways to benefit from its utilisation.

[2] Stimulering Duurzame Energieproductie en Klimaattransitie.

5.2.3. Financial uncertainty

Lack of certainty on the long-term need for flexibility is a significant barrier in the evaluation of the financial attractiveness of flexibility enablement. For consumers participating in the spot market or opting for retail contracts based on spot market prices, there is no price visibility beyond the next day. Similarly, while consumers participating in balancing markets can be contracted to provide balancing power in advance, the actual requirements are only known up to a day before activation, creating substantial uncertainty (Donkervoort, 2025; TenneT, 2025a,b).

5.2.4. Distorted market signals due to taxes and tariffs

Through the interviews, we learned that costs imposed by regulatory interventions form a significant economic barrier to flexibility in the Netherlands. Not only do these costs increase the energy expenses incurred by consumers, they also distort the market signals they respond to, causing suboptimal decision making. Among these costs, two have emerged as particularly concerning: network tariffs and energy taxes.

a) Network tariffs: while network tariffs are essential for the operation and maintenance of the grid, their structure and magnitude can be perceived as barriers by grid users. Athanasiadis (2025) showed that the maximum consumption limit reduces the ability of a steel manufacturing plant in the Netherlands to exploit electricity price variations. On the flip side, Princen (2024) showed that once a consumer transitions to the next higher network tariff category, the higher network capacity limit allows flexible prosumers such as horticulturists to utilise their flexibility more. However, these benefits are not large enough to offset the higher network tariff expenses (Princen, 2024).

b) Energy taxes: The Netherlands taxes electricity consumers based on their annual consumption levels, with taxes being the highest for small consumers (≤2900 kWh per annum), decreasing progressively with increasing consumption. Princen (2024) analysed the impacts of energy taxes and DSO tariffs on the operational decisions of horticultural consumers who own combined heat and power (CHP) generators along with heat buffers. They found that, in the current tax system with a discounted gas tax, horticulturists prioritised self-consumption of electricity generated by CHP, as opposed to purchasing from the market. However, when the discount on the gas tax is removed, it is more beneficial to purchase electricity from the market.

Further information on tariffs and the taxation regime in the Netherlands is provided in Section 6.

5.3. Regulatory barriers

For the purpose of this study, we consider a broad definition of the term 'regulatory' to include the set of legislation, policies and programs that influence the interaction of energy sector stakeholders with the system and the markets.

5.3.1. Lack of standardisation

There is no evidence that a lack of standardisation is a barrier in the Dutch market. The Dutch government has issued several regulations that specify how and which standards must be designed and implemented, including the Energy Act (Ministerie van Klimaat en Groene Groei, 2024), the Electricity Metering Code (T. N. A. f. C. M. ACM, 2023), the Electricity Tariff Code (T. N. A. f. C. M. ACM, 2022), and the Electricity Grid Code (Autoriteit Consument en Markt, 2022). The Royal Netherlands Standardisation Institute (NEN[3]) facilitates the creation and use of standards in the country in consultation with stakeholders. Among the currently active standards are: smart metering standardisation framework (Stichting Koninklijk Nederlands Normalisatie Instituut, 2015), device requirements for monitoring and measuring systems used for data collection, aggregation and analysis (Stichting Koninklijk Nederlands Normalisatie Instituut, 2025), and protection profile for smart meter - minimum security requirements (Stichting Koninklijk Nederlands Normalisatie Instituut, 2023).

5.3.2. Policy ambiguity

A lack of consistency in policy design has been observed as a significant barrier in the Dutch energy system and a source of persistent concern among its participants (Donkervoort, 2025). Consumers are hindered by the conflicting objectives of certain policies and regulations. For instance, horticultural consumers are required to shift away from gas-based combined heat and power plants to more sustainable technologies such as electric boilers and heat pumps (Ministerie van Algemene Zaken, 2019). As mentioned in Section 5.1, this would require higher power consumption from the grid. However, given grid congestion and the non-discriminatory grid access rule, an increase in their contracted capacity is uncertain, and it will also result in higher operating costs (Donkervoort, 2025; Princen, 2024). The interviewees remarked that the Dutch government fails to take a decisive role in infrastructure planning related to grid expansion and the location of energy-intensive industries. A lack of clear and realistic targets further contributes to investment uncertainty (Donkervoort, 2025).

5.3.3. Restrictive market entry criteria

In literature, a number of eligibility criteria for participating in energy markets are labelled as barriers. To understand whether similar barriers exist in the Dutch energy sector, we will first look at the energy markets and market products present in the country. The Dutch electricity market has a variety of trading products that can be utilised by both supply and demand in accordance with their techno-economic parameters. Consumers are able to submit bids for their total demand (implicit DR) as well as flexible demand (explicit DR) in the market, along with a bid price (reflecting their willingness to pay or accept). A brief overview of the exchange-based markets and products is provided in Table 6 (EPEX SPOT SE, 2025; ENTSO-E, 2025; European Union Agency for the Cooperation of Energy Regulators, 2023c; TenneT, 2022a; ENTSO-E, 2026; GOPACS, 2024a,b).

In addition to the wholesale market, market participants are also able to provide flexibility services in balancing markets through Balance Responsible Parties (BRPs) and Balancing Service Providers (BSPs). These products are procured by the TSO, TenneT. A brief overview of the products in balancing markets is provided in Table 7 (TenneT, 2022a; ENTSO-E, 2026; TenneT, 2025a,b,c).

The minimum bid size and minimum bid increment may form an entry barrier for small participants, both in the wholesale and the balancing markets. However, this barrier is mitigated by the presence of aggregators that can bundle capacity from small consumers and participate in the market on their behalf. The Dutch regulation allows direct participation of eligible demand response, storage and other distributed resources along with aggregation of the same in all balancing markets (European Union Agency for the Cooperation of Energy Regulators, 2023c). In fact, aggregators play an important role in connecting horticultural consumers in the Netherlands to the energy market (Princen, 2024; Donkervoort, 2025). Lampropoulos et al. (2018) also remarked that the participation fee charged by the market platform (such as EPEX Spot) may also form an entry barrier for small participants. However, if the participant chooses to go through an aggregator, the handling of such fees can be specified in the aggregation agreement, which is bilaterally determined. Thus, market entry criteria do not form a significant barrier for Dutch energy market participants.

5.3.4. Unsuitable flexibility product design

In literature, flexibility product design barrier is predominantly linked to the timing structures of various market products that DR can trade in. In particular, in the balancing markets, the time to activation (or ramp rates) and minimum availability duration are considered barriers by Lampropoulos et al. (2018). However, these criteria have been designed with the objective of swiftly restoring grid stability in

[3] Stichting Koninklijk Nederlands Normalisatie Instituut.

Table 6
Dutch electricity wholesale market design parameters.

Market	Minimum bid size	Minimum bid increment	Price floor (EUR/MWh)	Price ceiling (EUR/MWh)	Gate closure
Day ahead:auction-based market consisting of hourly volume-price bidding for 24 delivery hours of the following day. The trade can be performed for single hourly units or in blocks of several hours. Up to 256 bids are allowed in each time period.	1 MW	0.1 MW,0.01 EUR/MWh	−500	4000	D-1 12:00 hrs.
Intra-day Auction-based (IDA): implicit auction-based market part of Single Intra-day Coupling (SIDC) mechanism for cross-border capacity pricing and allocation with 15 min. tradable contracts.	1 MW	0.1 MW, 0.01 EUR/MWh	−9999	9999	IDA 1: D-1 15:00 hrs. IDA 2: D-1 22:00 hrs. IDA 3: D 10:00 hrs.
Intra-day Continuous: continuous matching of bids up to 0 min before delivery. 15 min., 30 min., and 60 min. tradeable products available.	1 MW	0.1 MW, 0.01 EUR/MWh	−9999	9999	D 0 min.
After-market trading: continuous trading of 15 and 60 min. tradable contracts for market participants to adjust their portfolios *after* the delivery of day-ahead and intra-day traded capacities.*(need to check if the parameters are the same as intra-day continuous market)*	1 MW	0.1 MW, 0.01 EUR/MWh	−9999	9999	D+1 08:30 hrs.
Congestion management market (GOPACS): TSO calls for participants to submit bids on the intra-day market to ease congestion in the grid. The bids are specifically for increasing or decreasing consumption (explicit DR) or generation. The market is symmetrical in nature, i.e., an increase in demand in one zone must be balanced by an equal reduction in demand in another.	1 MW	0.1 MW, 0.01 EUR/MWh	−9999	9999	D 0 min.

Table 7
Dutch electricity balancing market design parameters.

Market	Procurement method	Minimum Capacity	Activation	Time to activation	Minimum availability after activation
Frequency Containment Reserve (FCR): pooled market of 12 European TSOs for procuring balancing power through day-ahead auctions of symmetric products (up and down reserve) in four-hour blocks.	Auction	1 MW	Automatic	max. capacity within 30 s	15 minutes
automatic Frequency Restoration Reserves (aFRR): also called regulating power, real-time balancing power procured through daily pay-as-bid capacity auctions where the contracted party (balancing service provider) is required to submit energy bids for designated periods. In addition, voluntary energy offers can be made by qualifying BSPs	Contract (auction), Voluntary	Capacity bids: 1 MW, increments of 1 MW Energy offers: 1 MW, max. 999 MW	Automatic	Visible change within 30 s, Min. rate of 20% of bid size per minute	10 minutes
manual Frequency Restoration Reserve, directly activated (mFRRda): also called incident reserves, procured to hedge against unforeseen incidents and periods of long-lasting power imbalances.	Auction	1 MW, increments of 1 MW	Manual	Max. time for full activation (downward): 15 min Max. time for full activation (upward): 10 min	15 minutes

case of imbalances and sudden deviations (TenneT, 2022a; ENTSO-E, 2019). Relaxing these criteria can jeopardise the safety and reliability of the grid, particularly at a time when instances of grid imbalances are increasing (TenneT, 2024a). Thus, in the case of the Netherlands, flexibility product design is not considered a barrier based on the definition provided in Section 3.

5.3.5. Information insufficiency

At present, market participants lack long-term visibility of market conditions including prices and demand and supply of flexibility, congestion pricing, and congestion levels. The longest lead time available in current wholesale markets and balancing markets is one day, with participants able to trade only for the current and the following day (D and D+1) (EPEX SPOT SE, 2025; TenneT, 2024b). As a result, market information is available for only up to 24 hours of the next day. This does not provide adequate information for investment and operation planning by consumers (Donkervoort, 2025). While there is a futures market with products ranging from day-ahead to year-ahead, the liquidity in the market is very low and the time resolution of trading products is too small to be used for flexible demand (EEX, 2022). Another information barrier is the lack of outlook on flexibility requirements in the future that inhibits long-term planning by consumers. Absent reliable forecasts for long-term flexibility requirements and benefits, consumers are reluctant to invest in flexibility-enabling upgrades (Donkervoort, 2025).

5.4. Behavioural barriers

5.4.1. Lack of expertise

For many consumers, from residential consumers to mid-sized horticultural consumers and even some large industrial users, lack of in-house knowledge and expertise in energy markets is a major hurdle to enabling flexibility (Donkervoort, 2025; Geelen et al., 2019). Developing or acquiring such expertise requires both time and financial resources, compounding the difficulty faced by such consumers (Donkervoort, 2025). Path dependence and risk aversion also prevent potentially flexible consumers from opting for new transmission contracts discussed in Section 5.3.

5.4.2. Incompatible individual preferences

Individual preferences play a crucial role in determining the willingness of consumers to participate in flexible behaviour and the degree

of such participation. A long-term demand response study conducted by Kobus et al. (2015) revealed that consumers are less likely to modify their consumption when they lack easy-to-use energy management systems. Similarly, Geelen et al. (2019) found that merely viewing consumption data on smart displays or phone apps does not motivate consumers to change their behaviour. Rather, consumers would require more customised suggestions and guidance from the app on how to use that information (Geelen et al., 2019).

There is also an element of risk aversion, particularly among industrial consumers who are unwilling to jeopardise the stability of their operations by incorporating flexibility. Such consumers consider the benefit from flexibility to be outweighed by the potential loss of revenue due to operational disruptions despite the availability of incentives (Donkervoort, 2025).

5.4.3. Ambiguity in division of roles and responsibilities

The roles and responsibilities of different market stakeholders are clearly defined under the Energy Act (Ministerie van Klimaat en Groene Groei, 2024). However, conflict arises in the prioritisation of flexibility as an objective in decision making, communication styles and the collaboration and coordination between stakeholders. Previously, the system operators relied on consumers to make decisions on flexibility based on their private interests. However, the perspective is now shifting with regulators and system operators taking an active role in planning for flexibility utilisation and incentivisation (Donkervoort, 2025; Autoriteit Consument & Markt, 2024).

5.4.4. Diverging interests of stakeholders

The coordination and cooperation required between market participants and grid operators are undermined by the diverging interests of these stakeholders. Market participants are private entities that prioritise self-interest in the form of operational efficiency, cost minimisation and long-term profitability. Consequently, they prefer customised contracts and solutions that allow them to maximise the benefit from flexible behaviour, which may contribute to network congestion. On the other hand, grid operators are responsible for the safe and reliable operation of the network and aim to reduce imbalances and congestion. They prefer standardised solutions that ensure transparency and allow large-scale implementation (Donkervoort, 2025). Until policy and regulatory design are streamlined and stakeholders are aligned on their common goals and responsibilities, this barrier will continue to hinder flexibility deployment.

6. Discussion

In the previous section, we reviewed the barriers in the Dutch energy sector. A number of barriers that were identified correspond to the literature: operational and process constraints, investment and operation costs, network constraints, transaction costs, financial uncertainty, taxes and tariffs, policy ambiguity, information insufficiency and lack of expertise. On the other hand, there is limited evidence of certain barriers in the Dutch context, including metering, sensing and communication infrastructure limitations, lack of standardisation, and market entry criteria.

The interviews with Dutch energy sector stakeholders revealed a common theme: deficiencies in policy making and regulatory design. The major barriers - network constraints, financial uncertainty, and taxes and tariffs - were deemed to be attributable to shortfalls in policy formulation and regulatory alignment with system needs.

6.1. Network constraints

Fig. 3 shows the current grid situation with severe congestion in both transmission and distribution networks. Consumers who request new connections or increases in their contracted capacity face long queues with uncertain wait times. It is also worth noting that while some areas have capacity available in their regional grid, congestion in the high-voltage transmission grid reduces the possibility of new or supplemental contracted capacity. As mentioned in Section 5.1.3, a direct consequence of this is delay in the realisation of available flexibility.

An alternative for users to deploy flexibility despite grid congestion is to apply for variable transmission rights, or non-firm capacity, for the residual grid capacity available outside peak hours. The applications for non-firm capacity are entered into a separate queue, independent of the fixed (or firm) capacity queue, which can expedite grid access. In an amendment to the Electricity Grid Code, issued by the Authority for Consumers and Markets (ACM) on 16 July 2024, a set of alternative transmission rights (ATR) were added to the code, including fully variable transport rights, time-block bound transport rights and duration-bound transport rights (Autoriteit Consument en Markt, 2024). Consumers opting for ATRs gain from discounted network tariffs while network operators gain from more effective usage of grid capacity

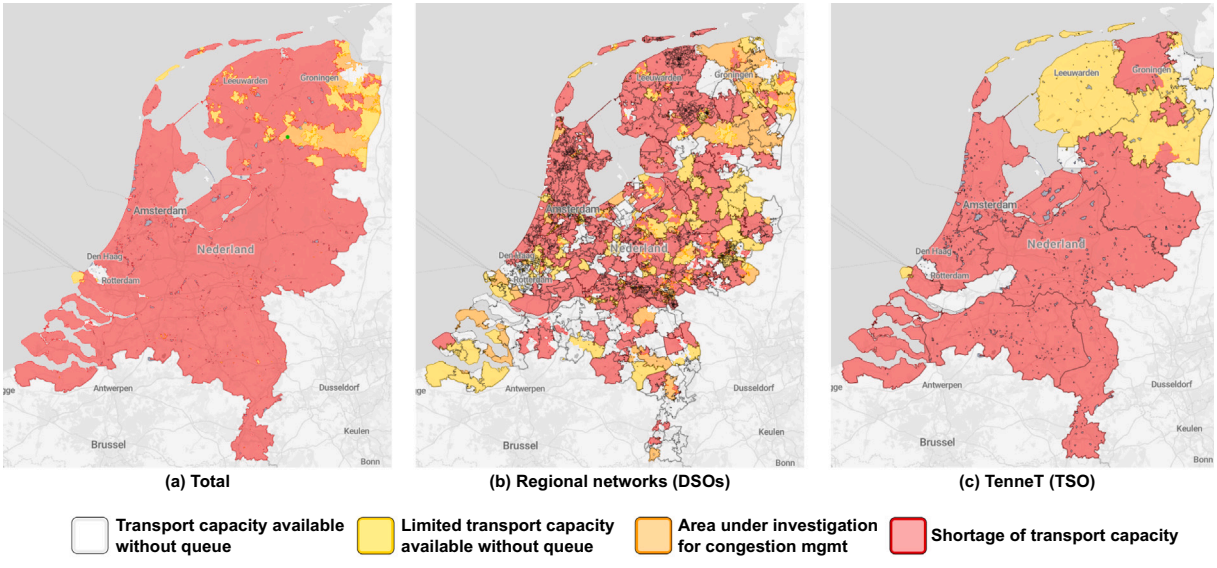


Fig. 3. Grid capacity availability for new connections.
Source: Netbeheer Nederland, Extracted on 20 Mar 2026 (Netbeheer Nederland, 2025)

and reduced congestion. Consumers also have the option to enter into capacity-limiting contracts (CBC[4]) under which they reduce their consumption during periods of congestion based on pre-negotiated terms with the system operator (Rijkdienst voor Ondernemend Nederland, 2024).

However, stakeholders expressed their concerns regarding the implementation of ATRs and CBCs. Utilisation of these instruments is obstructed by contractual complexity, unclear information, and differing objectives of stakeholders. While ATRs are designed to promote load shifting among large consumers, there is a reluctance among consumers to change their contracts, fearing disruption of operations and reduced security of supply (Donkervoort, 2025). Similarly, CBCs can expose businesses to load curtailment at unsuitable times, creating financial and technical risks (Bobocescu, 2025). At the same time, the ability of the consumer to dictate the price of CBCs can increase the cost of grid management for the network operator, making it an unattractive solution for them (Donkervoort, 2025). Thus, even measures designed to promote flexibility and more efficient use of the grid may prove ineffective.

6.2. Taxes and tariffs

A major concern for energy consumers in the Netherlands is the costs imposed by taxes and network tariffs as they can form up to 50% of their total energy costs (European Union Agency for the Cooperation of Energy Regulators, 2024). These include taxes on inputs: gas and electricity, taxes on outputs: carbon emissions, and tariffs on distribution and transmission networks usage. An overview of the key characteristics of these elements is provided in Table 8. This summary effectively depicts the large variation in their design and application, which can make determining optimal flexibility levels and energy consumption very complex.

Network tariffs: Network tariffs in the Netherlands vary considerably across connection sizes. Small consumers, connected to the low-voltage distribution grid, pay a fixed annual charge that is not linked to their consumption level. Consumers connected to the medium- and intermediate-voltage distribution grids pay a three-part tariff comprising a fixed charge per kW of connected capacity, a variable charge per kW of maximum power consumed in a month, and a volumetric charge per kWh of consumption. Large consumers connected to the high- and extra-high-voltage transmission grids pay a fixed charge per kW of connected capacity and a variable charge per kW of annual or monthly maximum consumption. Additionally, large consumers are constrained by limits on their maximum monthly consumption. Violation of this limit results in their transition to the next higher tariff category.

For consumers connected to medium, high-, and extra-high voltage grids, the capacity charge for maximum monthly or annual consumption forms the dominant component of network tariffs. The rationale behind this structure is to incentivise stable power consumption and discourage large fluctuations. Consequently, it also discourages flexible behaviour that would entail frequent changes in the consumption pattern, particularly if it leads to the exceedance of the maximum allowed consumption in the respective tariff category.

Grid tariffs are determined on the basis of actual grid operation costs in previous years. As seen in Fig. 4, tariffs rose sharply in 2023 with a further increase in 2024. The jump in tariffs in 2023 and 2024 can be largely explained by the sharp increase in energy purchase costs in 2021 associated with the procurement of balancing services (including control and reserve power, emergency power, primary reserve and recovery services) as well as grid losses(TenneT, 2022b; Autoriteit Consument en Markt, 2023; TenneT, 2023). These sudden changes, along with uncertainty surrounding future tariffs create hesitation among network users to implementing short-term behavioural changes or long-term structural changes as the benefit from the same cannot be foreseen.

Energy taxes: as shown in Fig. 5, electricity taxes disproportionately affect small and medium-sized consumers with annual consumption up to 50,000 kWh, while large consumers share a fairly low burden of taxation.

Similar to electricity, all end users of natural gas as well as its substitutes such as biogas are subject to gas tax that is levied per cubic meter (m^3) of consumption. A snapshot of the evolution of gas taxes is provided in Fig. 6 (Belastingdienst, 2024a). It must be noted that horticultural consumers using natural gas for heating are taxed at a lower rate for consumption up to 1 million m^3. At higher volumes (>1 million m^3), they are taxed at the standard rate. Furthermore, natural gas used in CHPs for self-consumption of heat and electricity is exempt from the gas tax (Belastingdienst, 2024b). However, following the amendment to the Fiscal Climate Measures for the Greenhouse Horticulture Act in December 2023, the discount on the tax for horticultural users will be gradually phased out between 2026 and 2035, at which point the tax rate will merge with that for general users (Ministerie van Financiën, 2023).

As described in Section 5.2.4, the trade-off between electricity and gas consumption at a given time is influenced by the applicable energy taxes on both carriers. High electricity taxes can tip the balance in favour of gas, which may adversely impact electrification, a major potential source of flexibility, particularly in heat-intensive sectors such as horticulture, chemicals and metallurgical industries.

The concerns of energy sector stakeholders in the Netherlands are grounded in the reality of a fragmented regulatory framework. While a number of regulations affect the deployment of flexibility, their impact may be an unintended or unforeseen consequence rather than an explicit policy goal. For flexibility to become widely viable, it must be accounted for in all energy-related policy making from the design of new network contracts to the determination of tariffs and taxes with the consensus of all stakeholders.

7. Conclusions and policy implications

There is a large body of literature on the barriers to flexibility, with authors employing a diverse set of frameworks for their analysis. The most frequently discussed barriers in literature are: metering, sensing and communication equipment deployment limitations, lack of expertise, imperfect information, financial uncertainty, market entry criteria, policy ambiguity, individual preferences, and division of roles and responsibilities. However, we observed a lack of consistency in the design of frameworks used for identifying, classifying and analysing barriers, which not only complicates the comparison of barriers in the existing literature but also limits their future study. Thus, the main research gap identified in this study is the lack of a framework that can be replicated and applied to different energy systems and geographies, particularly given the differences in regulatory frameworks, market design, socio-economic dynamics and fiscal structures.

In order to fill this gap, we present a systematic and comprehensive framework, provided in Section 4, that classifies all types of observed barriers to flexibility by their techno-economic characteristics. We collated the barriers found in the literature and analysed the reported categories, definitions and terminology and thus identified 16 types of barriers in four categories: technical, economic, regulatory and behavioural. Our framework is broad enough to cover all types of barriers but leaves room for subdivision into sector-specific elements. A salient example is taxes and tariffs under the economic barriers category. These elements can vary significantly from one country to another. For example, while one country may bundle all network costs into one tariff, another might levy separate charges for transmission and distribution networks and divide them into capacity and volumetric components measured at different periods. (European Union Agency for the Cooperation of Energy Regulators, 2025). The economic impact of all these tariff designs can be studied under the umbrella of taxes and tariffs.

[4] capaciteitsbeperkend contract.

Table 8
Policy parameters for electricity market participants.

	Electricity						
	Electricity taxes	**DSO network tariffs**	**TSO network tariffs**	**SDE++**	**Rooftop solar prosumer**	**Gas taxes**	**Carbon taxes**
Applicability	All consumers	All consumers connected to distribution grid	All consumers connected to transmission grid	Consumers/ generators with RE or emission reduction technologies	Consumers with grid-connected rooftop solar systems	All consumers	Industrial consumers, waste incinerators, nitrous oxide emitters
Consumer categories	Categorisation based on end-use type, subcategorisation based on total annual consumption level	Categorisation based on consumer size, subcategorisation based on connection size or connected voltage	Categorisation based on connected voltage	Categorisation based on technology for RE generation or CO2 emission reduction	Categorisation based on retail price contract type	Categorisation based on total annual consumption level	Categorisation based on total emissions
Components	Variable	Transport dependent (variable), transport independent (fixed)	Transport dependent (variable), transport independent (fixed)	Base amount, correction amount, base energy price, base GHG amount	Static (FiT) or dynamic (market price) tariff (variable)	Variable	Variable
Accounting period	Annual	Annual, monthly, time of use (hourly)	Annual, monthly, weekly	Annual	Annual, hourly	Annual	Annual
Variable	Energy consumption (kWh)	Connection size (kW), Maximum withdrawal(kW), energy consumption (kWh)	Contracted capacity (kW), Maximum withdrawal(kW)	Energy generated (kWh), emissions avoided/reduced (tCO2)	Energy injected into the grid (kWh)	Gas consumption (m^3)	CO2 emission (tons)
Unit	€/kWh	€/kW, €/kWh	€/kW, €/kWh	€/kWh, €/ton CO2 reduction	€/kWh	€/m^3	€/ton cO2
Exceptions and special conditions	Subsidised rate for EV users, energy tax credit provided to each consumer	None	Very large users allowed to negotiate tariffs	Dedicated budget for 'molecule' related technologies	None	Reduced rate for horticulture consumers	Large industrial consumers can have 'custom' agreements

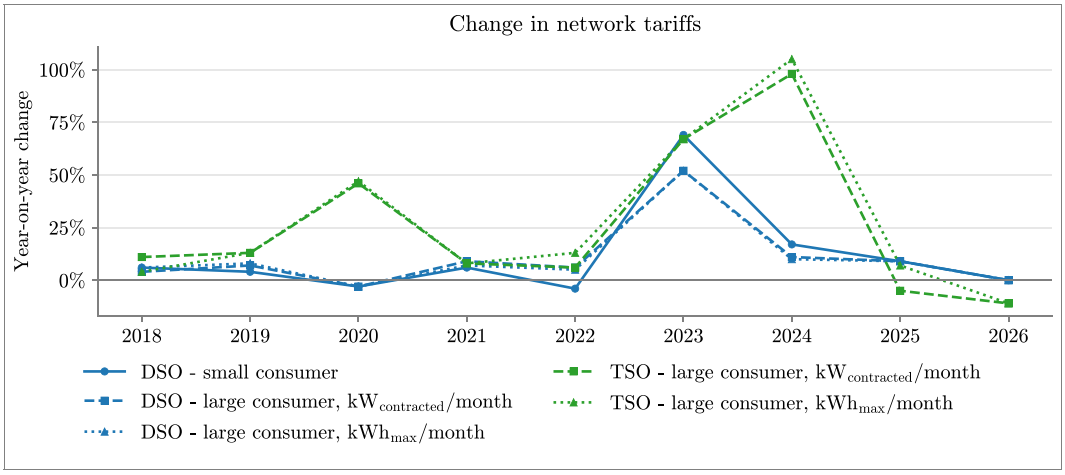


Fig. 4. Year-on-year change in network tariffs (Stedin, 2024; Autoriteit Consument & Markt, 2016, 2018, 2017, 2019, 2020, 2021, 2023, 2025; Stedin, 2026a,b).

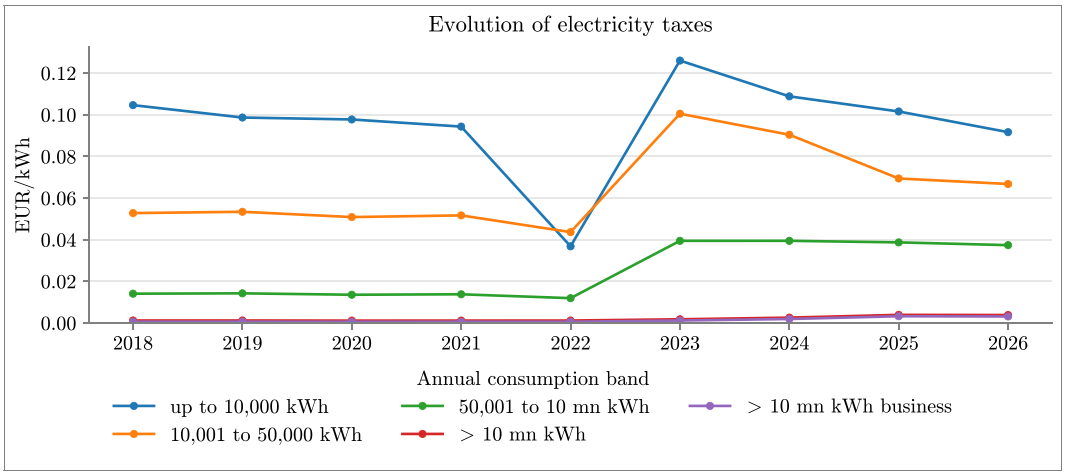


Fig. 5. Evolution of electricity taxes (Belastingdienst, 2024a).

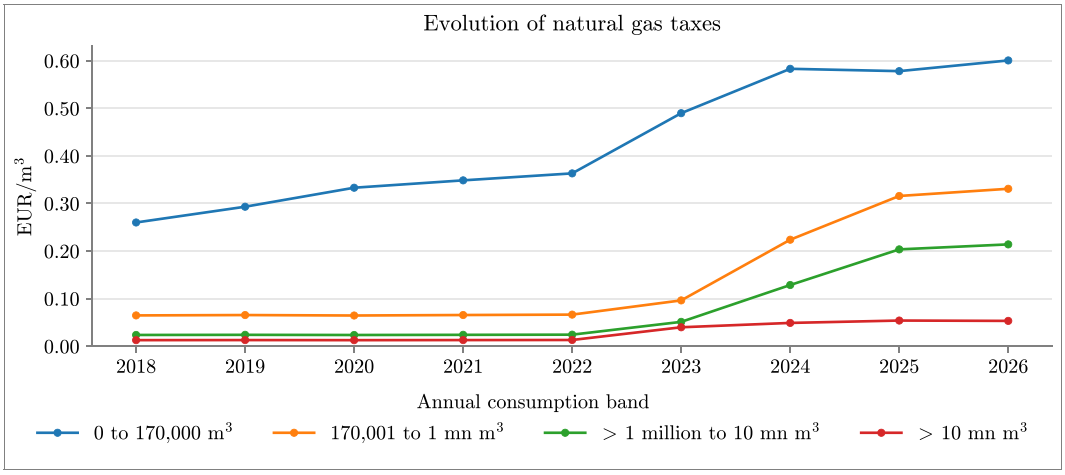


Fig. 6. Evolution of natural gas taxes (Belastingdienst, 2024a).

We demonstrated the analytical value of our framework by applying it to the Dutch energy sector. We applied a mixed-methods research design, combining a careful review of academic and grey literature with semi-structured interviews with Dutch energy sector stakeholders. As shown in Table 9, several barriers posed similar challenges in the Netherlands as found in the literature from other geographies, e.g., technical barriers such as process and operational dependencies and network constraints, economic barriers such as financial uncertainty and tariffs, regulatory barriers such as policy ambiguity and information insufficiency and behavioural barriers such as individual preferences and lack of expertise. Other barriers did not pose as big a challenge in the Netherlands as found in the literature, including market entry

Table 9
Summary of findings of the Dutch case study.

Category	Barrier	Relevance in the Netherlands
Technical	Process and operational constraints	High
	Metering, sensing and communication infrastructure limitations	Low
	Network constraints	High
Economic	High investment and operation costs	High
	High transaction costs	High
	Financial uncertainty	High
	Distorted market signals due to taxes and tariffs	High
Regulatory	Lack of standardisation	Low
	Policy ambiguity	High
	Restrictive market entry criteria	Low
	Unsuitable flexibility product design	Low
	Information insufficiency	High
Behavioural	Lack of expertise	High
	Incompatible individual preferences	High
	Ambiguity in division of roles and responsibilities	Low
	Diverging interests of stakeholders	High

criteria, lack of standardisation and limitations of metering and sensing equipment.

While the framework provides a suitable starting point for the study of barriers, we recognise that it does not offer a mechanism to quantify and rank the barriers based on their relative severity. We aim to overcome this limitation in our future studies. We will be conducting a quantitative analysis of the barriers to flexibility in the Dutch energy sector that will allow us to enrich and expand the current case study.

Finally, we would like to highlight another aspect of flexibility studies distinct from the study of barriers. In Section 2, we showed the diversity in the study of demand-side flexibility, from its very definition to the parameters assigned for its characterisation, types of questions studied and the methods employed for the same. We observed that in both the literature and the design of regulatory initiatives, demand-side flexibility is often viewed as a solution to be utilised only when the system is experiencing stress. This is also evidenced by our research on the barriers faced by stakeholders in the Dutch energy sector in enabling and providing demand flexibility. A number of stakeholders consider flexibility of demand to be a stop-gap measure, needed only until the grid can be reinforced and more network capacity made available. We argue that flexibility is an inherent characteristic of a consumer and can be expressed irrespective of external stimuli. Overlooking implicit flexibility creates a blind spot in policy making and may lead to short-sighted incentive schemes and solutions. Flexibility is already displayed by many consumers and prosumers on account of their behavioural factors even in the absence of external forces. Additionally, both academic studies and evidence from real-world projects suggest that this inherent flexibility can both be enhanced and beneficially tapped. Thus, we believe that it is time to shift the perspective from flexibility as a tradable product, be it short or long term, to flexibility as an inherent characteristic of the system and its participants.

CRediT authorship contribution statement

Sugandha Chauhan: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Wessel Donkervoort:** Investigation, Formal analysis, Data curation, Conceptualization. **Sebastiaan Hers:** Writing – review & editing, Supervision, Funding acquisition. **Milos Cvetkovic:** Writing – review & editing, Supervision, Funding acquisition. **Laurens de Vries:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of Generative AI and AI-assisted technologies in the writing process

Generative AI model ChatGPT, GPT-5, was used to assist in writing the Python code for visualisation and to improve the language and readability of the manuscript.

Funding

This work was completed as part of the DEMOSES Project ("Designing and Modeling future systems of Energy Systems"), which was funded by the Dutch Research Council (NWO) under the ESI-FAR grant program, grant number ESI.2019.004.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the Dutch energy sector stakeholders who agreed to be interviewed for this study.

Data availability

The authors do not have permission to share data.

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