Current Sustainable/Renewable Energy Reports (2025) 12:23
https://doi.org/10.1007/s40518-025-00268-7

REVIEW

Non-Firm Grid Connections: A Review of Access Types, Mechanisms, and Regulatory Frameworks

Manuel Romeo Monterde[1] · **Erik F. Alvarez**[1,2] · **Orlando Valarezo**[1]

Accepted: 11 June 2025

Abstract

Purpose of Review Non-firm (flexible) grid connection agreements are emerging as a fast, lower-cost alternative to traditional firm access for integrating renewable and distributed energy resources (DERs). This review examines: *Which types of non-firm agreements exist, how are they implemented, and what lessons can be drawn from recent regulatory pilots?*

Recent Findings Literature and pilot projects reveal four predominant models of non-firm grid connections: capacity-limited, time-limited, dynamic operating envelopes, and fully flexible based access. These models are being formalised through legislation or regulatory guidance in the United Kingdom, Australia, Spain, and in various countries of the European Union. Their implementation is increasingly supported by digital monitoring and growing links to local flexibility markets.

Summary Flexible connections can reduce connection costs by up to 80% and halve leadtimes, while safely expanding hosting capacity. Key challenges are curtailment predictability, compensation, and alignment with emerging market platforms. Clear, standardised regulatory frameworks and interoperable digital solutions are essential for scaling these agreements and accelerating DER integration.

Introduction

The ongoing transformation of electricity systems, driven by the rapid deployment of renewable energy sources (RES) and distributed energy resources (DER), such as rooftop solar photovoltaic (PV), battery energy storage systems (BESS), electric vehicles (EVs) and heat pumps (HPs), are introducing an increasing pressure on distribution grids. These traditionally passive, centrally managed infrastructures are now expected to support bidirectional power flows, variable generation and highly localised energy exchanges. One of the most pressing challenges in this context is the timely and cost-effective connection of new generation and loads to the grid, particularly in areas where grid constraints persist. Traditional "firm" connection agreements, which guarantee full and uninterrupted access to the grid, have long been the standard approach to providing access to grid users. However, these agreements often require significant grid reinforcement investments and extensive permitting processes, resulting in long connection lead times and increased capital costs. As a result, many potential DER developers face delays or prohibitive barriers when attempting to connect to already congested distribution grids [1].

To address these challenges, a growing number of grid operators and regulators have begun to explore non-firm or flexible connection agreements, which are contractual arrangements that allow DERs or flexible loads to connect to

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Manuel Romeo Monterde, Erik F. Alvarez and Orlando Valarezo, contributed equally to this work.

✉ Erik F. Alvarez
ealvarezq@comillas.edu; erik.alvarez@ri.se

Manuel Romeo Monterde
mromeo@comillas.edu

Orlando Valarezo
ovalarezo@comillas.edu

[1] Institute for Research in Technology (IIT), ICAI School of Engineering, Comillas Pontifical University, Madrid 28015, Spain

[2] Department of Measurement Science and Technology, RISE Research Institutes of Sweden, Göteborg 412 58, Sweden

the grid under pre-defined curtailment conditions or capacity limits [2, 3]. These agreements provide access to the grid based on real-time or predicted grid conditions, enabling faster and more cost-effective integration of new resources. Flexible connections are often facilitated by active network management (ANM) systems, which dynamically monitor network conditions near real-time and adjust the output of DERs accordingly to maintain system reliability. There are also purely contractual options, where operational limits are set on a pre-agreed basis, either in time or in the maximum capacity granted to the user. This results in several forms of non-firm connections, including capacity-limited agreements, time-limited off-peak access, dynamic operating envelopes (DOEs) based on real- time hosting capacity, and fully flexible ANM-controlled access [4]. Each type offers different trade-offs between grid utilisation, user predictability and operational complexity. While non-firm connections offer promising benefits in terms of accelerating DER deployment and deferring costly reinforcements, they also raise critical concerns regarding curtailment uncertainty, fairness, revenue implications for DER operators, and long-term market integration [5].

In parallel, emerging flexibility tools such as distribution network reconfiguration (DNR) and local flexibility markets (LFMs) [6] are being developed to complement non-firm access and enable new operational strategies for distribution system operators (DSOs). The coordinated use of these mechanisms can improve network efficiency, reduce curtailment and support the evolving role of DSOs as neutral market facilitators. The introduction of flexible connections is increasingly being driven by regulatory innovation. Countries such as the United Kingdom (UK), Spain, Belgium, Austria and other members of the European Union (EU) have taken early steps to define regulatory frameworks, pilot projects and market-based approaches for non-firm access. However, regulatory approaches vary widely, and the lack of standardised methodologies, cost-reflective pricing structures and consistent curtailment rules continue to hinder wider uptake.

This review paper aims to synthesise recent theoretical, technical and regulatory developments on non-firm and flexible access arrangements to electricity distribution networks. It seeks to provide insights into what are the main types and operating principles of non-firm connections, as well as how these are being interpreted and implemented across diverse regulatory frameworks. In doing so, it examines the evolution of relevant policies and legal instruments in selected jurisdictions such as the UK, Spain, Germany, Australia and others.

The remainder of the paper is structured as follows: Section 2 reviews the theoretical foundations, types and methods of non-firm access. Section 3 examines the regulatory context and highlights progress in the introduction of non-firm access in some countries. Finally, Section 4 summarises the findings.

Theoretical Concepts, Types, and Methods

Definition of non-firm Connection Agreements

Non-firm connection agreements - also known as *alternative*, *flexible*, or *curtailable* connection agreements - refer to contractual arrangements between a grid user (generator or consumer) and a network operator in which the user accepts conditional access to the electricity grid. Under these agreements, the user's right to export or import power is not guaranteed at all times, but rather subject to operational constraints imposed by the system operator to ensure network security and reliability.

These constraints may take various forms:

- Static limits, where maximum capacity values or curtailment periods are predetermined and fixed (e.g., time-limited and capacity-limited connections).
- Dynamic limits, where capacity thresholds vary over time and are determined based on real-time or forecasted grid conditions (e.g., dynamic operating envelopes and fully flexible connection agreements enabled through active network management).

Unlike firm connections—which ensure unrestricted access to the network at all times below the awarded firm capacity—non-firm connections allow operators to curtail, reduce, or fully disconnect a user's capacity during periods of network congestion, voltage deviation, or reverse power flow risks. Curtailment rules can be structured according to various principles, such as *Last-In First-Out (LIFO)*, *pro-rata*, or *curtailment indices*, depending on the regulatory framework and technical implementation.

An additional dimension to characterise non-firm connection agreements is the predictability of curtailment. This refers to how much advance notice or certainty a system user has about when and how their capacity will be curtailed. This classification is essential for understanding the level of risk and operational flexibility faced by users under different types of non-firm access. Curtailment can be fixed, where the limit is permanent and known (e.g., capacity-limited connections), or scheduled, when it occurs during pre-agreed time windows (e.g., time-limited connections). In more dynamic arrangements, curtailment may be foreseen, as in the case of Dynamic Operating Envelopes, where capacity limits vary in real time but are still communicated in advance with some forecasting horizon. At the most uncertain end of the spectrum are unforeseen curtailments, typical of fully flexible connections managed through ANM systems, where limitations are imposed in real time without prior notice.

Non-firm agreements can be:

- Temporary, serving as a transitional arrangement until firm access is made available through network reinforcements, or.
- Permanent, if both parties agree and the level of service is deemed adequate and economically justified.

In this paper the term “non-firm connections” is used. However, below is a list of several alternative names that can be found in the literature that are also used to refer to these types of connections:

- Non-firm access.
- Alternative connection agreements (ACAs).
- Flexible connection.
- Interruptible connection.
- Conditional connection.
- Constrained connection.
- Curtailable connections.
- Dynamic connections.
- Smart connections.
- Flexible interconnection.

Types of non-firm Connection Agreements

The main types of non-firm connection agreements identified are summarised in Fig. 1 and discussed in detail in the following subsections. Figure 1 shows a classification scheme that distinguishes non-firm connections types based on two key characteristics introduced earlier: the temporary variability of the capacity limits and the curtailment predictability.

Capacity-limited Connection Agreements

In a capacity-limited connection agreement, the contracted capacity is firm but lower than the requested by the user. These connections are often temporary and are agreed to be extended to the full firm capacity once the network upgrades have been completed. This type of connection is typically applied for users with an export/import capacity exceeding the available network capacity, as estimated by the system operator. A typical example of such an agreement is to provide access to the user as soon as possible, limited to less capacity than requested, until the necessary network reinforcements are made. The user can then be granted the full capacity requested.

Time-limited Connection Agreements

In time-limited connection agreements, the contracted capacity is firm except during pre-defined scheduled time windows - typically the network’s peak demand periods - when the contracted capacity must be reduced or curtailed. These scheduled curtailments are communicated in advance and embedded in the connection agreement, allowing users to plan their operations accordingly. This type of connection is often applied in contexts where grid constraints are predictable and concentrated in specific timeframes, such as winter evenings in high-demand zones. In this case, the user is offered firm access, but its capacity is limited during those hours of the year.

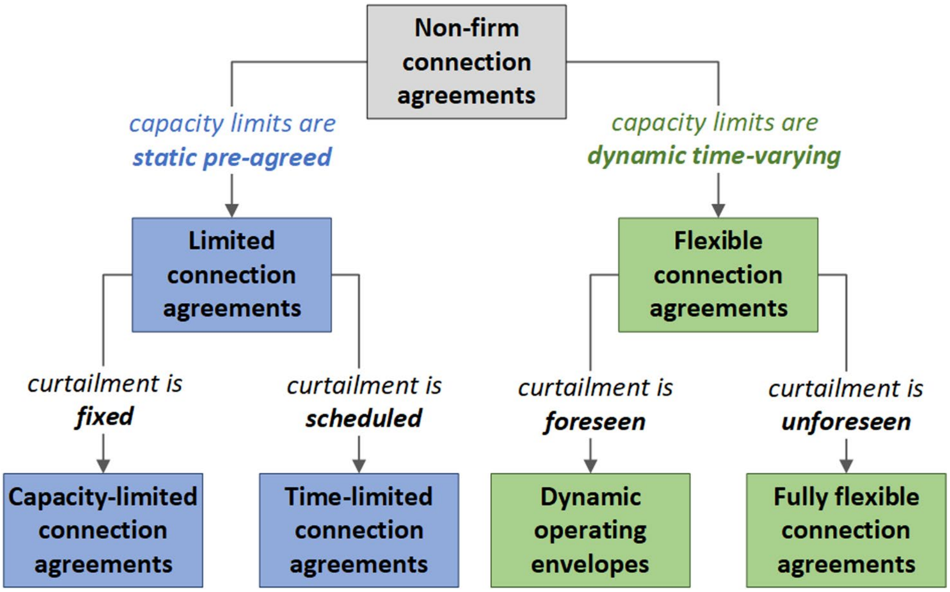

Fig. 1 Classification of the different types of connection agreements based on the temporary variability of capacity limits and the predictability of curtailment

Dynamic Operating Envelopes (DOEs)

Also known as "*Flexible export limits*", DOEs represent a form of dynamic non-firm access in which the capacity limits for export or import (operating envelopes) vary continuously based on real-time or forecasted network conditions. Although these variations are dynamic, the curtailment is considered foreseen because users receive updated capacity limits ahead of each dispatch interval (e.g., every 5–15 min), typically via automated communication interfaces. This enables users to adapt their behaviour and optimise operations within safe operating boundaries. DOEs are increasingly adopted in high-DER penetration areas where traditional fixed export limits are too conservative, unlocking additional hosting capacity in a secure and efficient manner.

The context in which these connections emerge is that the capacity limits agreed upon as part of the customer connection process are typically fixed and determined via conservative regulatory criteria, to avoid failures under worst-case congestion conditions. For example, distribution network operators (DNOs) in South Australia typically set 5 kW static export limits at each connection point for most small customers, to protect the integrity of the network for all customers [7]. However, many networks operate far from these limits for much of the time, especially outside peak hours. DOEs enable higher export/import limits when there is more hosting capacity on the local network.

Such connections emerge in Australia, and the validity of their operation was demonstrated in the Advanced Virtual Power Plant (VPP) Grid Integration project, which was jointly carried out by Australian DNO SA Power Networks and the Tesla South Australian VPP from 2019 until 2021. This project seeks to demonstrate how customer solar and battery systems can achieve increased energy exports to the grid by utilizing dynamic export limits instead of static ones, while also evaluating the benefits this approach offers to both customers and VPP operators. The initiative developed an application programming interface (API) that facilitates the real-time exchange of location-specific data regarding distribution network constraints between SA Power Networks and the Tesla VPP, allowing the VPP to adjust its output efficiently to maximize the use of available network capacity.

Fully Flexible Connection Agreements Enabled Through Active Network Management

In fully flexible connections, the timing of curtailment is determined in real-time and without prior notice, typically making curtailment unforeseen from the user's perspective. Users agree to connect to the network knowing that their capacity may be limited for certain periods of time depending on the system's needs. Unlike time-limited connection agreements, the periods of time during which capacity can be limited are not pre-agreed but are determined dynamically. Thus, they do not guarantee system users that their required capacity will be available anytime. However, curtailment follows the rules agreed in the connection agreement.

These agreements are typically implemented via active network management (ANM) systems, which are network control systems that actively monitor grid conditions and reallocate available capacity in real-time in each area to connected users in response to changing constraints. The most sophisticated version of fully flexible connections exists in the UK, and it allows network operators to actively curtail energy exports/imports as required to prevent constrained parts of the grid from exceeding their network limits. ANM systems require communications equipment and a centralized networks control system. This type of connection offers the highest level of flexibility and grid optimisation, but also entails the greatest level of operational uncertainty for the user.

Fully flexible connections can follow three types of curtailment rules: (1) Last-In First-Out, where newer connections are curtailed first; (2) pro-rata, where curtailment is shared proportionally among connected users during a constraint; and (3) curtailment index, which protects users from excessive curtailment by assigning a predicted curtailment threshold to each user and triggering intervention if it is exceeded [8].

The main testing framework for fully flexible connections was the Flexible Plug and Play (FPP) project, carried out by the British DNO UK Power Networks from 2011 until 2014 [9]. It was a pioneering initiative in mainland UK, conducted across a 700 km² area of their distribution network. This project was the first to investigate fully flexible connections, enabling distributed generation (DG) customers to connect to the network with their output dynamically controlled by the DNO to maintain operational limits, making use of the ANM scheme.

Attributes of non-firm Connection Agreements

Beyond their structural differences, non-firm connection agreements can also be characterised by a range of technical, operational and economic features that distinguish them from traditional firm access:

- Predictability of curtailment: Some agreements offer predictable schedules (e.g. time-limited), while others (e.g. ANM-based) involve uncertain curtailment patterns based on real-time conditions.

- Contract duration: Agreements can be temporary (in anticipation of reinforcements) or permanent (as an alternative to grid upgrades).
- Technical enablement: Flexible connections often require real-time monitoring, smart metering, remote control and interoperable information and communications technology (ICT) systems.
- Fairness and transparency: Transparent curtailment rules (e.g. last-in-first-out or pro-rata) are essential to ensure that all participants understand and accept the operational constraints.
- Regulatory and market compatibility: The design of non-firm connections agreements must be compatible with national or regional regulatory frameworks and should ideally allow for participation in local flexibility markets and network services.
- Customer incentives and risk allocation: Agreements need to balance system optimisation with incentives for DER investors who may face revenue risks due to curtailment.

Regulatory Context

The implementation of non-firm access arrangements is closely linked to the evolution of electricity regulation. While the technical and economic rationale for flexible access is well established, the practical implementation of such mechanisms requires clear regulatory frameworks, market design adjustments and supportive institutional arrangements.

This section provides a comparative review of the regulatory landscape of non-firm connection agreements in selected jurisdictions, drawing on recent policy developments and pilot projects. The first part focuses on the regulatory status within the EU Member States, followed by an analysis of selected countries and regions outside the EU. To facilitate comparison, Table 1 summarises the key regulatory documents and their respective maturity levels, the types of connection agreements in place, the terminology typically used in each jurisdiction, and the primary user groups targeted by the regulatory frameworks. While the table covers a broader set of countries and regions, the analysis that follows focuses on selected jurisdictions that represent a diversity of regulatory approaches and implementation stages. In addition, this review highlights drivers and challenges associated with implementing non-firm connection agreements across different national contexts.

European Union Regulatory Frameworks

The European Union has taken significant steps to recognise the role of flexibility in achieving its decarbonisation and energy system integration goals. In June 2024, the Directive (EU) 2024/1711 amended previous electricity market legislation to explicitly require Member States to develop regulatory frameworks enabling system operators to offer flexible grid connections in areas with limited network capacity [10]. The Directive further stipulates that such flexible connections should not delay network reinforcements and may be adopted as a long-term solution where grid expansion is deemed inefficient.

Furthermore, on 7 March 2025, ACER submitted its proposal for a new EU-wide network code on demand response to the European Commission [11]. The proposal outlines principles for coordinating flexible connection agreements with markets for local services, emphasising that the activation of flexible connections shall not lead to market distortion, and system operators shall not limit the possibility for system users with flexible connections agreements to provide balancing and local services in the relevant markets. However, despite these European Union-level developments, implementation remains uneven across Member States, as shown in the next part of this subsection and Table 1, reflecting national regulatory discretion and varying levels of technical readiness.

Spain

Spain benefits from abundant and low-cost renewable energy, positioning it as a strategic location for electro-intensive industries such as data centres, green hydrogen production, and clean-tech manufacturing. However, these high-demand consumers often encounter significant delays or outright refusals when requesting grid connections, primarily due to capacity limitations in the existing infrastructure [12]. In response to these challenges, Spanish authorities have prioritised the development of flexible connection arrangements tailored to large industrial users, aiming to facilitate their timely integration into the electricity system. Historically, Spain has relied on firm connection contracts, but increasing network congestions, particularly driven by the expansion of solar PV and wind has prompted regulatory innovation. A notable development in this regard is the publication of Circular 1/2024 on 27 September 2024, entitled Methodology and Conditions for Access and Connection to Transmission and Distribution Networks [13]. This regulation introduces the possibility for certain demand facilities to request access through flexible connection agreements. These include capacity-limited agreements, which permit grid connection at reduced capacity

Table 1 Regulatory readiness and implementation status of non-firm connections across selected countries

Country/Region	Current Regulatory framework (Maturity level)	Non-firm connection aggrement Type	Country/Regions Specific Terminology	Application focus (Type of users)
European Union (EU)	***(Emerging)*** 1) Directive (EU) 2024/1711, 2) ACER Proposal EU-wide Network Code on Demand Response (2025)	Fully flexible	Non-firm connections agreement Flexible connections agreement Flexible connections	Power system users at distribution and transmission level
Austria	***(Established)*** 1) Directive (EU) 2024/1711, 2) ACER Proposal EU-wide Network Code on Demand Response (2025)	Time-limited connection agreements	N/A (Not Applicable)	Producers, storage, and prosumers
Belgium	***(Emerging)*** 1) Federal Regulatory Framework: Proposal for ammend of the Code of Conduct (2024). ***(Established)*** 2) Wallonia Region regional Regulatory Framework (2016)	Fully flexible	Flexible access Flexible connections	1) Federal: Producers, consumers, and storage at transmission level 2) Wallonia Region: Producers and storage at local transmission network and distribution levels
France	***(Established)*** Arrêté du 12 juillet 2021 d'application de l'article D. 342-23 du code de l'énergie (2021)	Fully flexible	ORA-MP-raccordement alternative à modulation de puissance (alternative connection offer with power modulation), ORI-offres de raccordement intelligentes (Smart connection offers).	Producers and consumers at transmission level, Producers and storage at distribution level
Germany	***(Emerging)*** 1) Energiewirtschaftsgesetz (EnWG) (2024), 2) Renewable Energy Act (EEG)	Combination of capacity-limited and fully flexible (ANM)	Flexible Netzanschlussvereinbarungen (flexible grid connection agreements) Steuerbare Verbrauchseinrichtungen (controllable devices)	Small consumers
Portugal	***(Nascent)*** Diretiva n.3/2025 (2025)	Fully flexible	Acordo de Acesso com Restrições Acordos de ligação flexíveis	Producers and storage
Spain	***(Nascent)*** Circular 1/2024 (2024)	Capacity-limited Time-limited Fully flexible	Acceso flexible Capacidad flexible Conexión flexible	Large consumers
Australia	***(Emerging)*** 1) Export Limits Guidance Note (2024), 2) National Electricity Rules Version 226 (2025)	Dynamic operating envelopes	Dynamic Operating Envelopes Flexible Export Limits Flexible Trading Arrangements Dynamic Connections for Energy Exports	Small producers and consumers
Great Britain	***(Established)*** 1) Access and Forward-Looking Charges Significant Code Review: Final Decision (2022), 2) DCUSA Report Version 17.0 (2025)	Fully flexible	Non-firm Access Agreements Curtailable Connections Flexible Connections	Large producers and consumers
The United States of America	***(Nascent)*** FERC Order 2023-A (2023) (no focused on non-firm CA)	Fully flexible (ANM) (only tested in pilot projects)	Flexible Interconnections	Small and large producers

levels until reinforcement works are completed; time-based curtailment schemes, which are applied in areas facing seasonal or intraday constraints; and fully flexible ANM-driven agreements, currently under pilot implementation in collaboration with DSOs and technology providers.

Nevertheless, flexible access cannot be requested or granted until the National Commission on Markets and Competition (CNMC) adopts the necessary regulatory developments by resolution, enabling their full implementation. In support of this regulatory shift, the Spanish regulator recently approved a sandbox framework for fully flexible connections [14], enabling experimentation with ANM systems and real-time curtailment.

Despite the promising outlook, several critical challenges must be addressed to ensure the effectiveness and scalability of flexible connection models in Spain. These include persistent legal uncertainty surrounding long-term compensation for curtailed energy, the absence of standardised methodologies to allocate curtailment fairly among users, and the need for regulatory alignment with emerging EU directives concerning network access and system flexibility.

Germany

Germany's main challenge has emerged at the low voltage (LV) level, where the high demand for EV charging stations, heat pumps, and solar PV has resulted in long connection waiting times and, in some cases, outright rejections due to local overvoltage issues [15]. In response, German regulator has introduced a series of measures to enable more flexible and controllable access to LV networks, particularly for demand-side technologies.

A key element of this regulatory evolution is the *Energiewirtschaftsgesetz* (EnWG-14a) [16, 17], which mandates that certain controllable consumption devices (*steuerbare Verbrauchseinrichtungen*), such as EV chargers, HPs, batteries, and air conditioning systems with a capacity exceeding 4.2 kW must be controllable by DSOs [18]. Under this framework, DSOs are authorised to remotely limit consumption in specific grid situations in exchange for reduced network charges.

In parallel, flexible grid connection agreements (*Netzanschlussvereinbarungen*) have been introduced in both the EnWG (17-2b) [17] and the Renewable Energy Act (EEG-8a) [19], enabling both capacity-limited and fully flexible access arrangements, especially for distributed generation and storage. These flexible agreements provide a regulatory basis for connecting more users without costly and time-consuming network reinforcements by allowing the DSO to actively manage injections or withdrawals from the grid based on real-time constraints.

Notable elements of this framework include the definition of controllable devices under EnWG-14a and the mandatory nature of remote control for eligible assets above 4.2 kW, the legal framework for capacity limited and ANM-like connections under EnWG-17-2b and EEG-8a, and the voluntary adoption of flexible connection contracts in some regions to enable faster connection of battery storage projects and small-scale renewable installations.

Belgium

In Belgium, responsibility for energy policy is divided between federal and regional authorities, resulting in divergent regulatory frameworks across voltage levels and jurisdictions. This fragmentation is particularly evident in the regulation of connections with flexible access. For example, at the federal level, the relevant provisions are outlined in the Code of Conduct, where Article 61 specifies the procedures to be followed when the transmission system operator [20] proposes a connection with flexible access due to insufficient grid capacity. These provisions apply to generation units, energy storage facilities, and consumption installations in cases of permanent access refusal. In December 2023, the federal regulator (CREG) requested Elia (Belgium-TSO) to develop the necessary procedures and criteria to support the definition of a federal regulatory framework on connection with flexible access, based on these studies the proposal for amendment of the Code of Conduct was formally submitted by Elia to the CGRE in October 2024 [21]. At the regional level, further inconsistencies are observed. Since 2016, the Walloon Region has maintained a regulatory framework for flexible connections applicable to both DSOs and the local transmission network. In contrast, Flanders currently lacks a dedicated framework for such connections, instead, grid congestions must be addressed through market-based flexibility or, under specific conditions, via the technical flexibility provisions of the Flemish Electricity Decree. Similarly, the Brussels-Capital Region has not established a framework for flexible access. Although Elia has not yet encountered the need for such arrangements in Brussels, it has recommended the development of a flexible access regime in anticipation of future requirements.

Austria

In Austria, the legal framework for non-firm grid connections is established under the Electricity Act 2010 (ElWOG) [22], which permits temporary access to the network under certain system conditions. DSOs such as EVN have initiated pilot agreements with large energy consumers and EV charging operators. The Austrian model is characterised by the implementation of fixed curtailment schedules during periods of known network constraints and relies on bilateral agreements between DSOs and grid users. Despite these early initiatives, Austria faces several structural and regulatory barriers that impede the broader implementation of flexible access schemes. One major limitation is the lack of advanced digital infrastructure necessary to support dynamic curtailment and active network management, such as ANM systems. In addition, there is insufficient regulatory clarity regarding the compensation mechanisms for curtailed DERs. Furthermore, aligning non-firm connection arrangements with the emerging architecture of local flexibility markets remains a significant challenge.

Other Countries or Regions Regulatory Frameworks

United Kingdom

The UK (with specific emphasis in Great Britain) has experienced a significant increase in connection requests from distributed generators, especially wind and solar, in areas where distribution networks are already constrained by limited capacity, voltage issues, or reverse power flows [23]. To address these issues without delaying renewable integration, the UK became an early adopter of non-firm connection agreements such as ANM, enabling more generators to connect under curtailment conditions. The UK is now widely recognised as a pioneer in the development and implementation of flexible connection models, supported by a well-defined regulatory framework and numerous large-scale pilots. In December 2018, Ofgem initiated the Access and Forward-Looking Charges Significant Code Review (Access SCR), aimed at reforming access arrangements and network charging mechanisms to enhance the efficient and flexible use of electricity networks [24]. The final decision [25], published in May 2022, introduced a standardised non-firm access option for large network users (generation and demand), alongside the establishment of clear curtailment limits and defined end dates for non-firm agreements. These regulatory changes were subsequently incorporated into the Distribution Connection and Use of System Agreement (DCUSA) [26], which is the multi-party contract between licensed electricity distributors, suppliers and generators in UK.

A number of initiatives have underpinned the UK's leadership in this area. The Flexible Plug and Play project [9], developed by UK Power Networks between 2011 and 2014, successfully implemented ANM-based fully flexible connections, achieving cost savings of up to 87% and reducing connection lead times by 57%. Building on this experience, the Energy Exchange project [27] (2019 and 2021) explored market-based solutions for flexible connection customers. In addition, the UK regulator has introduced several supporting measures to foster flexible connections. These include the establishment of curtailment prioritisation rules, such as last-in-first-out and pro-rata methodologies. Curtailment caps have also been introduced to limit the exposure of DER investors to excessive uncertainty. Furthermore, new procurement mechanisms have been developed to enable the participation of non-firm DERs in flexibility markets, allowing them to provide balancing and congestion services.

Australia

In some regions of southern Australia, almost 50% of the rooftops have solar PV systems, creating substantial operational challenges such as reverse power flows, overvoltage, and local congestions [28]. States such as Queensland report some of the highest PV installation globally [29], further intensifying these challenges. In response, Australian energy stakeholders have adopted dynamic operating envelopes, which enable distributed energy resources to adjust their output based on real-time network conditions.

The increasing deployment of DOEs has required adjustments in the regulatory framework to support their effective and consistent implementation. In this context, the Australian Energy Regulator (AER) launched a regulatory review in 2022 to assess the requirements for integrating DOEs. This process culminated in October 2024 with the publication of the Export Limits Guidance Notes [30], which is a detailed specification guide on Flexible Export Limits for distribution network operators. In addition, the National Electricity Rules (NER) [31] set out the general framework for the connection and access to distribution and transmission networks in Australia.

Several notable initiatives have demonstrated the practical application and benefits of DOEs. For instance, the Advanced VPP Integration Project [7], a collaboration between SA Power Networks (DSO) and the Tesla South Australian VPP, showcased the ability of DOEs. The project aimed to demonstrate how customers with solar and battery systems can achieve increased energy exports to the grid by utilizing dynamic export limits instead of static ones. The initiative developed an interface (API) that facilitates the real-time exchange of location-specific data regarding distribution network constraints between SA Power Networks and the Tesla VPP, allowing the VPP to adjust its output efficiently to maximize the use of available network capacity. Similarly, in 2022, Queensland DSOs Ergon Energy and Energex introduced dynamic connection agreements to replace firm access contracts with dynamic operating envelopes [32].

United States of America

In the United States, there is currently no formal regulatory framework for non-firm connection agreements. The most recent regulatory advancement in this area is the Federal Energy Regulatory Commission (FERC) Order 2023 [33], which aims to modernise and streamline the interconnection procedures and agreements for large and small generation projects [34]. The order introduces several key reforms, including the adoption of the first-ready, first-served cluster study process, the imposition of deadlines and penalties for transmission providers that fail to complete interconnection studies in time, and the incorporation of technological innovations into the interconnection process. Clarifications and revisions to this order were subsequently codified in Order 2023-A, issued in March 2024 [35]. However, no mention is made of alternative connection arrangements or flexible connections.

Nevertheless, isolated initiatives are beginning to explore the potential of more dynamic and flexible access models. Notably, two pilot projects involving independent system operators and Avangrid, a subsidiary of the Spanish Iberdrola group, have demonstrated the feasibility of flexible connections at the transmission level to increase the integration of renewables [36, 37]. These projects tested fully flexible connections through active network management and automation, resembling fully flexible connection schemes implemented in the UK.

Conclusions

The increasing decentralisation of power systems, driven by the rapid penetration of RES, DERs, EVs and flexible loads, has created both significant opportunities and complex challenges for electricity distribution networks. Traditional, often rigid and reinforcement-heavy models of grid connection are struggling to keep pace with evolving grid requirements, resulting in high costs, extended connection times and under-utilisation of existing infrastructure. In this evolving landscape, non-firm or flexible connection arrangements have emerged as a critical tool to accelerate DER integration in a cost-effective, scalable and system-friendly manner.

This review has provided a multi-dimensional analysis of flexible access, examining the technical typologies, regulatory progress and real-world demonstrations of non-firm connections across multiple jurisdictions. The following conclusions can be drawn:

Flexibility as a Cornerstone of Modern Access Regimes

Non-firm connections - whether capacity-limited, time-limited, DOEs or fully flexible arrangements using ANM - mark a transition from static planning to dynamic, condition-based access. Enabled by smart grid technologies and real-time monitoring, they unlock latent grid capacity, allowing system operators to safely connect more users without immediate reinforcement. If well designed, these models can improve system efficiency while maintaining security of supply.

Curtailment and Enabling Technologies as Key Enablers

Effective curtailment mechanisms (e.g. LIFO, pro-rata or curtailment index) and enabling technologies (e.g. ANM systems, smart meters, forecasting tools) are critical to the success of flexible connections. Coupling these technologies with distribution network reconfiguration and local flexibility markets enhances the system's ability to manage congestion and balance local supply and demand in a cost-effective and transparent manner.

Diverse Regulatory Landscapes and Emerging Governance Models

A key finding of the review is the diversity of regulatory readiness and implementation pathways across jurisdictions. The UK stands out with a mature framework and widespread ANM deployment, while countries such as Spain, Germany and Belgium are at various stages of piloting or establishing flexible access frameworks. The EU Directive (2024/1711) provides an important regulatory anchor, requiring Member States to support flexible access models where appropriate. However, there are still challenges to widespread implementation, including:

a. Legal uncertainty regarding compensation for curtailed energy.
b. Lack of harmonised definitions, metrics and curtailment methodologies.
c. Investor risk due to limited predictability of access conditions.
d. Weak alignment between interconnection procedures and flexibility market design.

From Demonstration To System Integration

Evidence from large-scale pilots - such as Flexible Plug and Play (UK), Advanced VPP Integration (Australia) and regulatory sandboxes in Belgium - shows that flexible connections can deliver significant benefits: faster connections, lower costs and improved DER integration. The critical next step is to scale up these schemes into national frameworks, aligning them with grid codes, market design and long-term planning strategies that accommodate energy communities, prosumers and multi-energy integration.

Contextual Factors and National Priorities Trigger the Types of Connections Favoured by Regulation

The adoption and design of flexible access models vary significantly depending on national challenges and system priorities that need to be tackled. For instance, Spain's interest lies in facilitating connections for electro-intensive industries; Germany focuses on residential-level DERs and LV congestion; while Australia's dynamic limits tackle rooftop PV saturation. This heterogeneity underscores the need for tailored but interoperable approaches.

Key References

- The European Parliament and the Council and the Council of the European Union, "Directive (EU) 2024/1711 of The European Parliament and the Council," 2024.

  First EUwide legal mandate requiring Member States to offer flexible grid connections where capacity is scarce, providing a regulatory anchor for all subsequent national frameworks.

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  Demonstrates ANMstyle flexible interconnection at transmission level in the USA, signalling wider applicability beyond distribution grids.

Acknowledgements The authors would like to thank colleagues at the Institute for Research in Technology (IIT) at the Comillas Pontifical University and RISE Research Institutes of Sweden for their valuable discussions and feedback during the development of this work.

Author Contributions Author Contributions Statement Manuel, Erik and Orlando conceptualized the study and conducted the literature review. Erik led the structuring, drafting and discussion of the manuscript as well as regulatory analysis. Manuel contributed to the technical definitions, regulatory analysis and policy discussion. Orlando supported the review of international case studies, conducted regulatory analysis and contributed to editing and consistency checks. All authors reviewed and approved the final manuscript.

Funding Open access funding provided by RISE Research Institutes of Sweden. Open access funding provided by RISE Research Institutes of Sweden. Financial interests: The authors declare they have no financial interests. Non-financial interests: The authors declare they have no non-financial interests.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

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