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Managing the electricity distribution connection queue in Great Britain: lessons from auction theory and a potential position trading system

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Abstract
The connection queue in Great Britain (GB) is recognized as a major challenge for transmission and distribution networks and for the energy transition. The queue reached 726 GW in July 2024 for generation and storage, but it is also significant on the demand side. The drivers of this problem have been identified by the government, the regulator and the industry. One of the drivers is the inability of the First Come First Served (FCFS) rule – the *de facto* system of allocation – to account for the feasibility, progress and value of the different projects applying for connection. This paper explores this latter aspect, by taking inspiration from the literature on auction theory, mechanism design and queuing theory. The paper discusses potential changes to the initial (primary) allocation of connection rights in light of concepts such as the beauty contest and the Knapsack problem, and to queue management by potentially introducing a secondary trading of connection rights to increase efficiency. The paper also discusses the risks and potential biases of such changes, including asymmetric information and strategic behaviour.

Keywords Distribution System Operators, auction theory, queuing theory, grid connection queue.

JEL Classification D44, L94

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Managing the electricity distribution connection queue in Great Britain: lessons from auction theory and a potential position trading system[1]

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1. The problem of connection queues

The UK and other jurisdictions are experiencing queues for power network connection at both transmission and distribution levels[2]. With power consumption expected to increase in line with the electrification of transport, heating, cooling, and industry, the

[1] The authors wish to thank the participants in three UKPN stakeholder events for their helpful comments on earlier presentations of the ideas in this paper. Funding from the UKPN Trading Connections project is acknowledged. All errors are those of the authors and the opinions expressed in this paper do not necessarily reflect those of any organisation with which they are associated.

[2] This paper will focus on both the transmission and distribution levels, with a relative higher weight given to the distribution side. While different in many ways, including connection rules, some concepts apply to power grids and queuing in general and can thus be relevant for both transmission and distribution.

grid is likely to experience even more periods of demand for connection that exceeds capacity. Demand from additional generation assets, distributed energy sources (DERs) and from large demand customers (e.g. data centres, housing developments) will have to be managed in a context where aggregate grid capacity cannot always be adjusted in the desired timeframe. Moreover, the digitally enabled potential for optimizing the use of the grid by reducing or shifting consumption, or by reconfiguring the network in real time, and generally better matching variable supply and demand, introduces alternatives to network upgrades that need to be considered.

Substantial grid connection queues exist across Europe, Australia and North and South America. The IEA identified wind, solar and other renewables connection queues of almost 3000 GWs in 2022 (IEA, 2023, p. 43).[3] For example, in the United States, in 2023, the backlog of generation and storage capacity seeking interconnection stood at 2,600 GW (Berkeley Lab, 2024). In Great Britain, as of March 2025, the total connection queue including transmission and distribution stood at 771 GW[4] (of which 44GW on the demand side), a level that is more than three times the maximum expected capacity required in 2050 according to the Future Energy Scenarios 2024.[5]

It is widely believed that many of the projects in the queue will not materialize. Indeed the entire queue cannot be economically viable: even in the most optimistic scenario from NGESO (2024) for 2035, the addition of generation capacity required is 231 GW compared to 684GW of generation and storage currently in the queue (of which 353 GW of renewables and 234GW of storage).[6][7]

At the distribution level, while less pronounced, there is also a connection queue problem, often caused by transmission level constraints (DESNZ & Ofgem, 2023). As of March 2025, the size of the distribution connection queue was 173 GW, 68% (119 GW) of which is dependent on or assessed for transmission reinforcements.[8] The other 32% (55GW) of projects with a connection agreement did not need reinforcement work to connect or only needed distribution level reinforcements, which

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[3] The IEA did not show the UK as having the biggest queue.
[4] https://www.energynetworks.org/industry/connecting-to-the-networks/connections-data
[5] https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes
[6] NGESO (2024, p.26) envisages 289 GW in 2035 under its HT scenario. In 2023 capacity was 116 GW, assuming half of this is still on the system in 2035, this gives 231 GW of additional generation by 2035.
[7] https://www.energynetworks.org/industry/connecting-to-the-networks/connections-data
[8] https://www.energynetworks.org/industry/connecting-to-the-networks/connections-data

are “typically completed before customers are ready to connect and thus are not queueing at all” (ENA, 2023, p. II).

While the numbers are indeed smaller at the distribution level, they are still high in absolute terms. Based on an earlier estimate that 8% of the distribution queue does not require reinforcement (ENA, 2023), this would amount to 13.7GW which is more than 23% of the 2023 peak demand of 58GW[9]. This may have significant consequences on economic activity as many of the demand customers waiting in queues are businesses that are trying to expand their activity.

At the distribution level, beyond the transmission constraints and reinforcement works, actual connection also depends on ‘customer timelines, milestones management, and supply chains’.[10] Milestones represent contractual commitments taken by customers to ensure that the connection progresses following an agreed-upon and predictable timeline.[11] This includes certain deadlines for securing planning permission, land rights, construction plans and others.

The Energy Networks Association (ENA) guidelines on queue management enables network companies to intervene when projects are not meeting the agreed milestones, to avoid slow or stalled projects from affecting viable ones in the queue.[12] The guidelines also encourage companies to utilize flexible resources in queues to make better use of the available capacity. The process flow diagram below describes the queue management guidelines.

[9] https://www.nationalgrideso.com/document/322316/download (p. 26).
[10] https://www.energynetworks.org/industry/connecting-to-the-networks/connections-data
[11] https://library.ukpowernetworks.co.uk/library/en/Connectionsquotations/Customerresponsibilities/3.30-ENA-Industry-Queue-Management-and-Connection-Milestones/
[12] https://www.energynetworks.org/assets/images/Resource%20library/ON21-WS2-P2%20Updated%20Queue%20Management%20User%20Guide%20(30%20Jul%202021).pdf

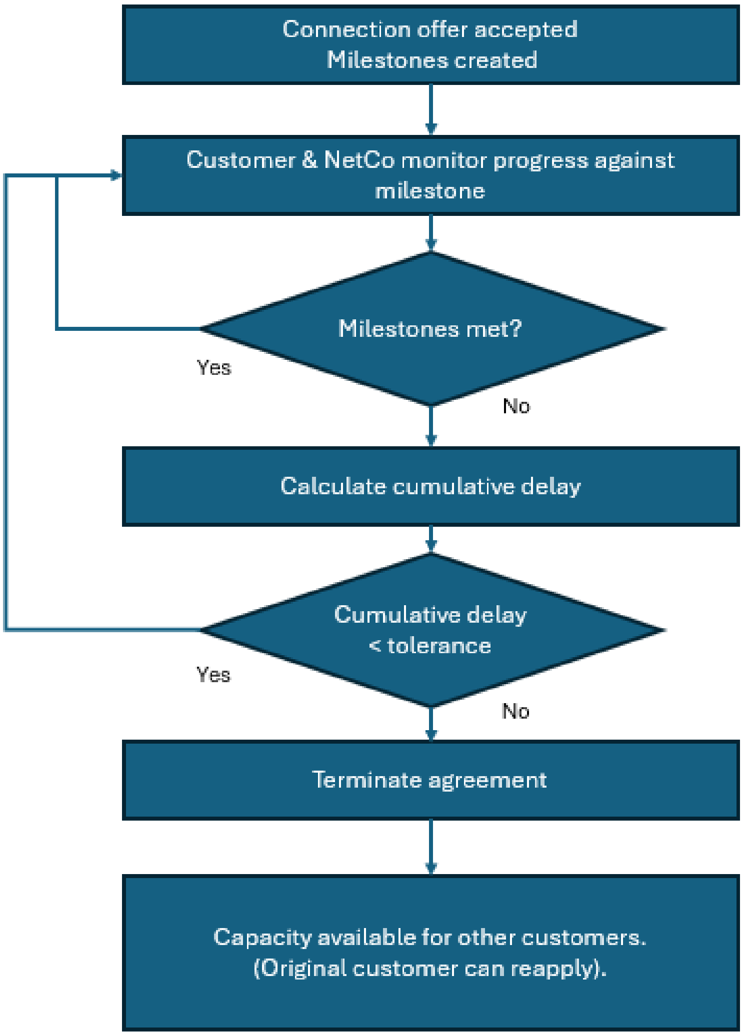

Figure 1: The ENA queue management guidelines. Based on ENA *(2021, p. 7)*. Finally, applying for connection under current rules may have an inherent problem of adverse incentives. As the grid operator does not have an incentive to maximize revenue for the grid connection service, the price being regulated, customers do not have the incentive to reveal their true value. They may have the oppositive incentive of demanding connections of larger sizes than they need, with accelerated timelines, since they do not bear much additional cost in doing so. On aggregate, this can result in inflated queues generated by customers requiring the services in higher quantities than they economically need. Addressing this fundamental mismatch of incentives is not trivial and requires thoughtful consideration.

1.1. The connection process and the drivers of the queue

Currently, UK prospective customers can request a transmission or distribution network connection, depending on their needs. For the purpose of this paper, the term customer refers to agents purchasing a network connection, either demand customers, or generation/storage, or both (prosumers). The system operators (Distribution Network Operators (DNOs) and the National Energy System Operator (NESO) at the transmission level) are required to offer a connection upon request after the applicants have submitted the required connection details and have paid any applicable fee.[13]

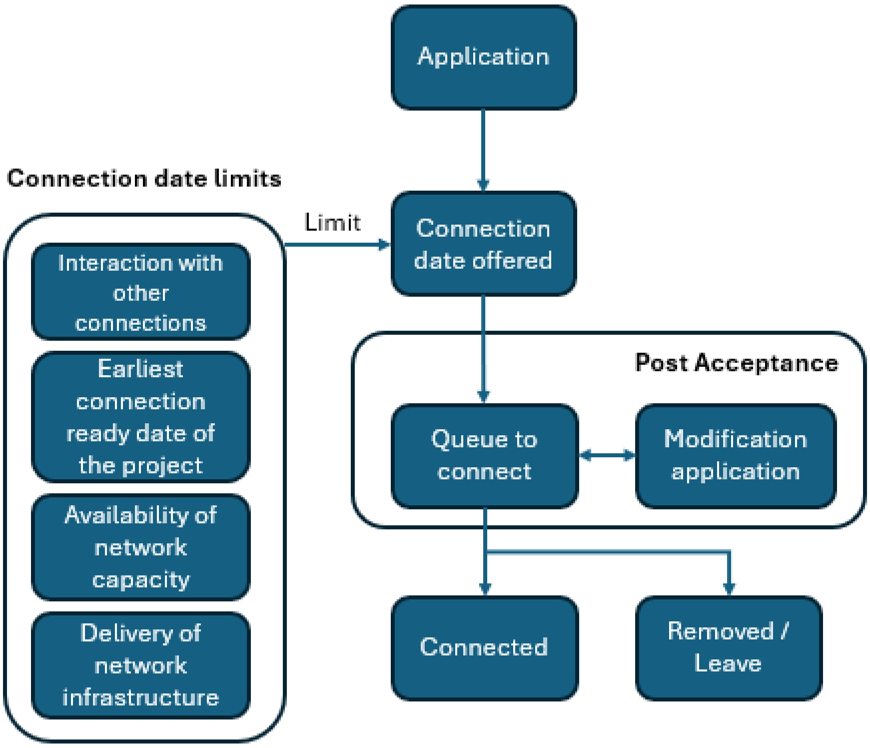

Figure 2: The connection process. Source: DESNZ & Ofgem *(2023, p. 16)*

Connection applications in the electricity sector are on a First Come First Served (FCFS) basis. This method involves evaluating each new request in the context of earlier accepted applications and assigning network capacity that is currently available or planned for the future. Although this process is standardised, it is not mandated by regulations (DESNZ & Ofgem, 2023).

A prospective customer applies for a connection and is given a quote. As soon as they accept the quote, they are allocated to the back of any existing queue, if such a queue is necessary. The position in the queue is determined by the application date and cannot be changed. If reinforcement work is required, prospective customers may have to wait to be energized for a period of time that can even extend to a few years.

[13] https://assets.publishing.service.gov.uk/media/6581730523b70a000d234bb0/connections-action-plan-desnz-ofgem.pdf

To ensure fairness, the NESO and network companies are governed by Ofgem license conditions (Condition 19) that prevent unfair discrimination among applicants.

Although FCFS is considered non-discriminatory, it has shown considerable drawbacks, especially when the system is congested. There are signs that the government is considering replacing FCFS with a 'first ready, first needed, first connected' approach to facilitate the ambitious net zero plans.[14] This resembles the 'first ready first served' concept applied in Australia (Simshauser, 2023).

The government and the regulator recognized the problem of large connection queues and have created a Connections Delivery Board[15] to coordinate the implementation of a Connections Action Plan that includes transmission and distribution, generation, storage and demand.[16] The action plan identifies several causes behind these queues. These include: the relative ease to obtain and keep a grid connection agreements even for highly speculative and slow-moving projects; the need for network reinforcements to facilitate connections; and the limits of the FCFS rule that fails to take into account the 'viability, status or merit to the wider energy system' (DESNZ & Ofgem, 2023, p. 17). The action plan's goals are:

- to tighten and standardize the application process to discourage speculative applications
- to 'clean up' the queue and release 90GW of capacity by switching to a 'first ready first served' system,
- to accelerate connection for up to 70GW of capacity by allowing temporary restricted connection ahead of reinforcement works,
- to release 3 GW of capacity by changing the network impact assumptions for storage,
- to deliver a reform that achieves better coordination between network planning and connection to release 46GW of capacity.
- to improve coordination and data sharing between distribution and transmission.

[14] https://assets.publishing.service.gov.uk/media/66cda5c1e39a8536eac0532e/sos-chris-stark-letter-clean-power-2030.pdf
[15] https://www.energynetworks.org/industry/connecting-to-the-networks/connections-delivery-board
[16] https://www.gov.uk/government/publications/electricity-networks-connections-action-plan

The progress on these action items is uncertain, at least looking at the minutes of the monthly meetings[17] of the Board, but the mobilization and motivation appear to be significant. These solutions[18], when implemented, will likely contribute to a reduction in the magnitude of the connection queue. However, potential new angles could be applied to the problem, exploring the possibility of altering the incentives in the primary allocation of connection rights, but also introducing the possibility of voluntarily changing places in a given connection queue. These angles are not included in the Action Plan but may contribute to the achievement of some of the action items.

The transmission level system operator (NESO) has already implemented a temporary two-step process to address the backlog of energy projects waiting for grid connection in the UK. [19][20] This initiative responds to the growing demand for integrating renewable energy sources into the grid. The new process involves issuing revised connection offers to eligible projects, thus expediting their integration.

This is being achieved by terminating contracted projects not progressing against agreed milestones to free up space for projects that are making real progress. This allows the transmission grid to ensure that capacity is fully utilised, and projects have the best chance to connect when ready.

In light of this, this paper aims to explore the issue of managing network connection queues using concepts from mechanism design, auction theory and queuing theory. The next section looks at the primary allocation of connection rights, the limitations of the current FCFS rule, and potential improvements in this process inspired by auction theory. Then, considering the initial allocation as given, the third section explores the literature on queuing theory and introduces a potential mechanism of voluntary reordering of the queue to increase efficiency. Section four contains a discussion on the major points of the paper. The final section draws some conclusions.

The paper is based on a review of literature, including internal documents supplied by UKPN regarding the connection process, and on two workshops with consumers, in May and July 2024. The consulted literature is at the intersection of auction theory

[17] https://www.energynetworks.org/publications/connections-delivery-board-meeting-minutes-june-2024

[18] ENA (2023) summarizes the drivers of the connection queue and a set of solutions and actions.

[19] https://www.nationalgrideso.com/industry-information/connections/queue-management

[20] https://www.edie.net/national-grid-completes-stopgap-process-to-ease-grid-connection-queue/

(f.Klemperer, 1999), mechanism design (f. Royal Swedish Academy of Sciences, 2007) and queuing theory (f. Sobel, 2018). The literature review included cases of congestion management in other countries including Spain, the US and Australia.

2. The primary allocation of connection rights and auction theory

In economic terms, DNOs (shorthand for companies managing grids in general) must allocate a scarce service – available connection capacity at a substation – in a situation where apparent demand exceeds supply and supply cannot always be adjusted in real time. The price of the service does not reflect market-based price elasticity and does not reflect temporal or spatial scarcity, being, instead, fixed through regulation. 'Customers' demand connections are of different size and belong to different types, residential, small business, large consumers, prosumers, generators, batteries, etc, and have different waiting costs. Economically speaking, the reason that the queue needs to be managed is that the DNO cannot adjust the supply of connection at the pace needed to meet apparent demand[21], which itself turns up in real time and is difficult to predict. It also cannot allocate the service to the customers who value the service most. Instead, connection is seen as a right and, as such, uses a system of rationing – queuing. Another consequence of an allocation rule that does not have revenue maximization as an objective is that customers do not have any incentive to reveal the true value of their connection, particularly in case of multiple applications. Customers may even have the opposite incentive: to demand more than they need, sooner then they need, since they incur little extra cost in doing so. This means that the queue may not stem from real demand but may partly be a reflection of this perverse incentive. Moreover, by joining the queue, the customers are in effect purchasing an option – a right but not an obligation to connect - and may choose to delay or forgo actual connection, creating artificial scarcity.

To conceptually approach this issue, notions from mechanism design and auction theory may prove useful.

[21] The constrained supply is determined by a multitude of factors including land or community constraints, which can severely delay the adjustment of supply to demand.

2.1. Mechanism design and auctions

A mechanism is an institution or procedure for determining a desirable outcome (Royal Swedish Academy of Sciences, 2007). The exact outcome is not known in advance but described by certain features. Through the repeated interactions of players, the mechanism itself generates the information needed to reach the outcome. In many applications, the most relevant issue is that individuals have private information that are required for the desirable outcome but may have incentives not to reveal it. Thus, a well-designed mechanism must be incentive-compatible – revealing the truth must be the dominant strategy for all players, i.e. the strategy chosen irrespective of what other players do. The idea of a mechanism is to give individuals the incentives to behave in a way that reaches the desired outcome, which also entails punishing agents who deviate from the prescribed strategy.

Auctions are a type of mechanism. They are used to allocate goods or services and have several specifications such as increasing versus decreasing bid increments, first price versus second price, sealed versus public bids, and others.

Their purpose is to incentivize interested buyers of a good or service to reveal their true value – information that is otherwise withheld. There are two main criteria to evaluate the outcome of an auction (Mochón and Sáez, 2015, p. 30). One is efficient allocation, ensuring that the good is allocated to the bidder who values it most. The other is revenue maximization, i.e., whether the seller raises the maximum possible revenue from the sale, equivalent to extracting all of the available willingness to pay on the part of the bidders.

As mentioned, the most important feature of an auction is incentive compatibility – an auction designed so that the dominant strategy of all bidders is to submit truthful bids. This would ensure that the bidder with the highest valuation would make the highest bid and therefore win the item. This results in efficient allocation and revenue maximization. Second price sealed-bid auctions (also known as Vickery auctions), where the highest bidder wins but pays the second highest price, are shown to satisfy this property.

‘Beauty contests’ represent another form of allocation mechanism where price is not the only criteria (Dykstra and van der Windt, 2004). A set of criteria with indicators and weightings are defined to best meet the goals of the procuring agent. Bids are then ranked by the aggregate score they receive on the various indicators.

An analogy could be made with agents requesting connection: instead of looking only at the price, there can be a set of criteria based on which some agents may rightfully demand priority of connection. These criteria might include financial strength, past record of rapid connection, accuracy of previous connection demand forecasts, jobs created in area, value added for UK economy etc. Tools have already been developed to look at wider economic benefit of electricity generation connection (e.g. Economic Impact Model of Electricity Supply EIM-ES).[22] These could be used to 'evaluate' a connection request. Spain is already experimenting with a competitive process for tendering transmission capacity for new generation, storage and hybrid facilities.[23] The ranking of bids takes into account feasibility, timelines but also socio-economic and environmental criteria, which are akin to a beauty contest.

Another relevant auction theory concept is the Knapsack problem (Bartholdi, 2008). One of the issues with multi-object auctions is that bidders demand lots of different sizes. This leads to the problem of fitting a set of objects with different sizes in a knapsack of fixed size in a way that maximizes value. The substation can be seen as the knapsack and the connection requests are the objects of different sizes. The procedure to ensure auction optimality is not trivial. Auctioning space in the knapsack can be a solution to ensure highest value objects are given priority in the knapsack. For example, the strike price can be per unit of storage in the knapsack. Similar to all auctions, the objectives are truthful bidding and revenue maximization. In some specifications, the unit size of the object can be adjusted, which could also apply to connection with customers willing to adjust their application. Other allocation mechanisms can be seen through the Knapsack lens, for example radio spectrum license auctioning for mobile phones, TV broadcast or other uses also involves different lot sizes (Milgrom, 2021).

In auction theory, the role of the auctioneer is of particular relevance, which may also draw an analogy to the case of grid connections. In a well-designed auction, the auctioneer refrains from affecting the efficiency of the auction and from interfering with strategies of the bidders. An important way to do this is for auctioneers to make it clear

[22] https://newclimate.org/resources/tools/eim-es-economic-impact-model-for-electricity-supply
[23] https://www.dentons.com/en/insights/articles/2022/june/27/tenders-for-capacity-on-the-transmission-grid

in advance of the auction how they will respond to information revealed through the auction. These actions need to be such that they do not undermine principles of good auction design. Thus, auctioneers can set reservation prices or set up trades with the auctioneer, rather than third parties. In the case of grid connections, the 'auctioneer' (who acts on behalf of the government or a regulated company) has an incentive to respond to information revealed by the auction, such as by making more or less capacity available depending on their own calculations. If the DNO is the auctioneer of capacity, high willingness to accelerate connection may result in bringing forward more capacity, more quickly and to reduce the value of bilateral trades. Equally the revelation of low willingness to pay for acceleration values might reduce incentives to accelerate connection. DNO may set high reservation prices for accelerating connection or offer compensation for moving connection to another sub-station. As long as bidders have to pay to accelerate their connection and connections are only accelerated if bidders are willing to pay enough, then, in theory, this should not interfere with the efficiency of the overall outcome.

Using the concepts from auction theory, we can describe the DNO queuing problem as follows: The goal of the 'auctioneer' (the DNO) is not revenue maximization nor efficient outcomes, but an allocation that respects the rules and is perceived as fair. Also, bidders do not compete in price but in time. The current allocation mechanism is largely first come first served (FCFS). While some customers are applying for a single connection, several are applying for multiple connections and thus their 'bids' are likely related, with no DNO information about this. The allocation mechanism does not encourage agents to reveal (much) private information. The current mechanism is therefore not strategy-proof – the dominant strategy is not to bid truthfully. Some of these issues may need to be addressed in the primary allocation of connection rights, and some of the work included in the Connections Action Plan may partially address them, such as raising entry requirements and moving away from FCFS.

3. Changing the initial allocation – trading positions in the queue

Even when the use of prices to reduce the primary allocation in the queue is not possible, queue members can, in theory, engage in secondary trading of their positions in the queue (Hassin and Haviv, 2003). This improves the allocation of existing services – those who value services at particular points in space and time bid them away from others who value them less. In general, it is in the interests of the primary seller to encourage this, as social welfare likely improves, especially where all buyers and sellers are well-informed and there is no private information on the primary availability of capacity (i.e. a buyer has no inside knowledge that more capacity might become available). Other advantages of secondary trading could be that it decentralizes decisions and avoids a central system of rationing, it may guide longer term decision on investments by revealing willingness to pay for more capacity and may regulate demand if the high willingness to pay be determine other consumers to not join the queue at a certain time. At the same time, there are also potential vulnerabilities in secondary trading, as the inherent scarcity of network connection may attract new agents to the queue who are only interested in selling their slot in the secondary market, thus artificially inflating the size of the queue. Making queue participation costly is one partial solution to this problem.

It is generally agreed in the literature that serving customers on a FCFS basis is an inefficient method of rationing scarce indivisible resources (El Haji and Onderstal, 2019). Customers have different waiting costs such as loss of revenue for firms or simply a different sense of urgency for their particular circumstance. The FCFS system is unable to account for these waiting costs and would thus lead to an inefficient outcome (El Haji and Onderstal, 2019).

In this context, **an efficient outcome is one that minimizes the sum of individual waiting costs** (Kayı and Ramaekers, 2010). Thus, an efficiency gain is defined as the decrease in the sum of the individual waiting costs after the trade of places has been completed.

There is literature that discusses these aspects. Kleinrock (1967) presents a model that proves efficiency can be enhanced if positions in the queue depend on monetary transfers. Rosenblum (1992) develops a model where customers in the queue consider having property rights over their queue position and engage in trading their position with other customers, resulting in a new queue order that ranks customers by their waiting costs. All models however acknowledge the Myerson- Satterthwaite impossibility theorem. The theorem claims that there is no system compatible with individual incentives that ensures that all efficient (mutually advantageous) trades are performed. This is because agents have private information about their valuation of the good they are trading and they have incentives to strategically misrepresent their true value in order to influence price (Myerson and Satterthwaite, 1983).

Ideally, the trading system should satisfy a number of conditions to reflect societal preferences. One set of conditions is presented in Kayı and Ramaekers (2010).

The first is *Pareto Efficiency*, which is generally defined as a state of a system where all Pareto improvements have been made. A Pareto improvement is one that makes at least one agent better off, without making any other agent worse off. Two sub conditions make up Pareto efficiency: queue efficiency and balancedness. *Queue efficiency*, as discussed above, implies minimizing total waiting costs after trading compared to before. *Balancedness* means that transfers between members in the queue should sum up to zero.

Other desirable system characteristics include fairness, symmetry, no-envy, anonymity and strategy-proofness. *Fairness* implies that agents with equal waiting costs should be equal in welfare (including the transfer) after the trade. *Symmetry* requires that agents with equal waiting costs should have access to the same bundles that sum up to the same welfare. *No-envy* means that no individual agent should, after trading, prefer a different bundle to the one they received. *Anonymity* means that the identity of agents should not be relevant in the trading process. *Strategy-proofness* would require that the payoff from revealing true waiting cost should be at least equal to the one from misrepresenting it. In practice, not all characteristics are feasible or relevant for a system to be functional.

3.1. The literature on potentially applicable systems for trading queue positions

Cui, Wang and Yang (2023) introduce a two-sided market that allows queuing agents to voluntarily swap their position in exchange for a payment. The high waiting cost (impatient) customer would pay the low waiting cost (patient) an agreed sum and they would swap places in the queue, leaving all other queuing customers unaffected. This is advantageous because it preserves the perceived value of FCFS (as all customers are allowed to maintain their queue position which they may perceive as property) while introducing the potential for efficiency gains in total welfare.

The marketplace can be managed by a third party, that may have technological advantages or perceived independence from the actual service provider. This may eliminate the perception that the service provider is extracting profits from trading within the queue.

It is assumed that joining customers can estimate the expected waiting time and, as such, the monetary transfer derived from their bid. The queue is constantly evolving as new customers join. Every new customer joining the queue must submit either an opt-out option or a bid which represents both i) the minimum amount requested for waiting an additional unit of time and ii) the maximum amount willing to pay for a reduction of one unit of time. The new arriving customer swaps positions consecutively with those customers with strictly lower bids (who did not opt out). The customer moving ahead in the queue pays the one moving back an amount equal to the bid multiplied by the number of units of time saved. All customers with higher or equal bids and who opted out keep their queue position.

The theoretical model presents some interesting findings. Agents with very high or very low waiting costs stand to gain the most from participating in the trading marketplace as opposed to FCFS, while the ones with medium waiting costs stand to gain the least. At the same time, agents with low waiting costs have incentives to overstate their waiting costs. Further, agents can earn rents by joining the queue and selling the position to future customers (scalping). Maximum social welfare is not achieved based on the model because of that.

A variant is also presented where the marketplace is managed by a profit-seeking platform manager. They charge an upfront fee only to customers who agree to enter the marketplace. This will decrease the willingness to join the system for customers with medium waiting costs but will not affect the trading behaviour of the others. The revenue model of the platform manager can be designed to induce efficiency seeking behaviour by limiting their pricing power, charging per transaction or volume.

Such a trading system would be vulnerable to ‘scalpers’ and ‘line sitters’. Line sitters provide a service for real customers by joining the queue on their behalf and extracting some value. Scalpers join the queue without receiving the service, increase the queue size and extract rents from customers. Scalpers can be deterred by imposing a high enough participation fee. Line sitters can contribute to efficiency but may capture some value away from the platform manager.

El Haji and Onderstal (2019) present two different systems and discuss results from an economic experiment. One system (called server initiated) has the service provider (server) auction the right to be served next and distributes the proceeds collected from the winner equally among all the non-winning customers in the queue. The other system (called customer initiated) is similar to the one presented earlier (Cui, Wang and Yang, 2023) with every new arriving customer in the queue having the option to offer higher placed customers a fee in exchange for swapping positions. The experiment confirms that both systems increase the system efficiency significantly. Based on surveys, customers perceived the server-initiated system as fairer, despite the fact that it is more forceful and does not feature the option of opting out and preserving the FCFS position.

The potential trading systems presented in the literature are susceptible to biases and risks. The biggest risk from a trading system is related to asymmetric information. There may not be an incentive for agents to reveal their private waiting costs. Indeed, for some, there may be an incentive to inflate them. However, overall the theory suggests that the amount of speculative bidding would be reduced if the financial cost of joining the queue and/or failing to be in a position to advance a connection if the front of the queue is reached was increased.

Two significant biases have been reported in the literature related to trading queue positions: the endowment effect and the sunk-cost effect have been identified in experiments (El Haji and Onderstal, 2019). The endowment effect occurs when agents with a certain queue position develop a sense of entitlement toward it which may lead to them expecting higher transfers than their rational optimal would suggest. This manifests itself if an agent's bid correlates with its initial position in the queue. The sunk-cost effect occurs when agents base their behaviour regarding trading positions on costs that cannot be recovered and are irrelevant to the decision at hand, such as the amount of time they already waited. The two effects – endowment and sunk-cost – may lead to an outcome that deviates from efficiency.

In addition, queuing represents a social system which develops its own rules for behavior, procedures and dispute settlement (Mann, 1969). Perceived fairness is highly relevant. The value of queuing may have social significations that cannot be fully covered by the payoffs (Oberholzer-Gee, 2006; Helweg-Larsen and LoMonaco, 2008). There is evidence that agents reject changes to the queue order even when those changes are happening in a portion of the queue that does not affect their waiting time (behind their position). There are also reported cases from experiments when agents accept swapping places but refuse the monetary reward. One explanation can be the abhorrence of exploitation of a situation of excess demand.

An obvious behavioural bias that we can observe with connection queues is the unwillingness of the regulator or the industry to – so far- propose financial solutions to queue management. This seems to be due to perceptions of difficulty of implementation or an unwillingness to acknowledge that queuing is a problem that we might allow market forces or more cost reflective pricing to solve.

3.2. Particularities of grid connections

The allocation of grid connections may have particularities that limit the application of certain concepts from auction theory and queuing theory.

Firstly, in the primary allocation, the goals of the auctioneer are not efficient outcomes (allocating the service to the agent that values it most) and revenue maximization (extracting all of the available willingness to pay). This limits the extent to which the allocation process could be improved in terms of incentive-compatibility, as agents will likely not incur costs for strategic behaviour.

On the secondary trading for reordering of the queue, the service is not homogenous but can differ between generation and load (with batteries having features of both) and can differ in size and complexity. Hence, trading between two agents may affect a third agent because of the different lead times of works. This issue will need to be addressed in a potential trading system by imposing certain limitations.

The good or service to be allocated can be divided into parts, which also makes it different. The application for connection can be divided, with only a part of it being available for trading. This may create an opportunity for aggregation and optimization but also raises the complexity of the trading system.

Another relevant particularity is that the ‘service’ is not sequential, in the case of substations. For example, a number of agents who missed the chance of being connected to a substation that reached capacity must wait in the queue for the reinforcement work to be completed. When that happens, they all get the service almost simultaneously. This means that the only relevant swaps in the queue are between positions that can connect prior to a one process of reinforcement and one that missed that opportunity. This may have implications for the actual number of truly advantageous swaps which may be lower than in queues that do not have this property.

3.3. A potential trading system for a DNO

Currently, when a customer receives a quote for a connection, they join the end of the connections queue (Fig. 3). They have no possibility to move up the queue. This means they must wait to get to the front of the queue to connect, even if they are ready to connect immediately. Long delays can be experienced due to customers ahead in the queue.

For distribution connections with no impact to/from the transmission network, it is proposed that introducing the ability to trade spaces in the connection queue could lead to customer benefits and improved network utilisation. For example, based on Fig. 3., if customer B's waiting costs are lower than customer H's, a swap in position improved the efficiency of the queue, by reducing the total waiting costs.

While there are potential risks and limitations, mentioned in the previous sections, a system could be piloted, gathering feedback from customers, and improved in time.

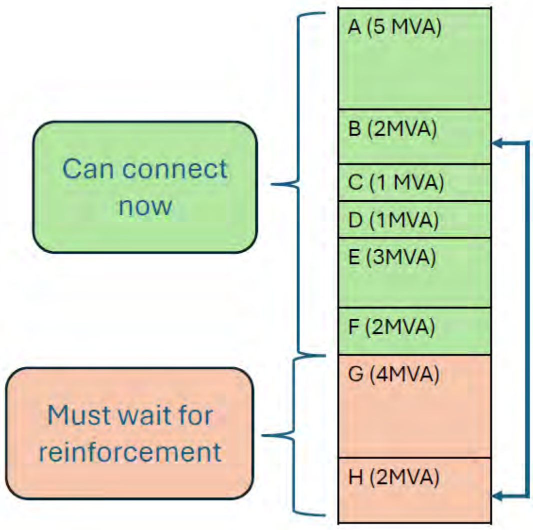

Figure 3: An illustration of the connection queue and a possible swap between customer B and customer H

3.3.1. The proposed process

When a customer joins the queue, they receive information on the estimated waiting time. During their wait, at any point, they can initiate a non-binding request for moving up or down the queue. Customers already in the queue can also set a price for their willingness to move up or down the queue. A platform managed by a third party could then match potential eligible trades based on certain characteristics and enable bilateral negotiation between parties. If the parties agree, they inform the DNO who then re-issues the connection offer information. Final agreement between the parties could be conditional on the connection offer terms not being materially different from what was initially envisaged (i.e. the cost of connection has not risen substantially).

A number of restrictions would be imposed to ensure the system is workable and avoids at least some of the most obvious risks. First, trading would be allowed for customers in distribution-only queues and only between customers in the same queue. Second, to ensure Pareto efficiency, the swapping of positions between two parties should not affect any other party in the queue. This is equivalent to only allowing customers to move up in the queue if their connection is equal or smaller than the trading counterparty. Third, a customer taking a new position in the queue also accepts the milestone obligations of that position and must meet or improve on them for the trade to be accepted. Finally, generation can only swap with generation and loads can only swap with loads.

Some features may be best evaluated after a trial. For example, whether customers could be allowed to divide their connection and thus only trade a subdivision of their initial connection request. This would imply the possibility of one customer trading with multiple other customers, increasing the complexity of the system (Fig. 4).

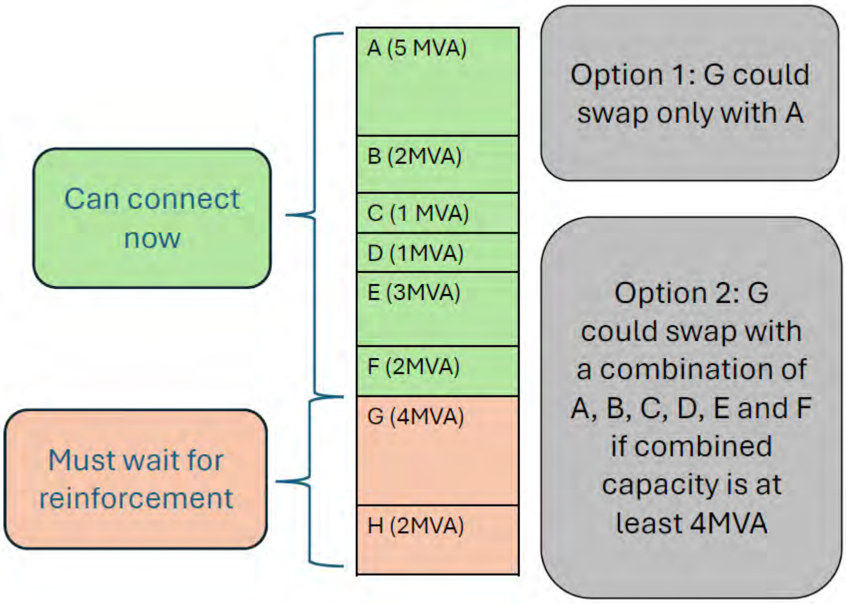

Figure 4: Potential swapping between multiple customers

Another element that could be trialled is the establishment of indicative prices or price caps to avoid the risk of speculation and scalping making the queue worse.

Further, it is important to decide what is carried over together with the swap in addition to the queue position and the energisation date and how upward adjustments in the connection fee will be handled. One could imagine that indicative changes in connection costs could be part of the information provided on the trading platform or that indicative trades might be binding if they did not involve unexpected rises in connection costs.

To enable trading to occur, customers should be able to accurately estimate the waiting time. Otherwise, the value of swapping positions would be difficult to appraise. Hence, the DNO will need to be able to provide information on the estimated time to connect for different queue members with some degree of certainty. When swapping positions, both agents should be able to know what their new timeline is to determine the worth of the trade.

The platform would contain information on the size of connections available for trading, milestones, and indicative costs. The platform would ensure anonymity until the moment of a match being accepted by both parties. This would ensure protection for the agents for whom the particularities of their grid connection or willingness to swap may be commercially sensitive. However, agents would be given the option to disclose more information in the platform, should they be finding advantageous.

4. Discussion

This paper has looked at the queues for network connection (particularly the distribution queue for demand customers) and presented concepts form auction theory, mechanism design and queuing theory that may be relevant in understanding and improving both the primary allocation of connection rights and the queue efficiency through secondary trading.

Several elements need further discussion and consultation with stakeholders.

On the **primary allocation of connection capacity**, several aspects may be worth exploring as solutions to the queue problem.

First, as acknowledged by the report of the government and the regulator, the FCFS rule is not mandated by law, but rather a particular application of the principle of ‘no undue discrimination’, present in the license condition (DESNZ & Ofgem, 2023, p. 16). Undue discrimination could be prevented while still introducing criteria that discourage behaviours that clog the connection process. Such criteria could form the basis of a form of beauty contest, as seen in Spain. Readiness, feasibility, timeline, social and economic value have been mentioned in the Connection Action Plan, and also by stakeholders.

Second, to some extent, speculative applications are believed to be determined by insufficient information available about the queue, with agents rushing to secure a place in an ever expanding queue. DNOs and the regulator may need to explore ways of providing more information about the size of the queue to reduce uncertainty and the urge to join the queue ‘just in case’. Effort can be made by the ENA to coordinate the analysis of queue information to assess whether individual applicants are entering multiple applications in different locations in order to challenge applicants on their intentions.

Third, a review of the connection fees is warranted. Bringing connection fees (or other associated upfront costs) closer to the value of connections may reduce 'overconsumption' and the artificial scarcity. Both Australia[24] [25] and the US[26] have introduced the concept that unless more serious financial commitments are made upfront, a position in the queue cannot be guaranteed. Finding the right level for the fee to generate this effect will be required, especially when the benefits to society vs the benefits to the customers may differ substantially.

On the **secondary market**, there are also several issues to consider.

First, it would be interesting to know if customers are already engaging in swapping positions (with or without monetary compensation). If they are not, this suggests that there are regulations that prevent it and such regulations are likely in need of change.

Second, the features of a distribution company supported potential trading system for queue positions also need to be consulted on.

Third, a particularly valuable development might be the possibility of 'trading' fractions of connection rights, on a temporary or permanent basis, as some agents may realize they do not need the full connection and could make it available for others. However, this increases the technical complexity of trading significantly because a single trade has changing characteristics over time.

Fourth, another aspect to clarify is the role of the platform manager for the trading system. If the DNO performs this task, the DNO will bear the possibility of the various risks materializing, including reputational damage. They would also need to cover such costs. On the other hand, assigning this role to a third party would require careful contracting to avoid the incentive to increase the number of trades, to cover fixed costs and to provide relevant insurance guarantees.

Finally, the transaction costs of trading would also likely be non-trivial and would depend on the complexity of the trading system. If they are too high, this reduces the incentive to participate in efficiency-improving swapping. Given that the absolute number of trades might be quite low, due consideration needs to be given to how transaction costs can be kept to a low level.

[24] https://api.repository.cam.ac.uk/server/api/core/bitstreams/ee68ee2e-bbd5-416f-9981-e03b4e7fb03d/content
[25] https://www.sciencedirect.com/science/article/pii/S0140988324003797
[26] https://www.energypolicy.columbia.edu/fercs-interconnection-reform-why-it-matters-for-the-clean-energy-transition/

5. Conclusions

This paper tackled the issue of queuing for power network connections using an economic perspective, with a focus on distribution networks in the UK.

While smaller than transmission (and generation/storage), the distribution-level demand connection queue is significant and can become larger over time. The queue is largely explained by the number of speculative applications, slow moving projects, transmission constraints, overly cautious grid impact assumptions, and the need for reinforcement works. However, part of the reason is also the inadequacy of the FCFS allocation rule.

This paper has explored this problem and the potential improvements to the FCFS rule by applying concepts from auction theory, mechanism design and queuing theory.

The current initial primary allocation of connection rights was found not to be incentive compatible, with the rational strategy of potential customers being to overstate their private value and to join the queue even with purely speculative projects. While an auction for connection rights may raise issues of discrimination and be legally difficult to introduce, the allocation may benefit from some changes.

These include reviewing connection fees to discourage speculative applications including holding more money up front or insisting that certain, costly, milestones be met before a place in the queue is fully secured. Also, the potential of a beauty contest with various non-price criteria should be explored. This is somewhat similar to the Action Plan proposals for better evaluating customer readiness. A beauty contest could go beyond readiness and include other priority criteria (such as positive local employment or housing impacts). These must result from consultations with stakeholders (including the government) to avoid the risk of a backlash from consumers and the risk implementing unfair discrimination.

Another improvement in allocation can be pursued by allowing trading of queue positions between consenting customers, allowing third parties to maintain their FCFS position. Such a mechanism has been found to have significant potential for efficiency improvements, even if not all welfare improving trades occur. The system may have some vulnerabilities, such as incentive for scalping, would incur some transaction costs, and may require restrictions on who can trade with who. There are important risks that need to be managed including a wider backlash against the perceived profiteering, undermining perceived fairness of the FCFS rule, especially if this is seen to accelerate projects with low actual or perceived public benefit (but low ability to pay) over those with high actual or perceived public benefit.

In addition, important aspects need to be clarified, and trialled, and are best suited for a consultation. These include the ability of multiple swapping, splitting connections into fractions, data privacy and protection of commercially sensitive information, the price setting process, the implications of a trade in terms of energization dates and connection fees, the allocation of oversight responsibilities and trading system fees, and the platform management.

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