cenex

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Transport

Energy Infrastructure

Knowledge & Enterprise

Vessel-to-Grid

An Analysis of Revenue Streams and Vessel Archetypes for Bi-directional Charging of Electric Vessels

AQUA superPower

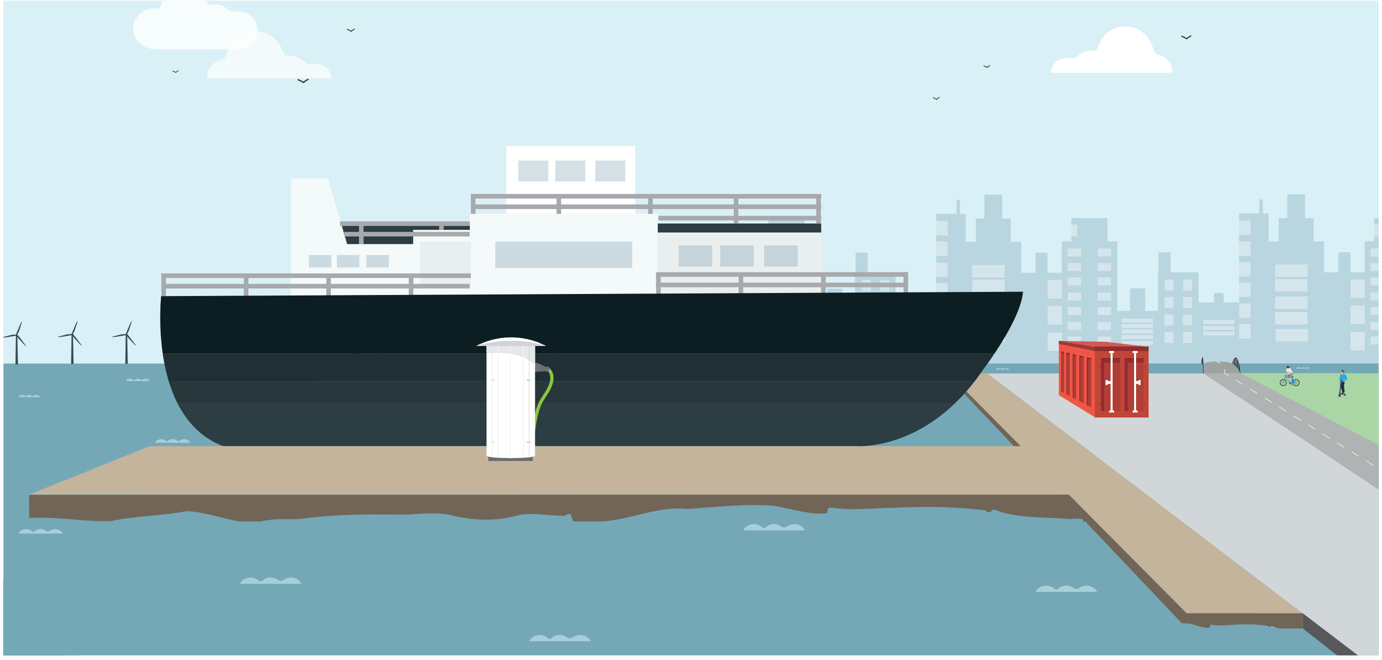
UKRI Innovate UK

Contents List

Abbreviations

Term	Description
ADSP	Ancillary Service Dispatch Platform
API	Application Programming Interface
BM	Balancing Mechanism
BOA	Bid Offer Acceptance
CPO	Chargepoint Operator
DNO	Distribution Network Operator
DR	Dynamic Regulation
DSO	Distribution System Operator
DUoS	Distribution Use of System
EAC	Enduring Auction Capability
EFA	Electricity Forwards Agreement (refers to the six, 4-hour electricity trading blocks in the day)
EFR	Enhance Frequency Response
ENA	Energy Networks Association
eMSP	e-Mobility Service Provider
ENA	Energy Networks Association
ESO	Energy System Operator
EV	Electric Vehicle
FFR	Firm Frequency Response
GSP	Grid Supply Point
MHSS	Market-wide Half-Hourly Settlement
MPAN	Meter Point Administration Number
MW	Mega Watt
NGESO	National Grid Electricity System Operator
PV	Photo-Voltaic
STOR	Short-Term Operating Reserve
V2G	Vehicle to Grid

Executive Summary



This report has been written as part of the Virtual Bunkering of Electric Vessels (VBEV) project, a feasibility study to determine the financial, technical, and operational business case for the deployment of bi-directional charging infrastructure in the marine sector. The focus of this report is on the value of bi-directional charging (V2G) for electric vessels.

Flexibility Services

Regulations, energy, and flexibility markets are all in the midst of significant change. This report covers the currently available revenue streams resulting from these changes. The key findings were:

- Newer response services are more suited to distributed and battery-based assets than the old services. This lowers barriers for V2G assets to enter the flexibility services market. NGESO's Enduring Auction Capability may make the provision of multiple reserve and response services easier to achieve from a single portfolio of flexible assets.
- DNOs are also increasing the volume of flexibility services they procure year on year. Whilst these are geographically dependent, they can provide a good income for assets sited in a constrained area of a distribution network.
- V2G could obtain a significant income through provision of response services today (for example Dynamic Regulation), but it is likely that the value will reduce as the market reaches saturation in the coming years.
- Although reserve services have a more positive price outlook, they are less suited technically for V2G provision. With a positive outlook and lower barriers to entry than previously, the Balancing Mechanism (BM) now provides a significant potential income for V2G propositions.
- There is likely to be significant price support for electricity wholesale prices over the coming decade, combined with higher volatility than in the last decade. These factors mean that both wholesale price optimisation, and time of use tariff optimisation (with smart tariffs, largely reflecting wholesale prices) are both likely to be strong revenue streams for V2G.

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Category	Revenue Stream/Market	Technical Requirements (Can V2G offer this?)	Market Accessibility	Potential Annual Revenue	Market Outlook
Reserve	Quick Reserve	Red	Amber	Amber	Amber
	Slow Reserve	Red	Amber	Amber	Amber
	Demand Flexibility Service	Green	Green	Amber	Amber
Response	Dynamic Containment	Amber	Amber	Green	Red
	Dynamic Moderation	Amber	Amber	Red	Red
	Dynamic Regulation	Green	Amber	Green	Red
	Static Recovery	Green	Amber	Red	Red
DSO Services	Sustain	Green	Amber	Red	Amber
	Secure	Green	Amber	Red	Amber
	Dynamic	Green	Amber	Amber	Amber
	Restore	Green	Amber	Red	Amber
Markets	Balancing Mechanism	Green	Amber	Green	Green
	Capacity Market	Amber	Amber	Amber	Unclear
	Electricity Wholesale Market	Green	Amber	Green	Amber
	Behind the meter tariff & renewables optimisation	Green	Green	Green	Green

Table 1: Revenue Stream Scoring for V2G

Archetypes

In order to reduce the complexity of the problem to something achievable, archetypes were created for the typical vessel types and use cases. To enable simple comparison between archetypes, a single metric was devised. In this case, it was important to represent the variability between use cases, combined with the impact of the power rating of the charger. As a result, it was decided to use "Revenue per kW of charging power" as the main metric. This way it is possible to compare both:

- **Similar use cases but with different power chargers**
- **Different use cases with the same power chargers**

Simulation modelling for a Vessel-to-Grid and Vessel-to-Marina use case for leading V2G archetypes in the marine sector provide an estimation of the revenue available from the most applicable revenue streams. The "Recreational Vessel" archetype had the highest annual revenue (using the "Revenue per kW of charging power" metric), with up to £382 per year in the Vessel-to-Grid use case (accessing the balancing mechanism and capacity market), or £284 in the Vessel-to-Marina use case (providing tariff optimisation and accessing the capacity market).

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It should be noted that for the period modelled (Aug 2022 to July 2023) energy prices exhibited high volatility (as shown in section 4.5). This is reflected in the tariff optimisation revenue (especially in the Vessel-to-Marina use case). Such revenue may not be possible with lower price volatility. Balancing Mechanism costs incurred by NGESO for the winter 22/23 were second highest recorded, being up to six times what they were during the previous decade. This results in higher revenue from the BM for V2G propositions. Whilst BM revenue has a positive outlook (from a V2G perspective), the value is not guaranteed.

Alternatively, by performing a carbon optimisation with the V2G unit, annual carbon savings of up to 79kg. CO2/kW are possible.

Conclusions

From this analysis, revenues of up to several hundred pounds per kW of chargepoint power appear possible for V2G, which is significantly higher than for smart charging alone. Whilst in practice, actual values obtainable over the coming years may be less (due to factors such as forecast error and reductions in price volatility), it will likely still be a very good revenue stream for the best archetypes. Some marine archetypes are used for less than 10% of the year making them particularly applicable, these will obtain significantly higher V2G revenue values than road based EVs, which are in use more frequently.

The leading archetype (recreational vessel) numbers in the tens of thousands across the UK. With these numbers, it could provide a significant source of flexibility to the GB energy system, potentially to the scale of hundreds of MW. These results are sufficient to justify further research and development of V2G for the marine sector.

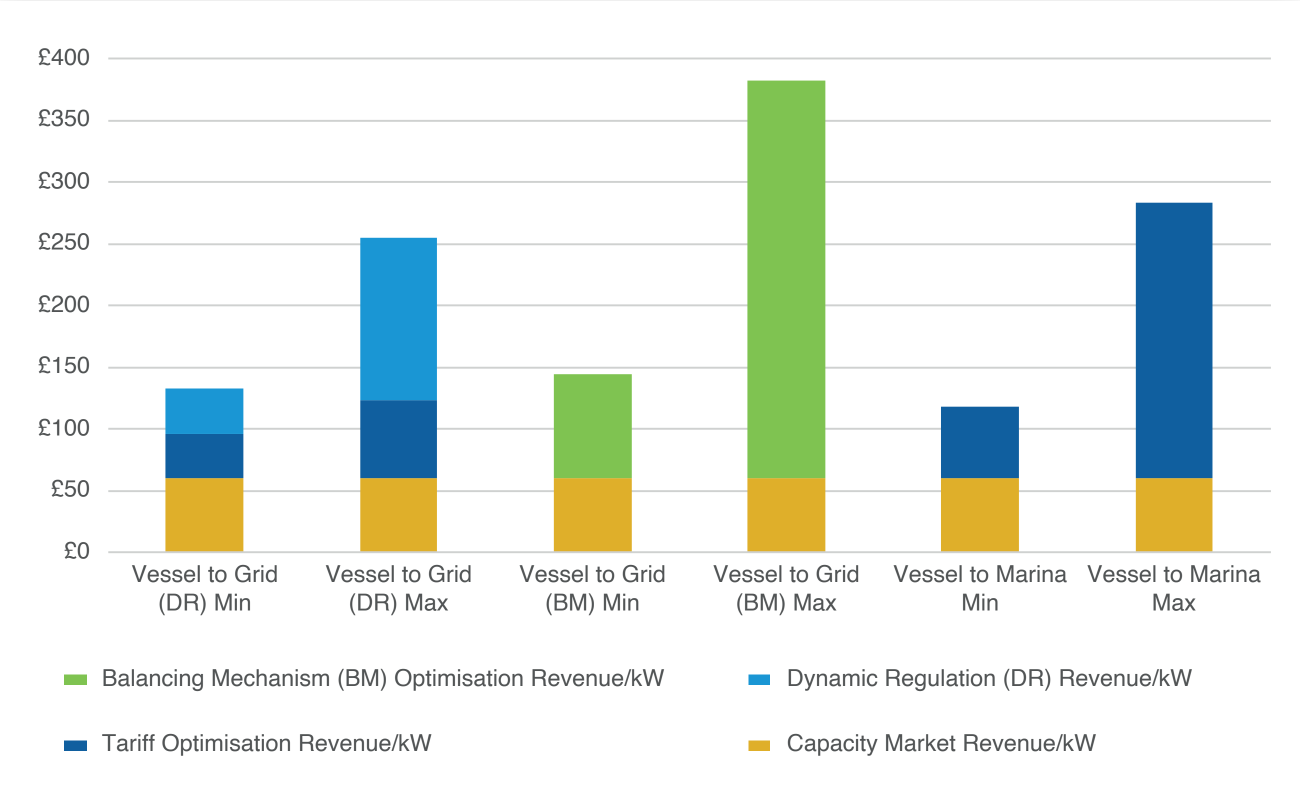


Figure 1: Ranges of annual revenues per kW of charging power, for different use cases and archetypes

Executive Summary

Recommendations

Customer Education:

Income is entirely reliant on vessels being connected to a charger whenever they are moored or not being used for a reasonable duration. Unlike the automotive market, vessels go through a mooring process, meaning that this behaviour should be more natural to the operators. However, it is still important to educate operators around this need.

First Target Customer Segment:

Recreational vessels are the logical first target market for V2G, provided they have a dedicated chargepoint.

Flexibility Service Tracking:

It is likely that the best revenue propositions for V2G would access several different revenue

Flexibility Service Prioritisation:

Flexibility services have seen significant change over the past couple of years. The following recommendations are made for each of the key services:

- Behind-the-meter tariff optimisation is a valuable revenue stream with an appropriate dynamic tariff. It has low barriers to entry, and doesn't require many other stakeholders, and so should be targeted first.
- Dynamic Regulation is the most promising of the newer NGESO flexibility services for V2G, and so should be targeted and investigated in further projects/developments in this area.
- Capacity Market revenue can be stacked with other revenue streams within the same time window, increasing the overall revenue which can be achieved. This should be targeted as a primary market for V2G.
- It is difficult to model the value obtainable from the Balancing Mechanism for V2G, but it shows high potential opportunity and should be investigated further as a potential source of income for aggregated V2G.
- DSO services, where they are geographically available should be considered, but cannot be relied upon for all business cases.

1 Introduction

1.1 Introduction to Cenex

Cenex was established as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies in 2005.

Today, Cenex focuses on low emission transport & associated energy infrastructure and operates as an independent, not-for-profit research technology organisation (RTO) and consultancy, specialising in the project delivery, innovation support and market development.

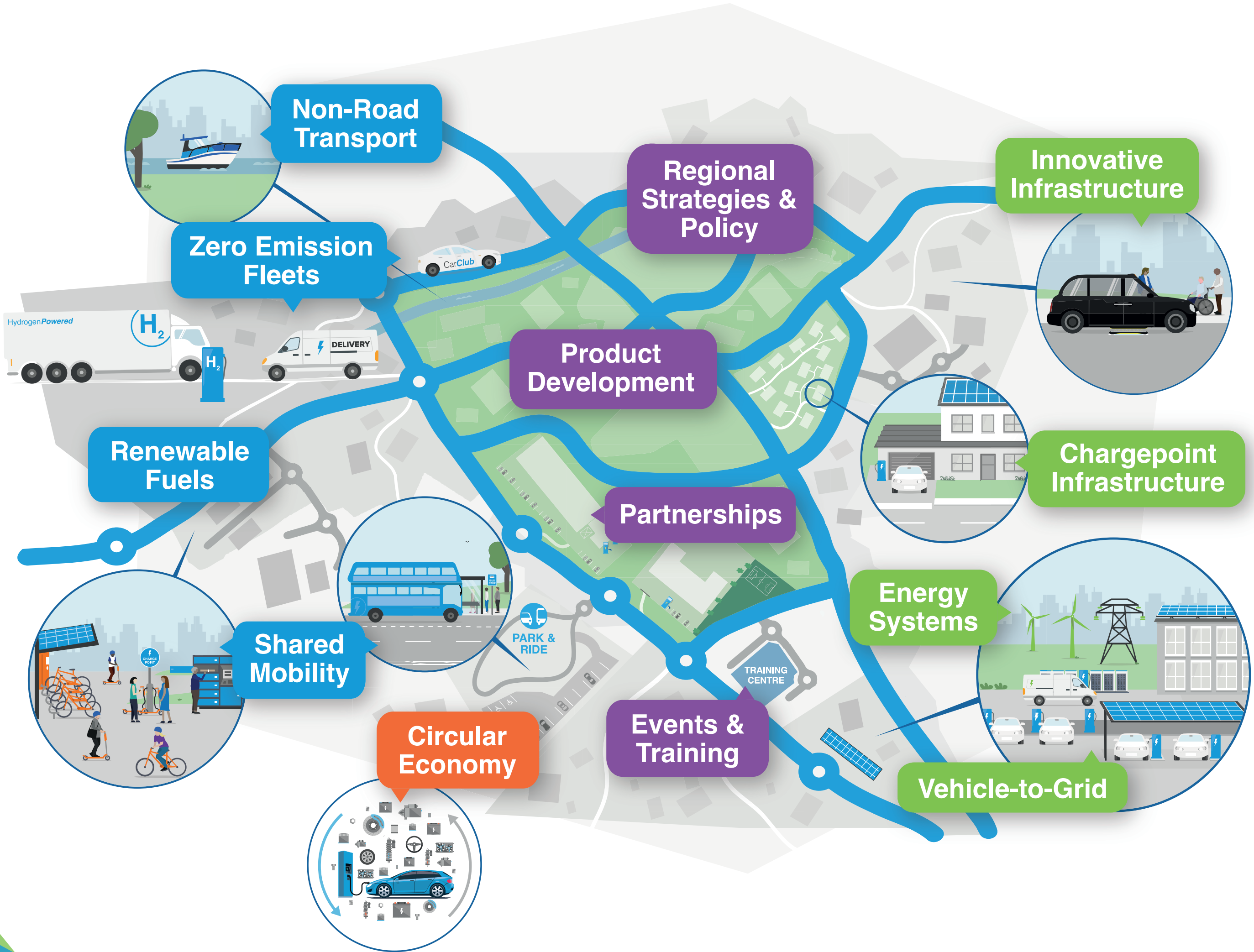
We also organise Cenex-LCV, the UK's premier low carbon vehicle event, to showcase the latest technology and innovation in the industry.

Our independence ensures impartial, trustworthy advice, and, as a not-for-profit, we are driven by the outcomes that are right for you, your industry and your environment, not by the work which pays the most or favours one technology.

Finally, as trusted advisors with expert knowledge, we are the go-to source of guidance and support for public and private sector organisations along their transition to a zero-carbon future and will always provide you with the insights and solutions that reduce pollution, increase efficiency and lower costs.

To find out more about us and the work that we do, visit our website:

www.cenex.co.uk



1 Introduction

1.2 Introduction to the Project

This report has been written as part of the Virtual Bunkering of Electric Vessels (VBEV) project. This project is a feasibility study to determine the financial, technical, and operational business case for the deployment of bi-directional charging infrastructure in the marine sector. The study also evaluates the environmental benefit, ultimately preparing the ground for a UK demonstrator of bi-directional boat charging.

Virtual bunkering enables aggregated electric boat batteries to provide additional value when not being used for propulsion. With the transition to electrically powered recreational and commercial craft, harbour and marina charging infrastructure will be required. The provision of sufficient power at an affordable price to harbours and marinas represents one barrier to the widescale adoption of electric boats. The high upfront cost is another, as well as potential battery degradation from infrequent use in leisure craft. This project will help to resolve these barriers by enabling existing electric boats to support the charging infrastructure without the need for expensive grid upgrades by providing a virtual electricity bunker service, delivering managed battery conditioning support and enabling additional revenue generation for boat owners.

This project brings together two leading UK businesses, electric boat charging operator, Aqua SuperPower and bi-directional charging manufacturer, Indra Renewable Technologies as well as research and technology experts Cenex and the University of Plymouth. The four partners engaged with electric boat builders, marina operators, the local and national grid as well as representatives of boat users to develop a detailed business case and plan for a world first demonstrator of Virtual Bunkering for Electric Vessels using bi-directional chargers.

2 Scope

Whilst the focus of this report is on the value of V2G for electric vessels, some of the research and findings will have a broader application. In recent years there has already been a significant amount of work that looks at V2G[1], the different value propositions[2] and revenue for EVs. However, there have been some significant market changes since much of that work was completed. In order to add the most value, this report focuses on the new flexibility services and ignores older ones such as Firm Frequency Response. This report covers the following markets as potential revenue streams for V2G for electric vessels.

- **Behind the Meter (self-consumption optimisation, time of use tariff optimisation)**
- **ESO services**
- **DSO services**
- Wholesale energy market
- **Balancing Mechanism**
- Capacity Market

Those in bold are assessed in additional detail though simulation modelling (*see Section 9*).

2.1 Stakeholders

The Energy System is complex, with a wide range of stakeholders, with organisations often holding multiple roles. This section describes the key stakeholder roles in this space, what they do, and why they are relevant. The stakeholders are shown in *Figure 2* with key relationships represented by arrows.

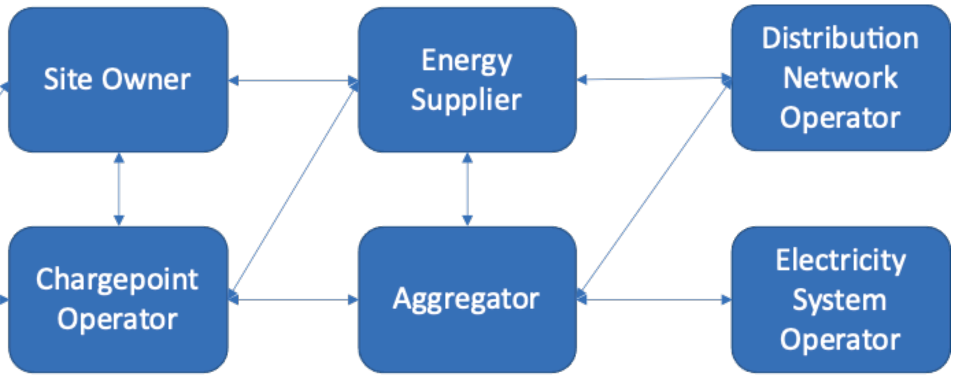
End User/Vessel Owner

Arguably the most important stakeholder is the one that uses the technology on a day-to-day basis. In the case of the VBEV proposition, this will likely be the vessel owner. However, in cases that the vessel is leased, then it would be the lessee. They will need the V2G technology to work for them, without compromising the condition or their use of the vessel.

Site owner

This refers to the owner of the site where the V2G chargepoint is located, which could be a marina, harbour, or port. Depending on the business model, they may own (or part own) the chargepoint. They are likely to want to see a benefit from having the chargepoint on their site, either through electricity bill savings from the V2G operations, or a financial payment from the vessel owner, or Chargepoint Operator (CPO).

Figure 2: Stakeholders and relationships



[1] https://www.v2g-hub.com/
[2] https://www.cenex.co.uk/app/uploads/2020/06/Fresh-Look-at-V2G-Value-Propositions.pdf

2 Scope

Chargepoint Operator (CPO)

The chargepoint operator is the body that would typically install the charging hardware. They then subsequently manage the operation of the chargepoint, charging money for each unit of electricity delivered by the chargepoint. It may be that additional layers exist at this point, such as an e-Mobility Service Provider (eMSP) who provide the digital interface between the end user/vehicle owner, site owner, CPO and potentially even the aggregator and DNO/DSO. Sometimes this role is delivered by the CPO, but often this is contracted out to a third party.

Aggregator

An aggregator is a body that will take the flexibility from a portfolio of small demand or generation assets (such as chargepoints, air-conditioning units, standby diesel generators etc.) and build them into sufficient volumes so that they can offer the flexibility into DSO or ESO flexibility markets. They will manage flexibility market access (which may be difficult for a single site or asset owner to manage), retaining a proportion of the revenue made from flexibility services as their fee.

Energy Supplier

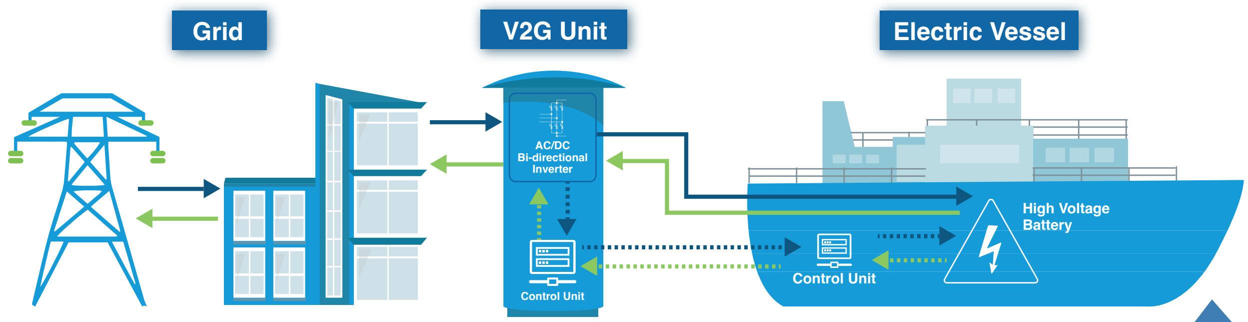
The energy supplier is the licensed body that provides the electricity to the site and chargepoints. Energy suppliers are regulated by Ofgem and have a larger set of obligations. They purchase energy from wholesale energy markets or generators and sell it to retail customers (e.g. the site owner)

Distribution Network Operator (DNO)

A Distribution Network Operator is a company that operates and maintains the electricity distribution network in a specific geographic area across the UK. They are responsible for delivering electricity from the point it leaves the transmission network to homes and businesses via their distribution network, including infrastructure such as cabling and substations. DNOs are sometimes referred to as Distribution System Operators (DSOs), which is meant to reflect the increasingly active role they are playing in actively managing the power flows across the distribution network.

Electricity System Operator (ESO)

The Electricity System Operator (ESO) is responsible for managing the power across the whole of the electricity system, ensuring system stability and continuity. One of their key roles is making sure that electricity supply and demand match in real time. Part of how they do this is by buying flexibility from both generators and flexible demand. The flexibility markets that the ESO provide can be a significant revenue stream for flexible assets like V2G.



3 Non-Financial Benefits of Bi-directional Charging in the Marine Sector

Although in this report the focus is on the financial benefits of V2G charging in the marine sector, there are also some non-financial benefits, which are discussed below.

3.1 Carbon Saving

In addition to a financially driven behind-the-meter optimisation (i.e., charging at low prices and discharging at high prices), it is also possible to perform a similar carbon driven optimisation. The grid carbon intensity varies continuously depending on the generation mix. Data on the carbon intensity is published by National Grid Electricity System Operator (NGESO),[3] with forecasts of the carbon intensity also provided. By using these forecasts, it is possible to use V2G to assist the incorporation of renewable generation into the grid and reduce the required running of fossil generation.

3.2 Grid Connection Optimisation

As the mooring location for many vessels will be coastal, these locations are likely to be towards the edges of the electricity distribution network. Such locations may have weaker network connections and could be expensive to upgrade. V2G can provide opportunities to optimise energy usage within the existing network connection limits. Not only can network connection upgrades be expensive, but they can also take a long time to be delivered. In these cases, V2G could enable additional loads to be connected within the existing connection limit.

3.3 Local Renewable Optimisation

Coastal locations may often be suitable for sites for wind or solar renewable generation. In such cases, where on-site renewables are installed, V2G can help maximise the self-consumption of the renewable energy. Not only can this reduce electricity costs, it can assist with incorporating the renewable assets into the grid. Increasing self-consumption can, for example help reduce voltage issues in the local distribution network.

3.4 Battery Health

Electrical storage batteries degrade not only through use, but also over time. The battery is an expensive and vital component of any electric vessel, and so prolonging its useful lifespan has multiple benefits. An investigation of the impact of V2G on battery degradation is beyond the scope of this report. However, this has been studied previously in the EV-elocity Project[4]. Results from the project showed that certain V2G charging strategies could contribute to a significant reduction in battery degradation.

[3] *https://www.nationalgrideso.com/future-energy/our-progress-towards-net-zero/carbon-intensity-dashboard*
[4] *https://www.ev-elocity.com/wp-content/uploads/2022/06/EV-elocity-Final-Report_published-compressed.pdf*

4 Recent Regulatory & Market Changes

This section provides a summary of some of the key recent material changes to the code, regulations and framework for power and flexibility markets in Great Britain.

4.1 Access Significant Code Review

In May 2022 Ofgem published their decision[5] on the "Access and Forward-Looking Charges Significant Code" review. The relevant parts of this significant code review concerned changes to the connection charge faced by those connecting to the distribution network. Their decision was to:

- Remove the contribution to reinforcement for demand connections by introducing a 'fully shallow' connection charging boundary. This will involve connecting customers paying for extension assets only.
- Reduce the contribution to reinforcement for generation connections by introducing a 'shallow-ish' connection charging boundary. This will involve connecting customer paying for extension assets and a contribution towards reinforcement at the voltage level at point of connection.

In essence this means that the demand customer will only pay for reinforcement of extension assets (or sole use assets), i.e. assets that will only be used by the demand customer requesting the increased capacity connection. It is worth noting that the cost of upgrading extension assets can run in to thousands of pounds. These changes came into effect in April 2023.

The decision also notes that storage would be treated as generation for the purposes of connection costs. However, storage that is co-located with demand may not be required to contribute to reinforcement costs (up to a certain amount). There is some ambiguity as to whether V2G would be classified as storage for the purposes of this code.

4.2 Market-wide Half-Hourly Settlement

Historically, meter point administration numbers (MPANs) with smaller annual demands have been settled on an estimated profile basis. This means that rather than metering the profile of demand across the day, the shape is estimated based on industry average shapes. This shape is then scaled for the individual meter based on the quarterly or annual meter reads. For MPANs that are not half-hourly settled, any changes to the actual demand shape (due to for example V2G) would not result in any change to the actual cost of the electricity settled. Larger demand sites will typically already have half-hourly metering and settlement. Each MPAN is assigned a specific profile class, depending on its type, which will in part determine how energy is settled for that meter. See below for a list of the different profile classes. Since April 2017 all MPANS in profile classes 5 to 8 are required to have the energy settled half-hourly.

Profile Class 1	Domestic Unrestricted Customers
Profile Class 2	Domestic Economy 7 Customers
Profile Class 3	Non-Domestic Unrestricted Customers
Profile Class 4	Non-Domestic Economy 7 Customers
Profile Class 5	Non-Domestic Maximum Demand (MD) Customers with a Peak Load Factor (LF) of less than 20%
Profile Class 6	Non-Domestic Maximum Demand Customers with a Peak Load Factor between 20% and 30%
Profile Class 7	Non-Domestic Maximum Demand Customers with a Peak Load Factor between 30% and 40%
Profile Class 8	Non-Domestic Maximum Demand Customers with a Peak Load Factor over 40%

Table 2: Meter Profile Classes

[5] *https://www.ofgem.gov.uk/publications/access-and-forward-looking-charges-significant-code-review-decision-and-direction*

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On 20th April 2021, Ofgem published its "Market-wide Half-hourly settlement: Decision and Full Business Case"[6] outlining how and when market-wide half-hourly settlement (MHHS) will be implemented. Ofgem has decided to introduce MHHS, based on the design working group's (DWG's) Target Operating Model (TOM), for all meter point administration numbers (MPANs). The original plan has now been updated and is now owned by the MHHS Programme[7]. The current timeline concludes the migration of all meters to be half-hourly settlement by Q4 2026.

In order to provide any V2G services, half-hourly settlement is a pre-requisite. However, given that most MPANs that remain non-half hourly settled are domestic, this is unlikely to cause an issue for any propositions in the VBEV project.

4.3 Recent and Planned Changes to ESO Flexibility Services

NGESO is required to meet operating guidelines that state they should be able to

- Recover frequency to within statutory limits within 60 seconds; and
- Restore frequency to within operational limits within 15 minutes.

Historically NGESO procured reserve and response services through tenders and bilateral contracts. They have been through a process of automating procurement of services via auctions closer to real time as part of their drive to reduce barriers to entry for a more diverse mix of service providers.

Response Services

As part of this transition, they are moving towards new response services. These are Dynamic Containment, Dynamic Regulation and Dynamic Moderation which are all now being procured. In time it is likely that the older services they are replacing (Firm Frequency Response (dynamic) and Enhance Frequency Response (EFR)) will be discontinued.

Static Recovery (not yet being procured) is likely to replace the older Firm Frequency Response (static) service.

Reserve Services

Quick reserve is a new service that will be used to help recover frequency during normal conditions. This will likely replace the older Fast Reserve service.

Short-Term Operating Reserve (STOR) is a current restoration service which will be replaced by Slow Reserve which will recover frequency to within 0.2Hz of 50Hz within 15 minutes.

Enduring Auction Capability

NGESO are currently developing a new way of procuring against their reserve and response requirements. The aim of this is to address challenges with providers having to split capacity or stack revenues across different services and mitigate against oversupply in one market whilst another may be undersupplied. This new platform is due to go live in Q4 2023.

The new platform could give significant new flexibility to providers. Currently auctions for each service are run independently. Participants must decide which one service they wish to offer ahead of the auction. The Enduring Auction Capability (EAC) will enable participants to offer more than one service into a single auction. The auction algorithm will then

[6] *https://www.ofgem.gov.uk/publications/electricity-retail-market-wide-half-hourly-settlement-decision-and-full-business-case*
[7] *https://www.mhhsprogramme.co.uk/*

4 Recent Regulatory & Market Changes

co-optimise across multiple services to optimise the market in the most efficient way.

The EAC provides significantly more opportunities for the stacking and dynamic switching of revenue streams within ESO services as all of the new reserve and response services are included in the platform.

4.4 Development of DSO Flexibility Services

The Energy Networks Association (ENA) has worked to co-ordinate the approach to DSO flexibility procurement and the definitions of the services procured. Summary definitions as provided by the ENA are shown in *Table 3*.

Active Power Service	Definition
Sustain	The Network Operator procures, ahead of time, a pre-agreed change in input or output over a defined time period to prevent a network going beyond its firm capacity.
Secure	The Network Operator procures, ahead of time, the ability to access a pre-agreed change in Service Provider input or output based on network conditions close to real-time.
Dynamic	The Network Operator procures, ahead of time, the ability of a Service Provider to deliver an agreed change in output following a network abnormality.
Restore	Following a loss of supply, the Network Operator instructs a provider to either remain off supply, or to reconnect with lower demand, or to reconnect and supply generation to support increased and faster load restoration under depleted network conditions.

Table 3: ENA Flexibility Services Definitions

Whilst the ENA is working to co-ordinate these services, there are differences in how the DNOs have interpreted them to work best for their own licence areas. These differences as highlighted by the ENA are reproduced in *Table 4*.

	Sustain	Secure	Dynamic	Restore
Network Constraint	Pre-Fault	Pre-Faul t/ Planned outage	Network Abnormality	Post fault - CI/CML
Procurement Timescale	Annual / Season	Annual / Season	Annual / Season	Annual / Season
Payment Mechanism	Utilisation only	Availability & Utilisation	Availability & Utilisation / Utilisation only	Utilisation only
Availability Agreement Period	Pre-determined	Week ahead / 2 Weeks ahead / Year ahead	No availability / Week Ahead / 2 Weeks ahead	N/A
Utilisation Instruction	Scheduled contract stage	Week ahead / Real	Real time / Within day / day ahead	Real time
Dispatch Mechanism	Scheduled / self-dispatch	API: 2-15 mins / Phone / Email	API: 2-15 mins / Phone / Email	API: 2-15 mins / Phone / Email

Table 4: DSO Services DNO Interpretations

The volumes of these services procured have been increasing significantly over recent years, and so provide and increasing opportunity for demand side flexibility providers. The ENA also produces a timeline of flexibility services procured by DNOs[8].

[8] *https://www.preceden.com/timelines/523803-flexibility-in-gb-timeline*

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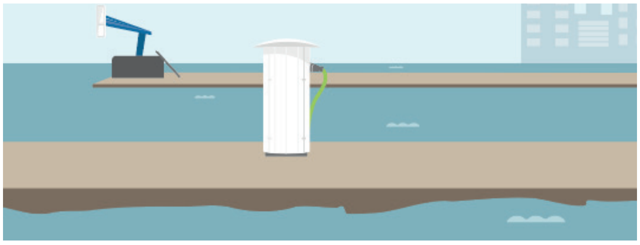
DSO Tenders	Sustain (MW)	Secure (MW)	Dynamic (MW)	Restore (MW)
Contracted for 2018	0	24	34	59
Contracted for 2019	0	10	121	125
Contracted for 2020	2	105	556	502
Contracted for 2021/22	28	375	926	538
Contracted for 2022/23*	37	192	643	220

Table 5: Contracted DSO Flexibility

* Figures up to August 2022

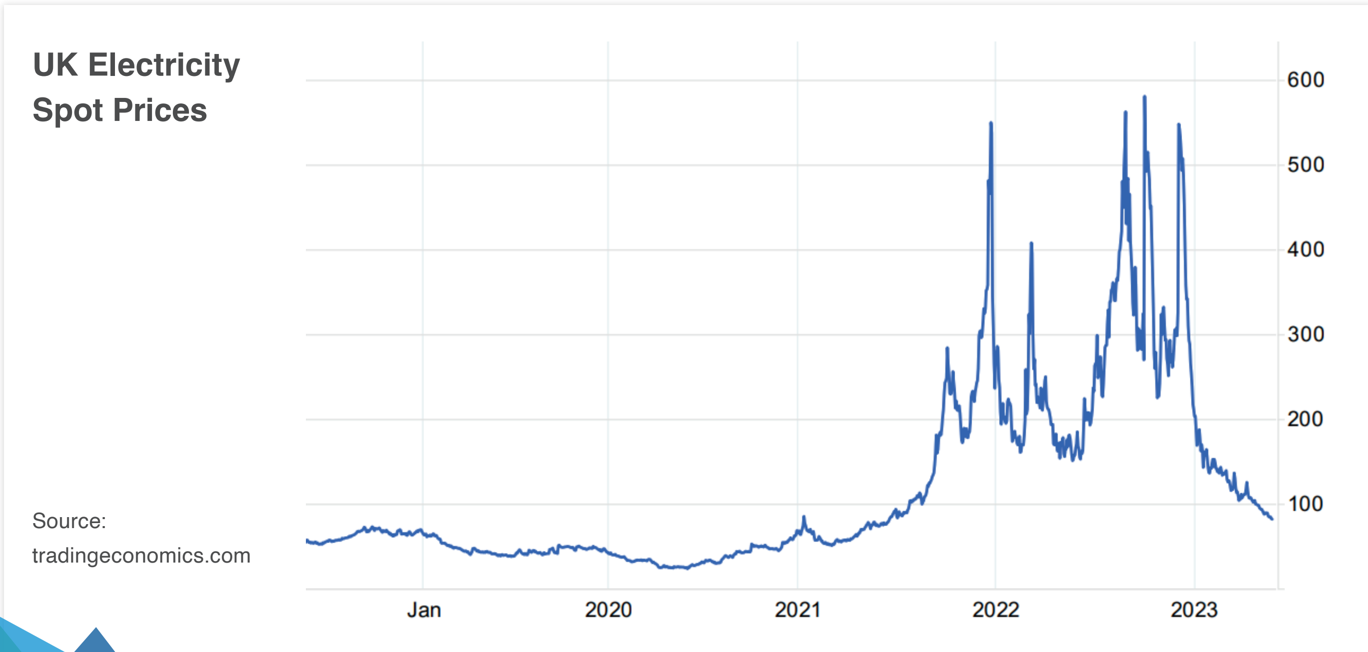
The majority of DSO flexibility services are procured via the Piclo Flex[9] platform. Additionally, flexibility requirements published by four DNOs (National Grid Electricity Distribution (NGED), Northern Powergrid, Scottish and Southern Energy Networks (SSEN) and SP Energy Networks (SPEN)) are available via the Flexible Power[10] website.



4.5 Electricity Wholesale Price Changes

A lot has changed with electricity prices over the last three years (*see Figure 3*). After a period of relatively stable power prices, a bounce back in energy demand during the opening-up of economies after COVID lockdowns drove an initial increase in prices during 2021. Following that, geo-political tensions in Eastern Europe and the invasion of Ukraine by Russia and subsequent sanctions by The West led to further price increase and a period of high price volatility. Prices in the UK peaked at an all-time high of 580.55 £/MWh in September 2022, over ten times average pre-COVID price levels.

Figure 3: UK Electricity Spot prices (£/MWh)



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Such increase in prices caused a huge benefit to on-site renewable generation, as avoiding importing energy became significantly more financially beneficial.

Figure 4 shows the daily standard deviations of half hourly system prices over the same period. This provides a measure of how much the half hourly electricity price fluctuates within day (i.e a measure of within day volatility). Note the logarithmic scale on the vertical axis of the chart. There is a clear increase around 2022. This is important for V2G, as within day price fluctuations determine the value of revenue that can be made from arbitrage strategies with V2G. The greater the within day price differential, the greater the potential savings that can be made from charging at low prices and discharging at high prices. This doesn't of course directly translate to profit since accurate forecasting of the price is also important for a successful strategy.

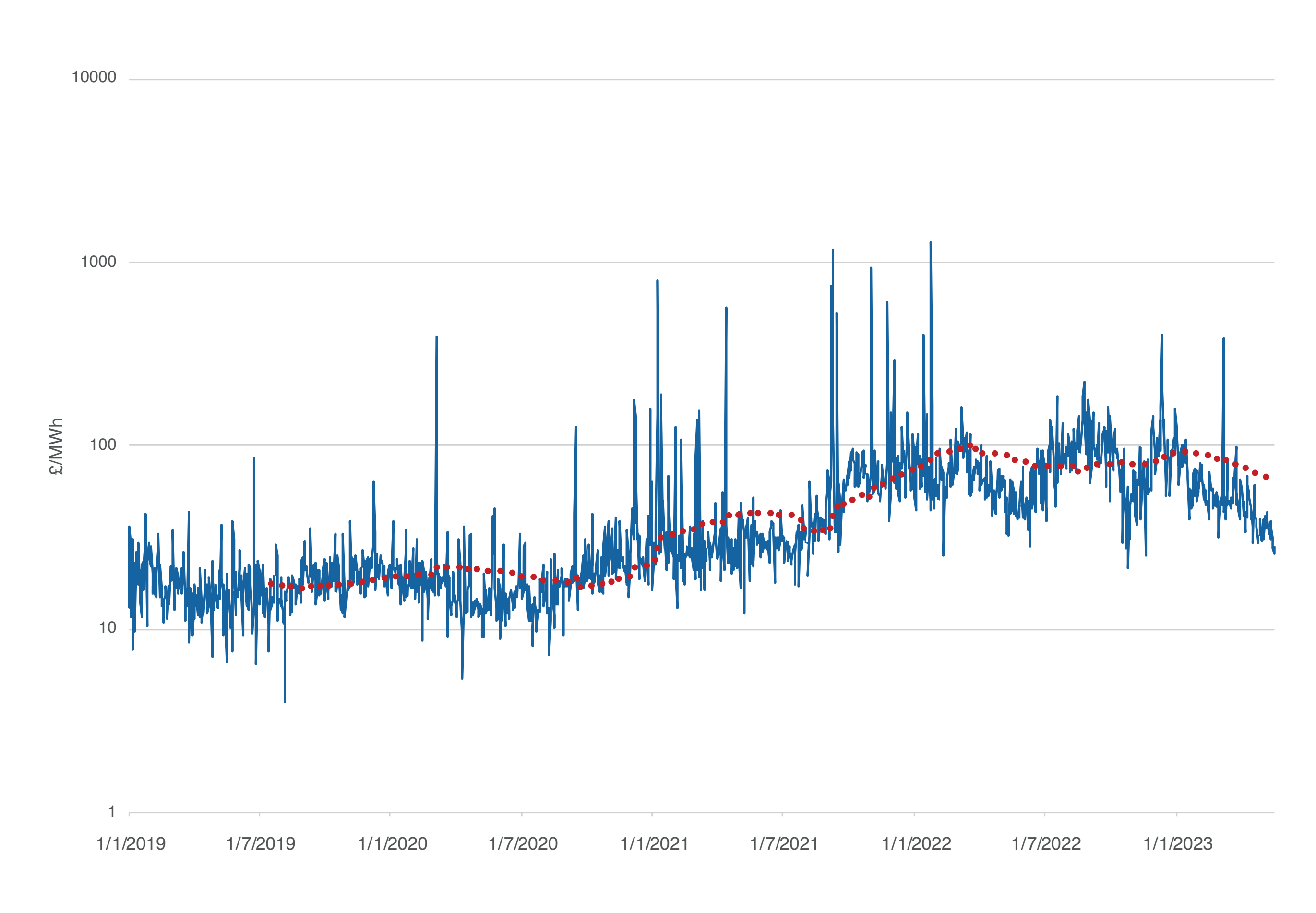


Figure 4: Daily Standard Deviation of Half Hourly Electricity System Prices (200 day moving average in red)

[9] *https://picloflex.com/*
[10] *https://www.flexiblepower.co.uk/*

5 Description of Flexibility Services & Markets

5.1 Flexibility Services Summary

This section provides a summary of the flexibility services procured by both NGESO and the DSOs. High level technical requirements are provided in *Table 6 & Table 7*. Note that due to the variation in service design, not all criteria apply to all the different services.

Product Criteria	Quick Reserve	Slow Reserve	Dynamic Containment	Dynamic Moderation	Dynamic Regulation	Static Recovery	Demand Flexibility Service
Minimum Capacity	1 MW	1 MW	1 MW	1 MW	1 MW	TBC	1 MW
Initiation Time	NA	NA	0.5 second	0.5 second	2 seconds	TBC	
Time to Full Delivery	1 minute	15 minutes	1 second	1 second	10 seconds	30 seconds	day ahead
Maximum Activation Period	15 minutes	120 minutes	15 minutes	30 minutes	60 minutes	TBC	30 minutes**
Minimum Activation Period	5 minutes	30 minutes	NA	NA	NA	TBC	30 minutes
Maximum Recovery Period	1 minute	30 minutes	State of energy management rules govern the recovery	State of energy management rules govern the recovery	State of energy management rules govern the recovery	TBC	NA
Aggregation Rules	Within GSP Group	Within GSP Group	Within GSP Group	Within GSP Group	Within GSP Group	TBC	National Basis
Dispatch Mechanism	BM -BOAs /Non-BM - ADSP	BM -BOAs /Non-BM - ADSP	ADSP	ADSP	ADSP	TBC	Day ahead instructions
Grid Frequency Metering	No	No	Yes	Yes	Yes	Yes	No
Operational Metering	1Hz	1Hz	1Hz	1Hz	1Hz	TBC	Half hourly
Ramp Rates	As per envelope*	As per envelope*	As per envelope*	As per envelope*	As per envelope*	TBC	NA
Baselining	60 minutes nomination baseline	60 minutes nomination baseline	Submitted by service provider	Submitted by service provider	Submitted by service provider	TBC	Average consumption over previous 10 working days
Exclusions			Cannot provide other reserve in the same window	Cannot provide other reserve in the same window	Cannot provide other reserve in the same window	TBC	Assets that participate in the BM, other ancillary services or DNO services, or that have a capacity market contract.
Description	Used to recover frequency back towards 50Hz.	To assist with the recovery of system frequency post fault to 0.2Hz within 15 minutes.	To prevent frequency deviations outside - 0.8Hz/+0.5Hz following large losses.	Assists with keeping frequency within 0.2Hz, especially during more volatile conditions.	Assists with keeping frequency near to 50Hz during normal conditions.	To recover frequency to 0.5Hz within 60 seconds following large losses.	A new flexibility service to allow the ESO to access additional flexibility when national demand is at its highest (during winter peak days). Incentivising consumers to voluntarily reduce/flex their electricity usage.
Notes	Service windows are 2 hours currently but will be 30 minutes in the future. * *See Figure 5*	Service windows are 8 hours in overnight, 2 hours in the day. * *See Figure 5*	Contract delivery is over 4-hour EFA blocks. * *See Figure 5*	Contract delivery is over 4-hour EFA blocks. * *See Figure 5*	Contract delivery is over 4-hour EFA blocks. * *See Figure 5*	This will replace the older FFR static service.	Requires and aggregator/supplier ** Bids are for 30min settlement periods.
Link	https://www.nationalgrideso.com/industry-information/balancing-services/reserve-services/quick-reserve	https://www.nationalgrideso.com/industry-information/balancing-services/reserve-services/slow-reserve#Document-library	https://www.nationalgrideso.com/industry-information/balancing-services/frequency-response-services/new-dynamic-services-dcdmdr#Technical-Requirements	https://www.nationalgrideso.com/industry-information/balancing-services/frequency-response-services/new-dynamic-services-dcdmdr#Technical-Requirements	https://www.nationalgrideso.com/industry-information/balancing-services/frequency-response-services/new-dynamic-services-dcdmdr#Technical-Requirements		https://www.nationalgrideso.com/industry-information/balancing-services/demand-flexibility-service-dfs#Pre-consultation-webinar

Table 6: NGESO Flexibility Services

5 Description of Flexibility Services & Markets

Product Criteria	Sustain	Secure	Dynamic	Restore
Minimum Capacity	0 to 100kW*	0 to 100kW*	0 to 100kW*	0 to 100kW*
Initiation Time	> 1 day	> 1 day	> 15 mins	> 15 mins
Time to Full Delivery	30 minutes	15 - 30 minutes*	3 - 30 minutes*	3 - 30 minutes*
Maximum Activation Period	NA	NA	NA	NA
Minimum Activation Period	30 minutes	30 minutes	30 minutes	30 minutes
Maximum Recovery Period	NA	NA	NA	NA
Aggregation Rules	Within procured constrained zone	Within procured constrained zone	Within procured constrained zone	Within procured constrained zone
Dispatch Mechanism	Scheduled /self-dispatch	API - 15mins / Phone / Email	API - 15mins / Phone / Email	API / Phone / Email
Grid Frequency Metering	No	No	No	No
Operational Metering	Half Hourly	Half Hourly	Half Hourly	Half Hourly
Ramp Rates	NA	NA	NA	NA
Baselining	Historic	Historic or nominated	Historic or nominated	Historic or nominated
Exclusions				
Description	Procured ahead of time, a pre-agreed change in input or output over a defined period of time is provided, to prevent a network going beyond its firm capacity.	Procured ahead of time, the ability to access a pre-agreed change in input or output based on network conditions close to real time.	Procured ahead of time, the ability of a provider to deliver a change in output following a network abnormality.	Following a loss of supply, then network operator instructs a provider to either remain off or reconnect with a lower demand or reconnect supply generation to support network restoration.
Notes	* Varies by DNO	* Varies by DNO	* Varies by DNO	* Varies by DNO
Link	https://www.energynetworks.org/assets/images/Resource%20library/ON-WS1A-P3%20Active%20Power%20Services%20-%20Final%20Implementation%20Plan-PUBLISHED.23.12.20.pdf			

Table 7: DSO Flexibility Services

5 Description of Flexibility Services & Markets

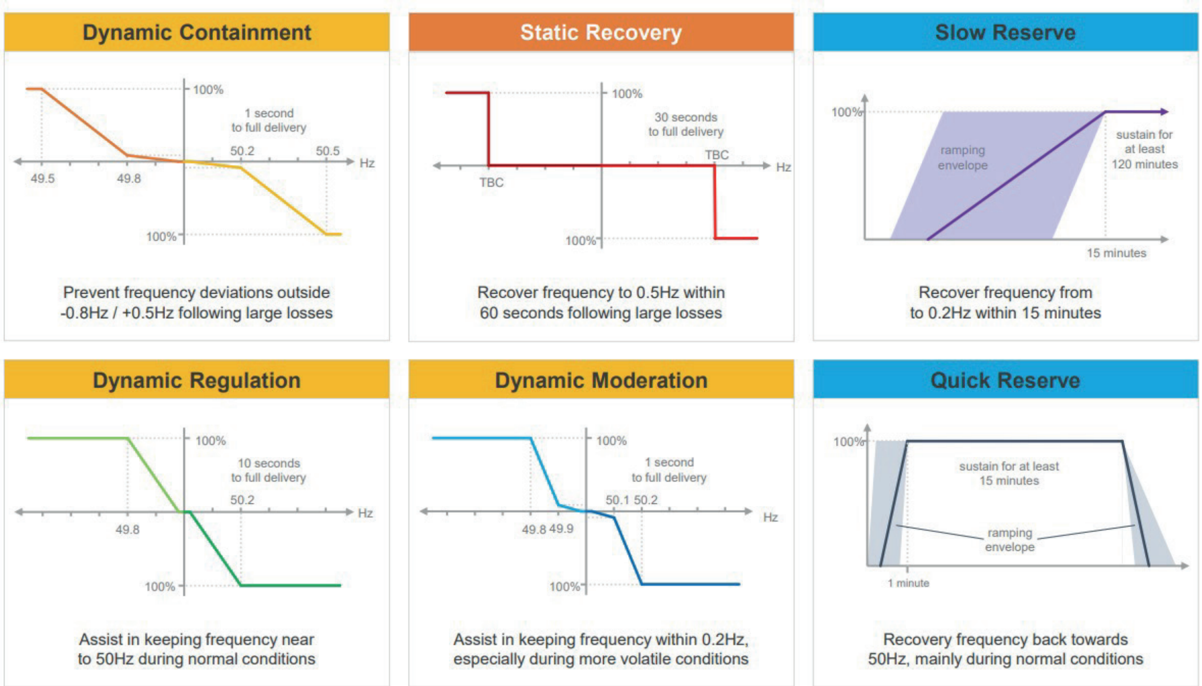


Figure 5: Summary of new ESO reserve and response services ramp rate envelopes (Source NGESO)

Figure 5 above shows the response envelopes for the NGESO flexibility services. For the four response services, these are expressed in terms of power response against the change in system frequency. For the two reserve services, it is shown as power response against time from notification.

5.2 Markets Summary

In addition to the services outlined above, there are three markets that V2G can potentially participate in to earn revenue. These are described in this section.

The Balancing Mechanism

The BM is NGESO's primary tool for balancing the system. It is an online auction where providers offer flexibility and NGESO accepts the most competitive bids and offers to balance the system in real time. Historically, access to this market was restricted to larger generators, but now routes exist for small flexible assets to participate via either a licenced energy supplier or a Virtual Lead Party[11].

The Capacity Market

The capacity market was introduced to provide an incentive to build or make available generation (or demand reduction) capacity to meet winter peak demand, providing an economic signal over long enough time frames to allow new build assets. Capacity providers participate in annual auctions to win capacity agreements (of up to 15 years). These agreements provide the value they are entitled to receive for each future year. Access to the capacity market will need to be via an aggregator to meet the minimum size threshold. V2G is not currently defined as a separate generation technology class within the capacity market, however its more formal inclusion is being considered by Government.

The Electricity Wholesale Market

This market is not normally accessible to electricity consumers. It is a half-hourly market that ranges from the same day delivery to months ahead, being used primarily for generators to sell their energy and suppliers to purchase for their demand portfolio. Access to this market is via an aggregator or licenced energy supplier.

[11] https://www.nationalgrideso.com/industry-information/connections/use-system-uos-and-virtual-lead-party-vlp

5 Description of Flexibility Services & Markets

Behind The Meter

Not strictly a market, behind-the-meter refers to actions taken by flexible demand to optimise the time of electricity consumption or maximise the self-consumption of renewables generated on site. Optimising the self-consumption of renewables requires them to be connected behind the same meter as the V2G unit(s), however it does not require any other relationships or market access. Optimising the time of electricity consumption requires a time varying electricity tariff along with half-hourly settlement in order to realise any savings.

5.3 Review of UK and EU Tariff Opportunities

In order to perform behind the meter electricity tariff optimisation, a multi-rate electricity tariff is required. The larger the difference in the highest and lowest rates, the larger the potential savings that are possible from a V2G based optimisation.

UK Electricity Tariffs

In the UK the two rate Economy-7 tariff has been available to domestic customers for many years. However, there are now a few more innovative dynamic tariffs emerging. Octopus Agile[11] is the prime example, providing dynamic half-hourly varying tariff with API access to the tariff data.

There is also the TIDE[12] time of use tariff by Green Energy. However, this has been temporarily withdrawn due to wholesale market price volatility.

Industrial and Commercial tariffs typically have a day rate and a night rate for electricity. They may also have a separate rate for weekends. The difference in day and night rates can be around 30% as observed from recent bills. This difference is driven partly by distribution use of system (DUoS) charges, that vary by time of day and weekday/weekend.

UK Electricity Tariffs

Figure 6 shows the availability of different types of time of use (ToU) tariffs across Europe. The figure is reproduced from ACER analysis in 2016 and whilst is now somewhat out of date it does show the variations at the time. It is likely that the hourly time of use pricing would present the best opportunity for V2G.

In Finland consumers can chose a dynamic electricity tariff whereby they pay an hourly price for electricity, based transparently on the Nord Pool spot price for Finland. Hourly metering is required but is widespread in Finland.

In Norway, all consumers now have smart meters, and over 90% of households have dynamic electricity contracts based on the hourly spot price.

In contrast, in Germany historically two rate tariffs did not exist. The smart meter roll out has also be slow. Consequently, only around 100,000 electricity customers currently have dynamic tariffs.

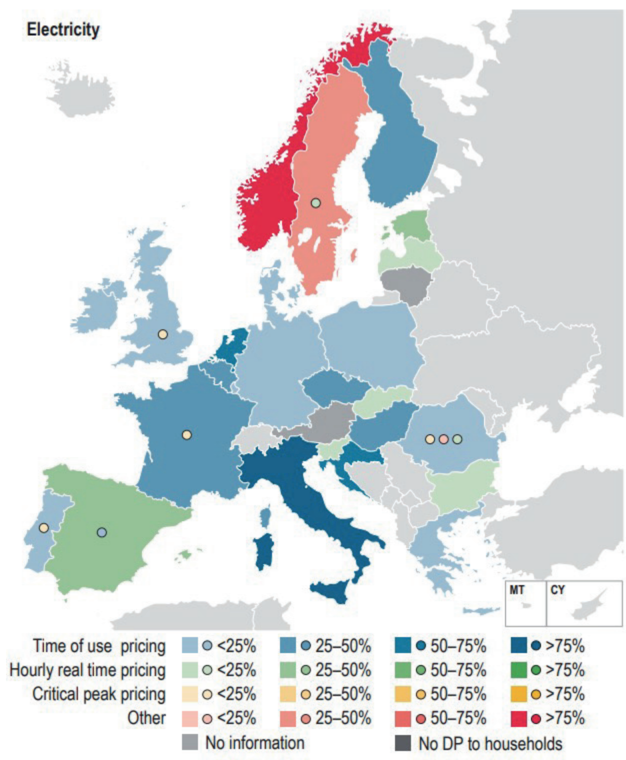


Figure 6: Prevalence of TOU pricing in Europe. Countries coloured according to most representative ToU method. Coloured dots represent additional ToU pricing methods. (Source ACER Market Monitoring Report 2015)

6 Value Assessment of Flexibility Services & Markets

In this section, the recent value of the different flexibility services and markets are presented.

DSO Flexibility Services

The value of these services varies considerably by location and the DNO. The ranges of values from procured services are presented in *Figure 7* and *Figure 8*, with the mean values shown as blue circles. For the dynamic and secure services both an availability and utilisation payment may be made. Whilst restore and sustain services only have a utilisation payment.

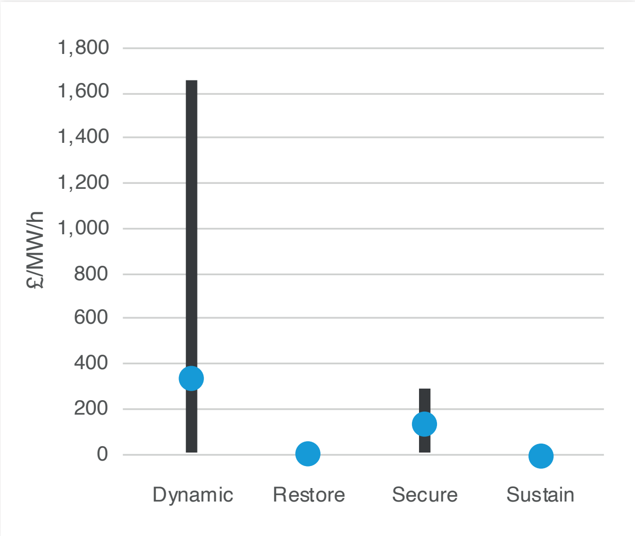


Figure 7: Range of availability prices for DSO services

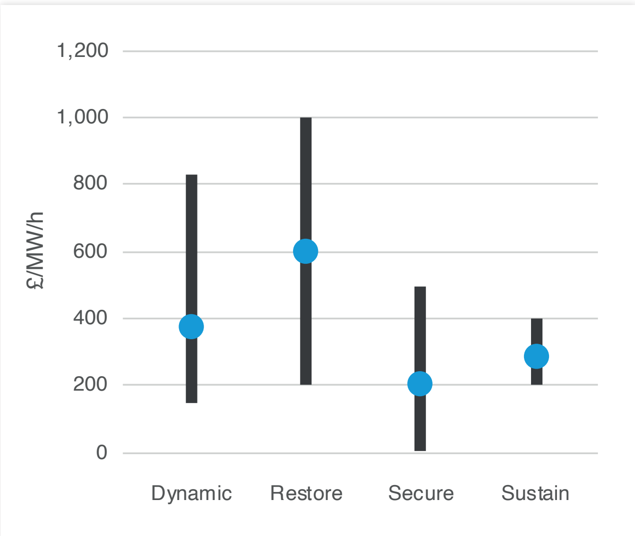


Figure 8: Range of utilisation prices for DSO services

Whilst it is unclear if the value of these contracts is likely to increase in the future, they are likely to become more prevalent as DNOs continue to adopt flexibility as a way of managing grid constraints. With the demand on the distribution grid forecast to rise significantly from the electrification of both heat and transport, grid constraints will increase over the coming years without huge distribution network upgrades.

ESO Response Services

There have been some significant fluctuations in prices of response products over recent years. Historically they have had a higher value than reserve services, as there have been fewer assets that have had the ability to respond quickly enough to qualify for response services. However, as fast responding battery storage devices become more widespread this has been changing.

The requirement for response is lower than for reserve (NGESO currently procure 1.7GW STOR daily, and ~1.2GW of DM, DR, DC combined). The number of grid-connected battery storage assets (either stand alone battery storage, or batteries within EVs) is expected to increase significantly in coming years, so it is likely that in the coming years the response markets will become saturated, and the price will decline significantly.

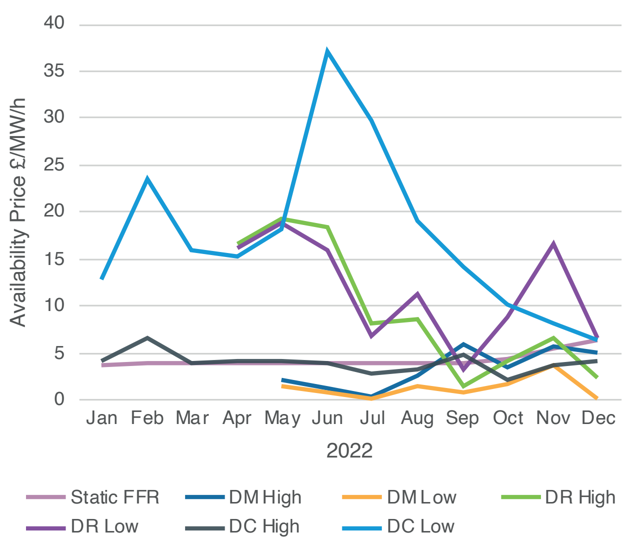


Figure 9: ESO response products average monthly prices

6 Value Assessment of Flexibility Services & Markets

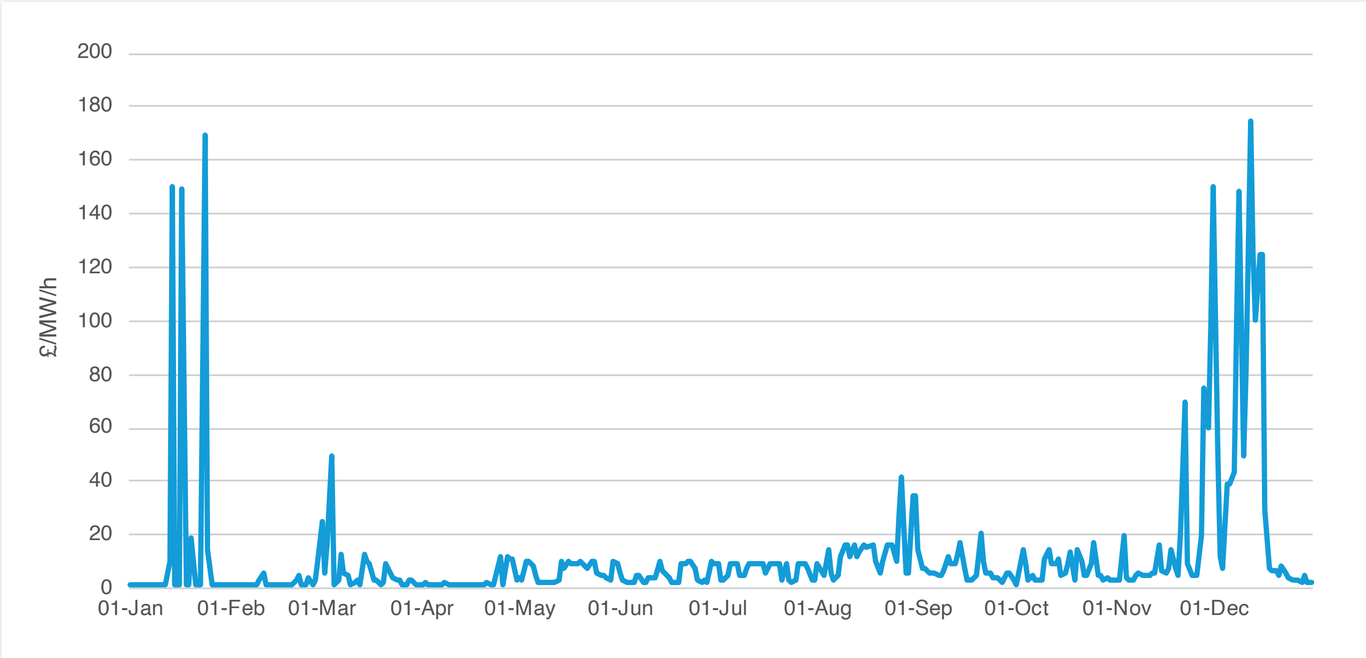


Figure 10: STOR auction clearing prices for 2022.

ESO Reserve Services

The main reserve service procured by NGESO is Short Term Operating Reserve (STOR), which since April 2021 has been procured via a day ahead pay as clear auction. Clearing prices from the auction vary significantly, as can be seen in *Figure 10*.

There is also a seasonal component to the prices, with average winter prices higher than summer prices. The scale of this can be seen in *Figure 11*, which shows the average STOR availability price for each month in the year from the STOR auctions to date.

The requirement for reserve services is set to increase over the next decade as the energy system continues to decarbonise. NGESO are continuing to work to remove barriers to market entry for flexibility providers. This gives reserve services a positive outlook for V2G.

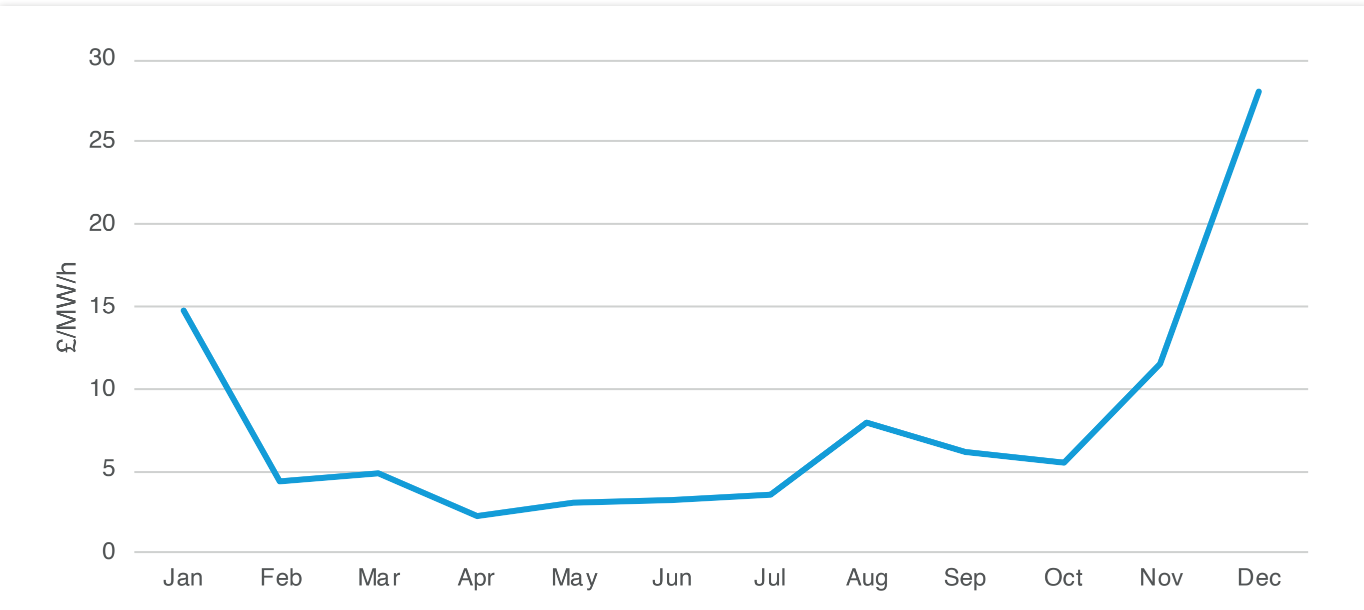


Figure 11: Monthly mean STOR clearing prices from April 2021 to July 2023.

6 Value Assessment of Flexibility Services & Markets

The Balancing Mechanism

The total value of the BM has increased in recent years, as can be seen in *Figure 12* with NGESO spending £1.2Bn in the Winter of 2022/23. This value has been driven both by an increase in volumes of energy traded in the BM and by the increase in the accepted offer prices by participants (as shown in *Figure 13*). With increasing amounts of intermittent renewable generation on the grid, it is likely that this trend will continue, giving the BM a positive outlook for V2G.

It is currently unclear what prices V2G could attract within the BM. The closest equivalent are battery assets currently participating. In the NGESO Power Responsive Annual Report 2022[15], battery assets monthly average accepted bids ranged from around £75/MWh to £250/MWh and offers from around £230/MWh to £550/MWh.

The Capacity Market

The value of Capacity Market Contracts has undergone a significant increase over recent years, with the most recent four year ahead (T-4) auction clearing at £63/kW/year. This increase in price is also reflected in the year ahead (T-1) auction.

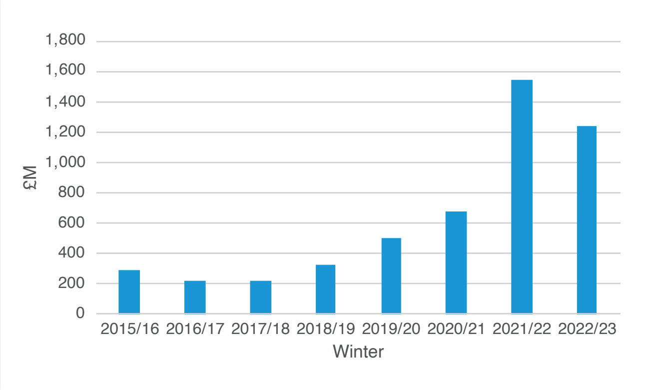


Figure 12: Total Value of the BM by Winter Season.

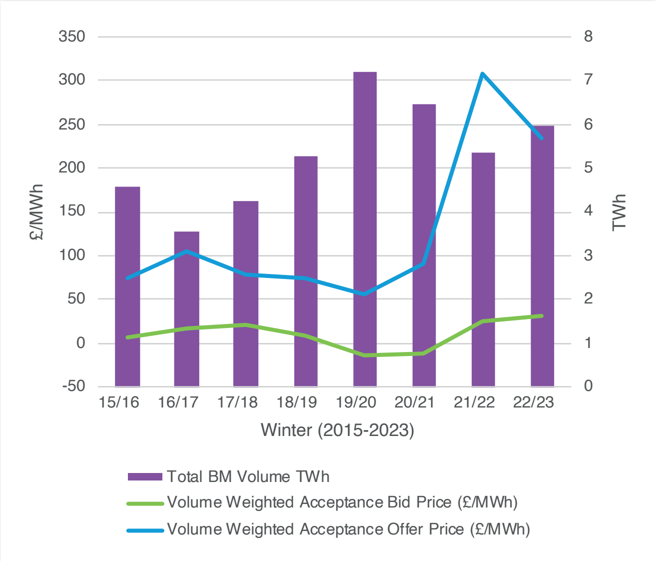


Figure 13: Prices and Volumes in the BM by Winter Season

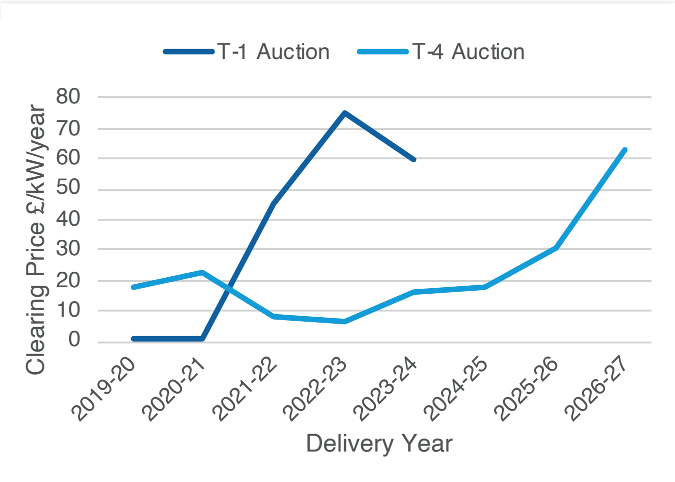


Figure 14: Recent Capacity Market Auction Clearing Prices by Delivery Year

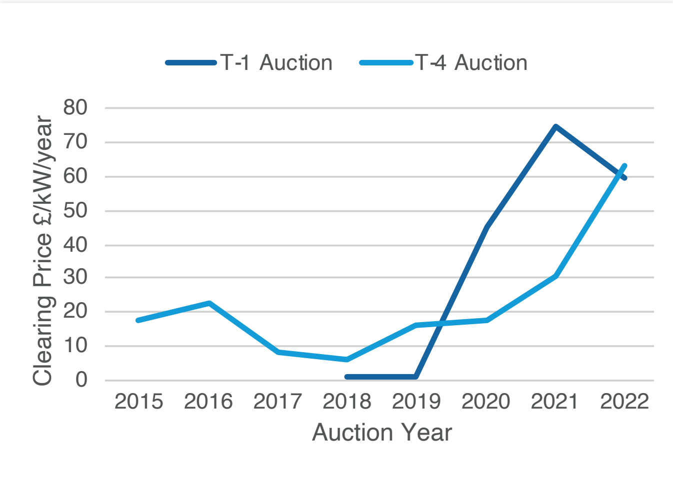


Figure 15: Recent Capacity Market Auction Clearing Prices by Auction Year

[15] https://www.nationalgrideso.com/document/282066/download

6 Value Assessment of Flexibility Services & Markets

The Electricity Wholesale Market

Whilst power prices have declined significantly over the last six months, it is unlikely that they will return to the levels we saw in 2020. Without a significant resumption of Russian pipeline gas, the UK and Europe are reliant on LNG imports, creating support for electricity prices. Cornwall Insight (a leading expert in GB power markets) forecast that, whilst average prices will decline from recent highs (driven in part by the connection of new offshore wind) they will likely remain above 100 £/MWh until the end of the decade.

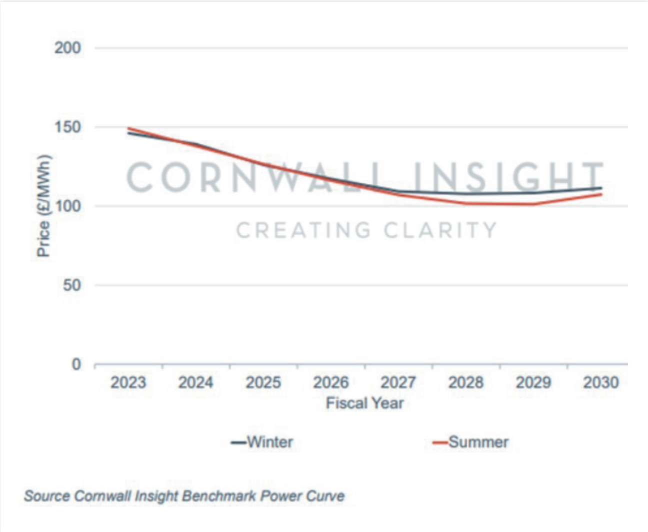


Figure 16: GB Power Price Forecast from Cornwall Insight

As already noted, there has recently been an increase in price volatility (both seasonally and within day). Over the coming years there is likely to be continued high volatility both within day and across months and seasons driven by an energy system that incorporates increasing volumes of renewables. High price volatility provides increased chances for savings from V2G energy optimisation.

Behind The Meter

The value of behind-the-meter optimisation is driven by the differential in import and export tariffs, and the within day differences in import time of use tariffs. The within day differences are driven by the within day volatility of the wholesale energy market and the shaping of DUoS charges, neither of these are likely to reduce in the near future. The differential between import and export tariffs is driven primarily by levies and other charges applied to import electricity. Whilst there has been talk of removing some of these levies little progress has been made. It is also likely that smart tariffs will become increasingly available, which would increase the potential for behind the meter optimisation.

7 Stackability

Out of the revenue streams identified in this report, any of them theoretically can be stacked with any other in different time periods (i.e. delivering one service during one period of time, and another during a separate time period). As some revenue streams are more valuable at certain times of the year, it can be advantageous to change revenue streams depending on the prices available.

The procurement timeframe also comes into consideration. Different services procure at different periods ahead of delivery. So, failure to be procured for one service may mean that a second services can be offered closer to delivery. Conversely, by committing to a service further from delivery, you will then be prevented from offering a service that tenders with a shorter lead time. So, the tendering strategy should be carefully constructed with preference given to those services with the highest value.

Only a few revenue streams can be stacked with each other over the same time period. Generally, the same MW of flexibility will not be paid for twice from separate sources. One exception to this is the Capacity Market, where other ESO flexibility services may concurrently be offered by the same asset. The complete comparison of which services can be stacked in the same time period as which other services is provided in *Table 8*.

		ESO							DSO				Markets			
		Quick Reserve	Slow Reserve	Dynamic Containment	Dynamic Moderation	Dynamic Regulation	Static Recovery	Demand Flexibility Service	Sustain	Secure	Dynamic	Restore	Balancing Mechanism	Capacity Market	Electricity Wholesale Market	Behind the meter tariff & renewables optimisation
ESO	Quick Reserve		No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
	Slow Reserve	No		No	No	No	No	No	No	No	No	No	No	Yes	No	No
	Dynamic Containment	No	No		No	No	No	No	No	No	No	No	No	Yes	No	No
	Dynamic Moderation	No	No	No		No	No	No	No	No	No	No	No	Yes	No	No
	Dynamic Regulation	No	No	No	No		No	No	No	No	No	No	No	Yes	No	No
	Static Recovery	No	No	No	No	No		No	No	No	No	No	No	Yes	No	No
	Demand Flexibility Service	No	No	No	No	No	No		No	No	No	No	No	No	Yes	No
DSO	Sustain	No	No	No	No	No	No	No		No	No	No	Yes	Yes*	Yes	No
	Secure	No	No	No	No	No	No	No	No		Yes	Yes	No	Yes*	No	No
	Dynamic	No	No	No	No	No	No	No	No	Yes		Yes	No	Yes*	No	No
	Restore	No	No	No	No	No	No	No	No	Yes	Yes		No	Yes*	No	No
Markets	Balancing Mechanism	No	No	No	No	No	No	No	Yes	No	No	No		Yes	Yes	No
	Capacity Market	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes*	Yes*	Yes*	Yes*	Yes		Yes	No
	Electricity Wholesale Market	No	No	No	No	No	No	Yes	Yes	No	No	No	Yes	Yes		No
	Behind the meter tariff & renewables optimisation	No	No	No	No	No	No	No	No	No	No	No	No	No	No	

Table 8: Stackability of revenue streams within the same time period

* Could expose the provider to risk of capacity market penalty.

8 Assessment of Applicability and Accessibility

In this section the applicability of and accessibility to V2G for each revenue stream is assessed. Recent market prices for each ESO and DSO flexibility service have been collated and summarised in *Table 9* which also provides an estimate of possible annual revenue from V2G for each of these revenue streams. Flexibility services have been grouped into Reserve, Response, and DSO Services. Recent average availability and utilisation prices have been taken from market research. Possible annual availability hours are given based on the number of hours in the year that each service is procured. The likely utilisation of the services has been calculated from historical information. The figures are then combined (Availability Price x Availability Hours + Utilisation Price x Likely Utilisation) to give a possible annual revenue. Note that this is an optimistic estimate as it assumes success in the tendering process for all the possible availability hours. Note also that the DSO services are locationally dependent, so are only accessible in limited geographical locations. The possible annual revenue assumes that the V2G unit is available for all the annual availabiltiy hours. It is expressed as £/kW of V2G chargepoint discharge capacity.

Table 10 provides a broader assessment of the different revenue streams. A red/amber/green rating has been provided for each of technical requirements, market accessibility, potential revenue and market outlook. This provides an overview of both the ease of providing each service, and the potential short- and long-term rewards for provision.

Category	Revenue Stream/Market	Availability Price £/MW/h	Utilisation Price £/MWh	Possible Annual Availability Hours	Likely Utilisation %	Possible Annual Revenue £/kW	Comments
Reserve	Quick Reserve	7.9	180	8760	0.41%	76	Average clearing price from STOR auctions, utilisation price from STOR Season 14. Assumed successful in all daily auctions
	Slow Reserve	7.9	180	8760	0.41%	76	Average clearing price from STOR auctions, utilisation price from STOR Season 14.
	Demand Flexibility Service	0	4650	20	100.0%	93	Based on average price in live events Winter 2022/23, and 20 hours of utilisation per year.
Response	Dynamic Containment	18.4	0	8760	0.56%	161	Based on high + low provision 2023 mean tendered price. Utilisation based on simulation for 2018 frequency data.
	Dynamic Moderation	4.6	0	8760	2.6%	40	Based on high + low provision 2023 mean tendered price. Utilisation based on simulation for 2018 frequency data.
	Dynamic Regulation	21.1	0	8760	11.0%	185	Based on high + low provision 2023 mean tendered price. Utilisation based on simulation for 2018 frequency data.
	Static Recovery	4.2	0	8760	0.0%	37	Based on Static FFR prices for 2022. Utilisation likely to be very low.
DSO Services	Sustain	0	215	636	9.0%	12	Availability taken from average hours tendered on Piclo platform. Median prices taken from accepted tenders.
	Secure	124	200	86	4.2%	11	Availability taken from average hours tendered on Piclo platform. Median prices taken from accepted tenders.
	Dynamic	7	317	7447	0.3%	60	Availability taken from average hours tendered on Piclo platform. Median prices taken from accepted tenders.
	Restore	0	600	6924	0.1%	4	Availability taken from average hours tendered on Piclo platform. Median prices taken from accepted tenders.
Market	Capacity Market	-	-	-	-	60	Based on Most recent T-1 auction

Table 9: Possible annual revenue from V2G for each revenue stream

8 Assessment of Applicability and Accessibility

Revenue Stream/Market	Technical Requirements (Can V2G offer this?)	Market Accessibility	Potential Annual Revenue	Market Outlook	Comments	Relevant Stakeholders
Quick Reserve	Red	Amber	Amber	Amber	V2G could not meet the maximum recovery period requirements.	ESO, Aggregator
Slow Reserve	Red	Amber	Amber	Amber	V2G could not meet the maximum recovery period requirements.	ESO, Aggregator
Demand Flexibility Service	Green	Green	Amber	Amber	Not stackable with other services	ESO, Aggregator or Supplier
Dynamic Containment	Amber	Amber	Green	Red	0.5 second initiation time is quick, but possible. Would require grid frequency monitoring.	ESO, Aggregator
Dynamic Moderation	Amber	Amber	Red	Red	0.5 second initiation time is quick, but possible. Would require grid frequency monitoring.	ESO, Aggregator
Dynamic Regulation	Green	Amber	Green	Red	Would require grid frequency monitoring.	ESO, Aggregator
Static Recovery	Green	Amber	Red	Red	Full details yet to be defined, but it is likely that V2G could provide this.	ESO, Aggregator
Sustain	Green	Amber	Red	Amber	Markets are locationally dependent.	DNO, Aggregator
Secure	Green	Amber	Red	Amber	Markets are locationally dependent.	DNO, Aggregator
Dynamic	Green	Amber	Amber	Amber	Markets are locationally dependent.	DNO, Aggregator
Restore	Green	Amber	Red	Amber	Markets are locationally dependent.	DNO, Aggregator
Balancing Mechanism	Green	Amber	Green	Green	Access to BM through virtual lead party.	ESO, Aggregator
Capacity Market	Amber	Amber	Amber	Unclear	V2G not yet defined within the Capacity Market, but it is likely it could provide the service. Market outlook unclear	ESO, Aggregator

Scoring	Technical Requirements (can V2G offer this?)	Market Accessibility	Potential Annual Revenue	Market Outlook
Red	Cannot be done by V2G	Impossible to access	Annual revenue £/kW < £50	Value likely to decline
Amber	Can be provided by V2G with careful management	Possible to access	Annual revenue £/kW between £50 & £100	Value likely stable
Green	Can easily be provided by V2G	Easy to access	Annual revenue £/kW > £100	Value likely to increase

Table 10: Assessment of revenue streams

8 Assessment of Applicability and Accessibility

8.1 Key V2G Revenue Streams Discussion

Based on the information summarised in *Table 8*, *Table 9* and *Table 10* a short list of revenue streams for V2G is derived below.

First, V2G is unable to technically provide Quick reserve or Slow Reserve, and so these services are excluded from the short list.

Out of the response services, Dynamic Regulation (DR) is the most accessible, so should be targeted first. However, with NGESO's enduring auction capability developments, in the future it will be easy to switch to other response services, at least from a market accessibility perspective.

DNO services are so locationally dependent that they cannot be relied upon as a revenue source. The Secure service has the highest average availability price, so where this service if procured, it should be provided in preference to response services. Although the Dynamic service may have a higher annual income, it would require dedication to the service for more hours, locking out other potentially higher revenue streams (such as DR) during those hours.

The Demand Flexibility Service could be provided, however due to the likely low number of activation hours it would be a small income. It should only be provided where it doesn't preclude provision of other services.

Behind the meter tariff & renewable optimisation, Electricity wholesale market and Balancing Mechanism can all technically be provided by V2G. In addition, they are likely to provide a reasonable revenue and have a positive or neutral outlook, so are also included.

It is likely that V2G can qualify for the Capacity Market. Provision of this service can be stacked with almost all other revenue streams, so should be included.

The resulting shortlist is presented below.

V2G Revenue Streams Shortlist

- **Dynamic Regulation**
- **DNO Secure**
- **Behind the meter tariff & renewable optimisation**
- **Electricity wholesale market**
- **Balancing Mechanism**
- **Capacity Market**

9 Modelling of Revenue Streams with Archetypes

This section combines the V2G revenue streams shortlist (*from section 8.1*), the VBEV use case scenarios (*see section 9.2*) and a shortlist of possible vessel archetypes (*see section 9.1*). The combinations are then modelled to quantify the possible annual revenue in each case.

9.1 Introducing V2G Archetypes

Within work package 2 of the project, a longlist of 36 archetypes for the marine sector was produced. This longlist of archetypes was then assessed for suitability of V2G. The detail of this process is reproduced in *Appendix A – Marine Archetypes Assessment*. A shortlist of archetypes resulting from this work was selected for further modelling analysis, based on:

- Likelihood of electrification of the vessel in the medium term (including consideration of likely duty cycles).
- Applicability of vessel for V2G based on hours and patterns of usage.
- A possible suitable location for V2G charging of the vessel.

For each archetype in the shortlist, an annual usage pattern was simulated based on the information in *Table 12* below. This simulation provided the usage data with which to assess the archetypes against the V2G Revenue Streams Shortlist. The likely chargepoint power has been estimated based on both industry standard powers and a realistic charging time that would work with the vessel's usage schedule.

9.2 Introducing the V2G Use Case Scenarios

Within the VBEV project concept there are three use case scenarios that have been identified. These are:

- **Vessel-to-Grid (no behind-the-meter demand)**
- **Vessel-to-Marina (all vessels behind the meter offsetting on-site demand, but no export to the grid)**
- **Vessel-to-Marina with renewables integration (as above but with PV added)**

Each of these use case scenarios is investigated within the modelling approach.

Archetype Name	Usage Pattern	Possible Trip Months	Possible Trip hours	Possible Trip Days	Approximate Total Annual Trip hours	Trip Duration	Likely Battery Size (kWh)	Likely Chargepoint Power (kW)	Time to recharge fully (hours)	Energy used per trip (kWh)
Recreational vessel	Simulated	April to Sep	9am - 6pm	All days	100	75% 3.5 hours, 25% 7 hours	100	12	8.3	45 (half day), 90 (full day)
Canal boat (home mooring) mostly leisure	Simulated	April to Sep	9am - 6pm	Mostly weekends	400	50% 3.5 hours, 50% 7 hours	40	12	3.3	19 (half day), 38 (full day)
Canal boat (home mooring) permanently occupied	Simulated	All	9am - 6pm	All days	200	7 hours	40	12	3.3	38
Personal watercraft	Simulated	April to Sep	9am - 6pm	Mostly weekends	30	1 hour	20	7	2.9	10
Inland river tours (short distance)	Schedule	All	April to Sep: 11am - 4pm, Oct to Mar: 11am - 2pm	All days	912	1 hour	120	150	0.8	100
Passenger ferry (~147 passengers)	Schedule	All	April to Sep: 7am - 8pm, Oct to Mar: 7am - 6pm	All days	2373	1 hour	900	1000	0.9	800

Table 12: Archetypes Shortlist

9 Modelling of Revenue Streams with Archetypes

9.3 Modelling Approach

The revenue that can be captured by bi-directional charging against time-varying prices is not simple to estimate, especially when several different revenue streams may be accessed at different (and potentially even the same) times. To overcome this difficulty, an approach using a perfect foresight optimisation model was decided. This approach can accurately simulate the possible revenue that can be captured from the multiple revenue streams. It does, however, provide an upper limit on the possible revenue obtained, as it makes the necessary assumption that it knows all the prices and vessel usage data in advance. For this reason, revenues stated in this section should be seen as upper bounds to potential revenue.

We have used the previously developed Cenex REVOLVE model to provide the simulation and optimisation. For further information on the REVOLVE model see *Appendix B – The REVOLVE Model*.

Real world data for the archetypes modelled was not available during the project, so realistic vessel usage was simulated for each archetype. Trips for vessels were simulated simply over an entire year using the data in *Table 12*. The same energy demand was used for each trip a vessel makes of similar duration. For each archetype, 50 vessels were simulated and combined within the model runs. This approach was used to remove the impact of outliers inadvertently created during the simulation process. The mean revenue result across each archetype group is used for the results in this report.

9.3.1 Revenue Streams

Historical prices for each revenue stream in the shortlist have been analysed, and the resulting price data from the period 1st Aug 2022 until 31 July 2023 has been used in each case.

The REVOLVE model was used to simulate the revenue from

- Dynamic Regulation
- Behind the meter tariff & renewable optimisation
- Balancing Mechanism

The DSO secure service is extremely geographically specific in its needs, and because of this, only co-located assets can be aggregated to provide the service. The needs and timings of the product vary on a case-by-case basis. However, for vessels that are only used for part of the year, it is likely that (given the right location) they could provide the service for a season. Given the uncertainty in providing this service, possible revenue has been handled outside of the model.

The capacity market, being a simple annual value and stackable with other services is also handled outside of the model.

Unfortunately, historical electricity wholesale market data could not be obtained within the time and budget of the project, and so has been omitted from the analysis.

For tariff optimisation, the half hourly varying Octopus Agile tariff was used for import energy, and the Octopus Outgoing tariff used for export energy.

9 Modelling of Revenue Streams with Archetypes

These tariffs are designed to reflect the wholesale electricity prices, and so provide some compensation for not modelling the electricity wholesale market revenue directly. *Figure 17* shows a histogram of the Octopus Agile import tariff used over the period. This shows a large variation in prices from less than zero to 0.85£/kWh. The median value is around 0.27£/kWh. Note that this distribution exhibits a long tail on the upper end of prices (i.e., there are significantly more bins above the median value than below it).

When providing DR, it is assumed that the assets operate as part of a larger portfolio, so they can provide the service for any half-hourly window across the year. It is also assumed that they are successful in any auctions they enter and obtain the cleared price from the auction.

A thorough analysis and modelling of balancing mechanism bids and offers is complex to perform and beyond the scope of this project. However, System prices published by Elexxon are constructed from the actual balancing costs incurred by NGESO for each half hour. These have been used as a proxy for balancing mechanism price data.

It should also be noted that income is entirely reliant on vessels being connected to a charger whenever they are moored or not being used for a reasonable duration. In the modelling it has been assumed that vessels are always connected to a charger when not in use. This will in most cases require a dedicated charger for the vessel as well as users reliably plugging in the vessel.

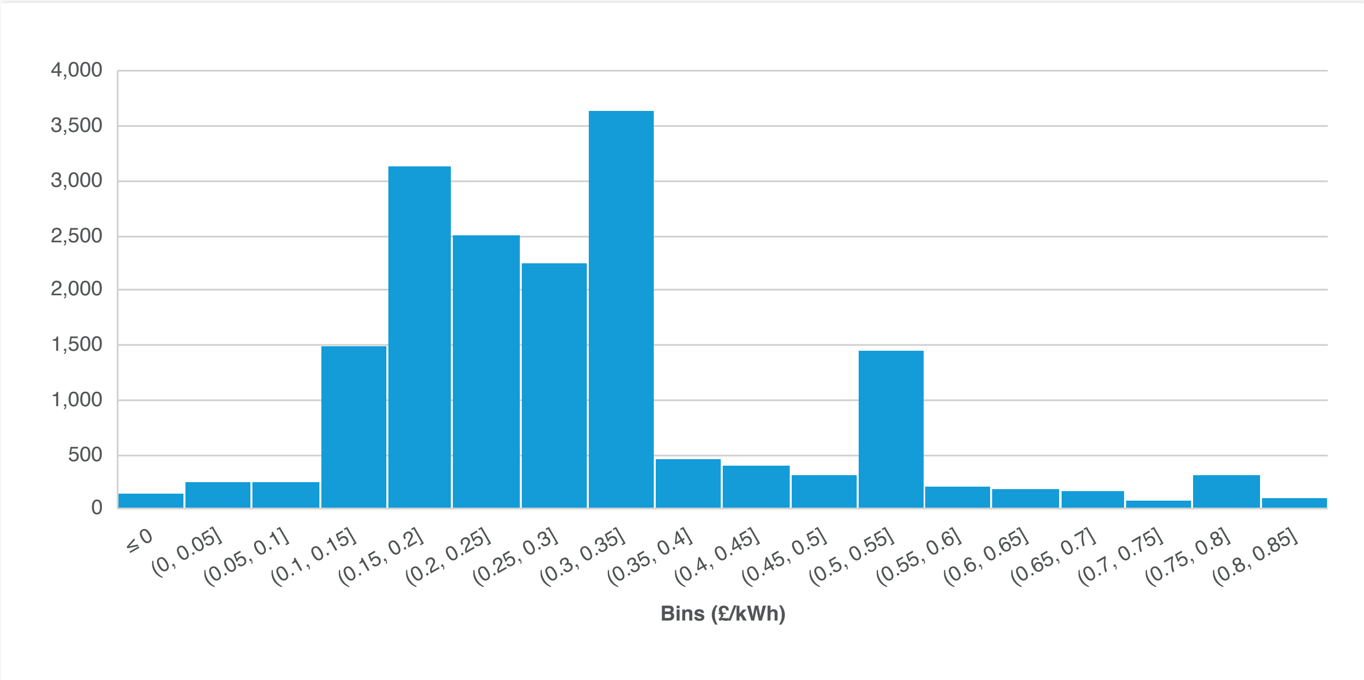


Figure 17: Histogram of Octopus Agile half-hourly electricity tariff Aug 2022 to Jul 2023

9 Modelling of Revenue Streams with Archetypes

9.4 Model Runs

A variety of model runs are required to obtain the results. Each model run is described in brief below.

9.4.1 Vessel-to-Grid Unmanaged

An unmanaged charging run is performed to be used as a baseline for the Vessel-to-Grid use case. In this run the Octopus Agile import tariff is used, and the vessels plug in to charge as soon as they return from their trips. They charge at full power until full. No V2G operation is simulated.

9.4.2 Vessel-to-Grid Tariff Optimisation

In this run, again the Octopus half hourly tariffs are used. There is no behind the meter demand in this use case, and so any discharging from the vessels is paid at the Octopus Outgoing tariff rate. Vessels charge and discharge optimally to maximise revenue from the import and export tariff price differences. Vessels are also charged sufficiently for every trip that they need to perform.

9.4.3 Vessel-to-Grid Tariff & Dynamic Regulation Optimisation

This run is like the one above, but with the addition for provision of the Dynamic Regulation service as an additional revenue stream.

9.4.4 Vessel-to-Grid Balancing Mechanism Optimisation

In this run, the optimisation is performed against the time varying system prices. Instead of a regular electricity tariff, the system prices are used for both import and export rates to simulate possible revenue from provision of balancing services in the BM.

9.4.5 Vessel-to-Grid Carbon Optimisation

In this run, the optimisation is performed against the time varying grid carbon intensity. Vessels will charge during periods of low carbon intensity, and discharge during periods of high carbon intensity. Vessels are also charged sufficiently for every trip that they need to perform.

9.4.6 Vessel-to-Marina Unmanaged

An unmanaged charging run is performed to be used as a baseline for the Vessel-to-Marina use case. Half hourly Octopus tariffs are used. There is a significant behind the meter demand. Vessels plug in to charge as soon as they return from their trips. They charge at full power until full. No V2G operation is simulated.

9.4.7 Vessel-to-Marina Tariff Optimisation

In this run, again the Octopus half hourly tariffs are used. There is a significant behind the meter demand in this use case, and so any discharging from the vessels offsets this demand. No energy from discharging is exported onto the wider grid. Vessels charge and discharge optimally to maximise revenue from the import tariff price differences. Vessels are also charged sufficiently for every trip that they need to perform.

9.4.8 Vessel-to-Marina with Renewable & Tariff Optimisation

In this run, again the Octopus half hourly import tariff is used. However, a fixed export tariff of 6p/kWh is applied. There is a behind-the-meter demand and PV array. Whilst the PV may export to the wider grid, no energy from discharging is exported onto the wider grid. Vessels charge and discharge optimally to minimise costs from the import tariff and maximise self-consumption of the PV energy. Vessels are also charged sufficiently for every trip that they need to perform.

9 Modelling of Revenue Streams with Archetypes

9.5 Revenue Results for Vessel-to-Grid Use Case

In this section the results are presented from the model runs for the Vessel-to-Grid use case. In this use case, there is no other behind the meter demands, and vessels are able to export power onto the wider grid. The chargepoint powers from *Table 12* have been assumed for each archetype. *Figure 18* and *Figure 19* provide the revenue determined through the REVOLVE model runs (Vessel-to-Grid Unmanaged, Vessel-to-Grid Tariff Optimisation, Vessel-to-Grid Tariff & Grid Optimisation). The revenue available from tariff optimisation is presented, and the incremental revenue obtained from Dynamic Regulation in the grid optimisation run is also given. Results are split into larger and smaller vessels to aid comparison.

The annual unmanaged energy cost is shown in red as a comparison against the revenue. The tariff optimisation revenue can be seen to correlate with the unmanaged energy cost. Of the smaller vessels, the Recreational Vessel archetype has the highest potential annual revenue from both tariff optimisation and Dynamic Regulation. Note that these two revenue figures presented are stackable.

For comparison, for the recreational vessel, smart charging (using a fully optimised unidirectional charger) was found to be able to reduce the energy costs by £235 per year. Taking this into account, the net benefit of V2G above smart charging for tariff optimisation was £527 with the recreational vessel.

The revenue from the Passenger Ferry archetype (larger vessels) dwarfs all the others. This is due to the much greater battery capacity and charger size (1MW) of this vessel.

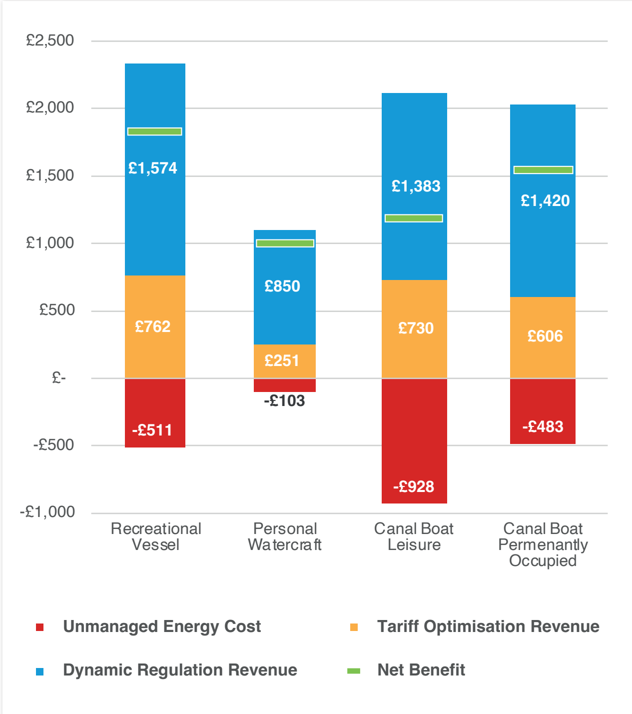


Figure 18: Annual cost and revenue for smaller vessels

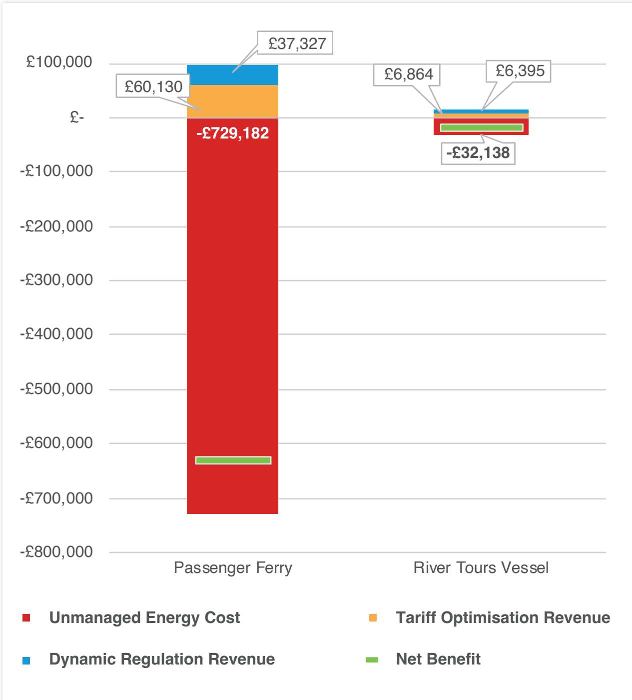


Figure 19: Annual cost and revenue for larger vessels

9 Modelling of Revenue Streams with Archetypes

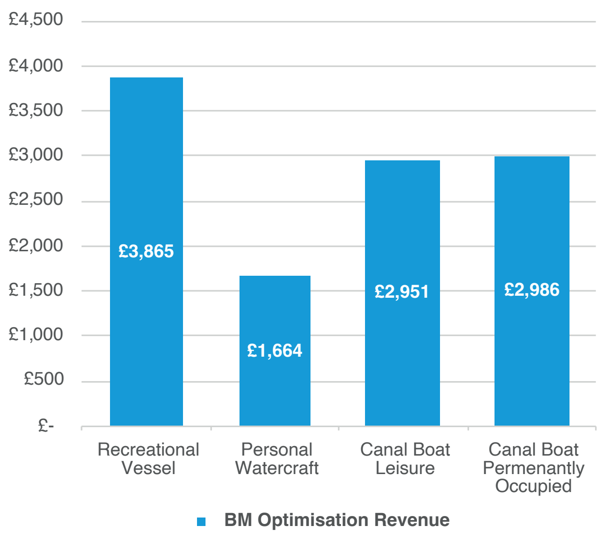


Figure 20: Annual cost and BM revenue for smaller vessels

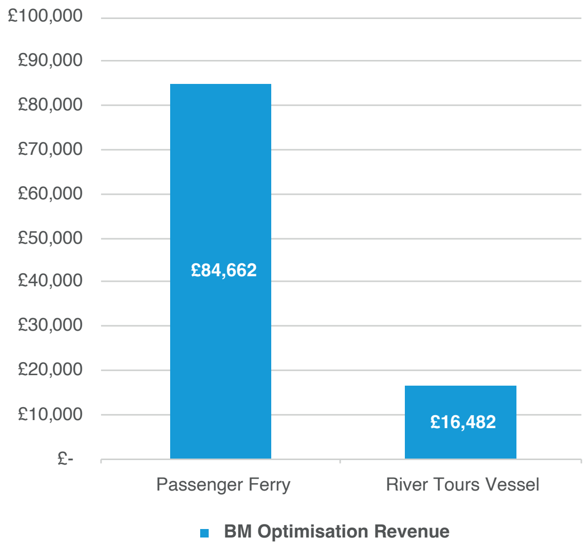
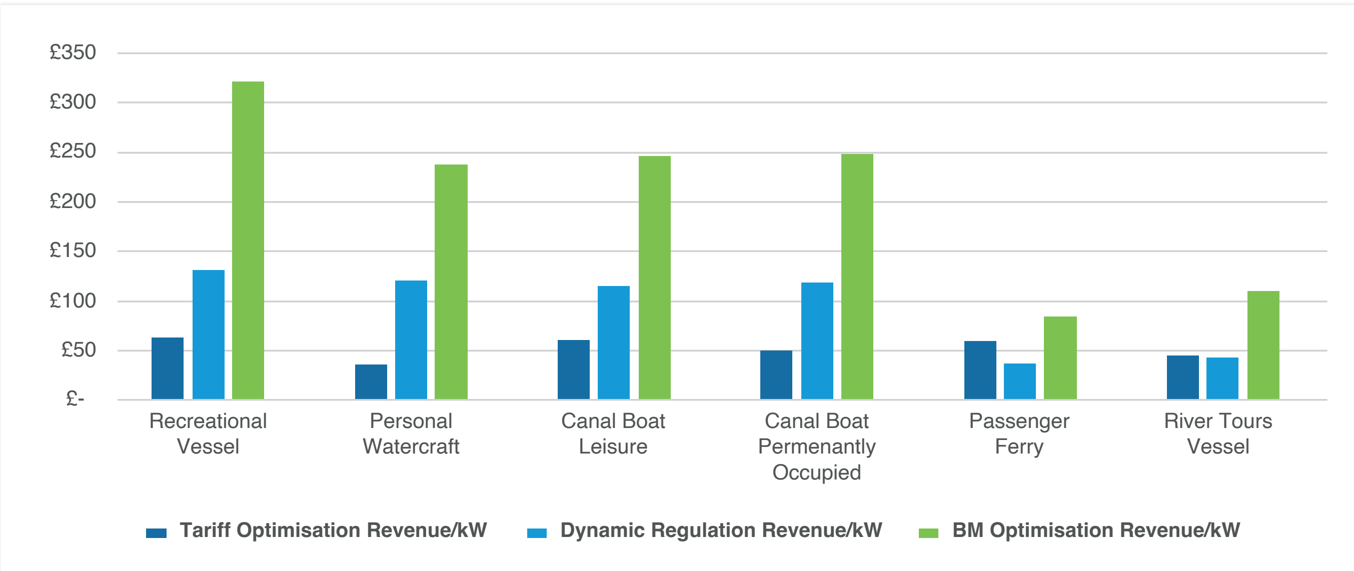


Figure 21: Annual cost and BM revenue for larger vessels

A separate model run to estimate the possible revenue from the balancing mechanism was also performed (Vessel-to-Grid Balancing Mechanism Optimisation). Note that results from this run are not stackable with the revenue in the previous runs. This run used electricity system prices for both import and export rates instead of a regular tariff. Results are shown in *Figure 20* and *Figure 21*. Note that these are significantly higher than revenues in the previous run. However, care should be taken with these results as these are estimations made by using system prices as a proxy for simulating the Balancing Mechanism directly. These results significantly overestimate the possible revenue obtainable, due to the perfect foresight nature of the model used. This includes the assumption that the asset being entered into the BM would be accepted for every bid and offer it makes.

In order to make a fairer comparison between such diverse vessels and charging infrastructure, revenues expressed per kW of charger power are given in *Figure 22*. On this basis, the annual revenue obtainable for each archetype are much more similar. The Recreational Vessel has this highest revenue from each of the three revenue streams modelled.

Figure 22: Annual revenue per kW of chargepoint power



9 Modelling of Revenue Streams with Archetypes

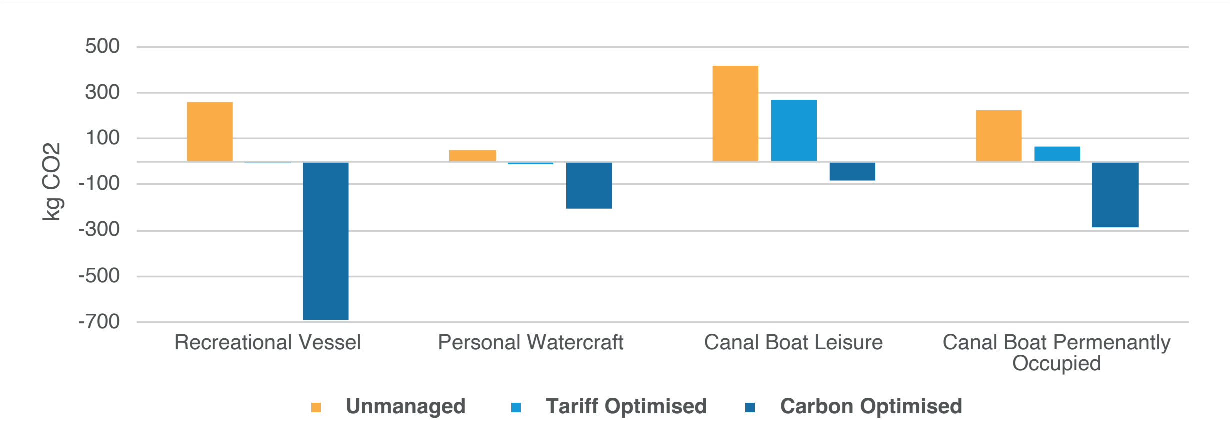


Figure 23: Annual grid carbon impact for smaller vessels

9.6 Carbon Results for Vessel-to-Grid Use Case

In the model runs, accounting of the grid carbon intensity is also included. The half-hourly grid carbon intensity as published by NGESO is used. The carbon intensity at the time vessels charge is deemed to be 'used' by the vessel. Whilst, if the vessel discharges, then it is credited for the grid carbon intensity at that time. This process, when employed at scale can help reduce the running of fossil-based generation and help to incorporate additional renewable generation into the energy system. An additional carbon optimised run was performed, where the objective of the optimisation was to reduce carbon rather than cost (performing a sort of 'carbon arbitrage'). Results from running the model in an unmanaged, tariff optimised, and carbon optimised way are presented in *Figure 23* and *Figure 24*. Performing the tariff optimisation achieves a significant reduction in carbon. However, much greater reductions are possible with a dedicated carbon optimisation.

Again, for easier comparison the results per kW of chargepoint power are also presented in *Figure 25*. This shows that the Recreational Vessel achieves the highest reduction in carbon per kW for both the tariff and carbon optimisation.

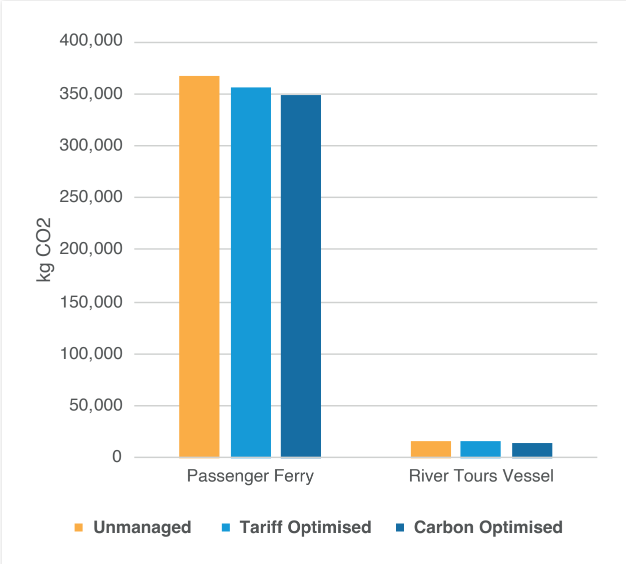


Figure 24: Annual grid carbon impact for larger vessels

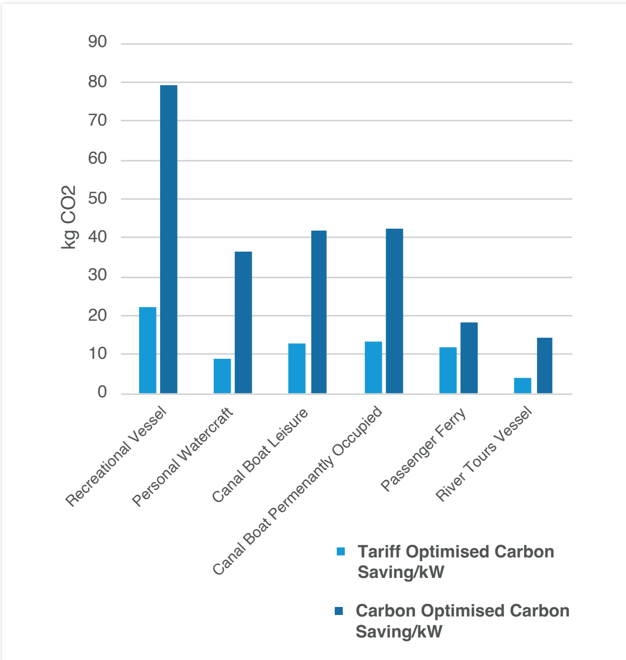


Figure 25: Annual grid carbon saving per kW of chargepoint power

9 Modelling of Revenue Streams with Archetypes

9.7 Revenue Results for Vessel-to-Marina Use Case

This section presents the results from the Vessel-to-Marina use case. In this use case, there is a significant behind the meter demand, such that any discharging by the vessel is deemed to offset the demand, and there are no exports to the wider grid. The annual revenue from a tariff optimisation for small and larger vessels is shown in *Figure 26* and *Figure 27* respectively.

These results show significantly higher revenues than available in tariff optimisation from the Vessel-to-Grid use case. This is due to the long tail in the distribution of the Octopus Agile import prices (see *Figure 17*). With high priced import demand that can now be offset by vessel discharging, the savings are increased versus the case where there is no other demand assumed.

Again, presenting the results in terms of chargepoint power in *Figure 28* shows that the Recreational Vessel can make the highest revenue.

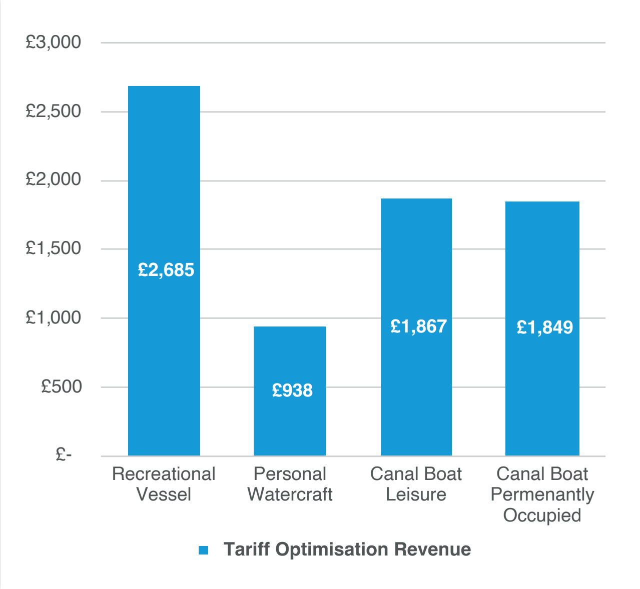


Figure 26: Annual revenue for smaller vessels

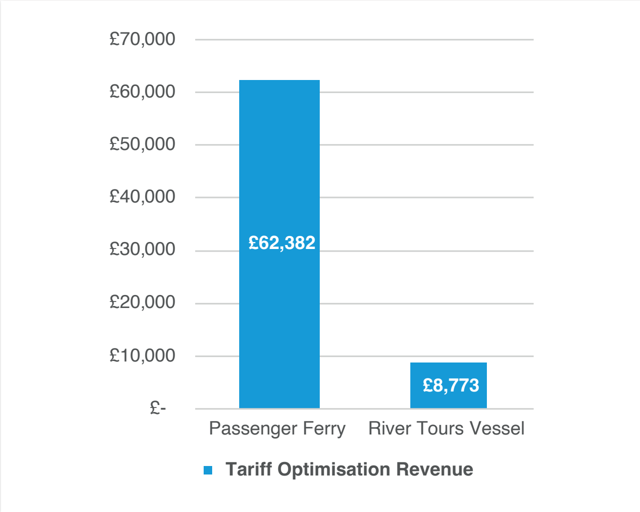
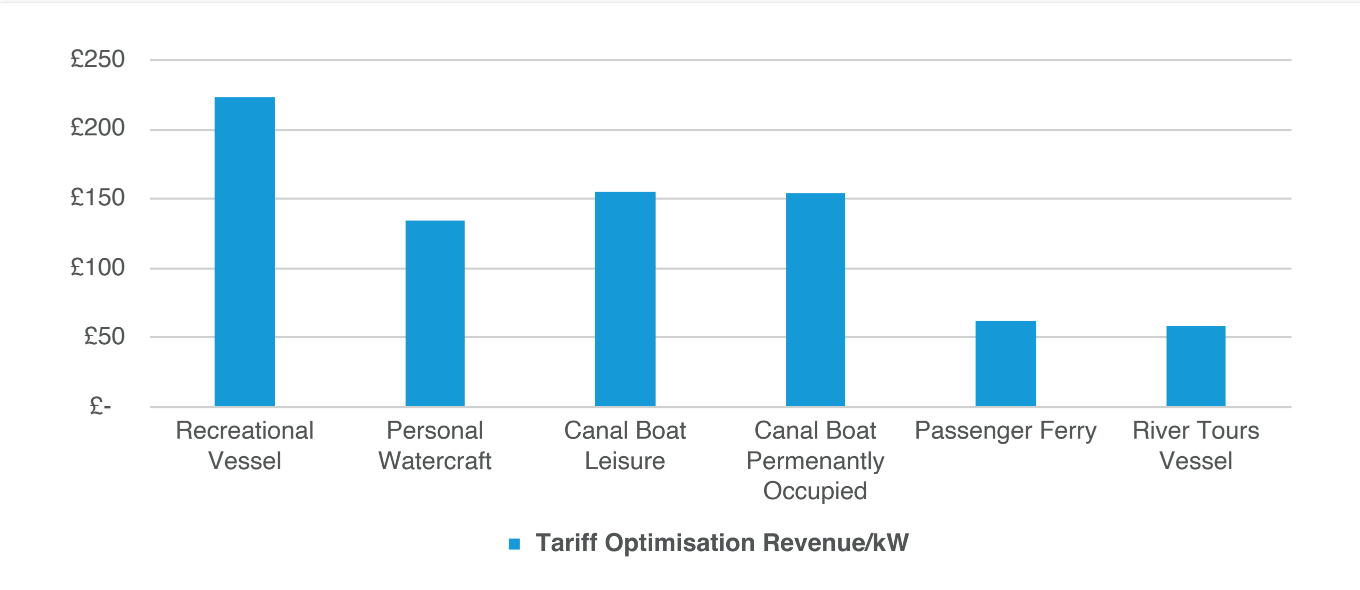


Figure 27: Annual revenue for larger vessels

Figure 28: Annual revenue per kW of chargepoint power



9 Modelling of Revenue Streams with Archetypes

9.8 Vessel-to-Marina with Renewables Integration - Case Study

The third use case identified within the project is Vessel-to-Marina with renewables integration. This is similar to the Vessel-to-Marina case study in that the vessel does not discharge to the wider grid. However, as well as behind-the-meter demand, there is also behind-the-meter PV generation.

The value that can be captured by optimising such as system varies significantly on a case-by-case basis depending on the quantity and profile of the electricity demand, the size of the PV, and the usage profile of the vessel. Here we consider a specific example as a case study. For the example the recreational vessel archetype is used in conjunction with a marina with an annual behind-the-meter demand of 30.6MWh and a 10kW PV array with an annual yield of around 9.4MWh. Key results from the model runs are given in *Table 13*.

	Unmanaged	Renewable & Tariff Optimisation
PV Export (kWh)	1,993	65
PV Self-Consumption	79%	99%
Annual Energy Imported (kWh)	24,639	25,755
Annual Energy Cost	£7,632	£6,051
Total Optimisation Savings	-	£1,580

Table 13: Vessel-to-Marina with renewable integration results

In this particular case study, there is an annual saving of £1,580 which is derived from using the V2G chargepoint to both increase the self-consumption of the PV generation (thereby reducing more expensive imports) and shift the behind-the-meter demand to times with lower import prices. For an example of energy profile results for a single day see Appendix C – Vessel-to-Marina with Renewables Integration – Case Study Single Day.

9.9 Comparison of Revenue for Archetypes and Use Cases

The revenue results from the Vessel-to-Grid and the Vessel-to-Marina use cases are compared in this section. Due to the variations in the Vessel-to-Marina with Renewables Integration use case on a case-by-case basis, this has been excluded from comparison here.

The results from the two remaining use cases are presented on the next page in *Table 14* in terms of revenue per kW of chargepoint power. Additional stackable revenue streams from the Revenue Stream Shortlist (*section 8.1*) have been included to provide a total stackable revenue result for each use case and archetype. Capacity Market revenue can be stacked with all other revenue streams. The Secure DSO service may be beneficial to provide as it is priced competitively, however it may slightly reduce revenue from other services, as it cannot be stacked within the same time periods. Note that there are two sets of results presented for the Vessel-to-Grid use case. The first which covers the tariff and Dynamic Regulation optimisation. The second which covers Balancing Mechanism optimisation.

9 Modelling of Revenue Streams with Archetypes

Use Case	Archetype	Recreational Vessel	Personal Watercraft	Canal Boat Leisure	Canal Boat Permanently Occupied	Passenger Ferry	River Tours Vessel
-	Assumed Chargepoint Power (kW)	12	7	12	12	1,000	150
Vessel-to-Grid	Smart Tariff Opt. Revenue/kW*	£20	£7	£34	£23	£59	£44
	Tariff Optimisation Revenue/kW	£63	£36	£61	£50	£60	£46
	Dynamic Regulation Revenue/kW	£131	£121	£115	£118	£37	£43
	Capacity Market Revenue/kW	£60	£60	£60	£60	£60	£60
	Total Stackable Revenue/kW	£255	£217	£236	£229	£157	£148
	BM Optimisation Revenue/kW	£322	£238	£246	£249	£85	£110
	Capacity Market Revenue/kW	£60	£60	£60	£60	£60	£60
	Total Stackable Revenue/kW	£382	£298	£306	£309	£145	£170
Vessel-to-Marina	Tariff Optimisation Revenue/kW	£224	£134	£156	£154	£62	£58
	Capacity Market Revenue/kW	£60	£60	£60	£60	£60	£60
	Total Stackable Revenue/kW	£284	£194	£216	£214	£122	£118
Either	Secure DSO Service/kW**	£11	£11	£11	£11	£11	£11

*The value that could be obtained from tariff optimisation with a unidirectional (smart) charger, for comparison
**Additional revenue that may reduce the already stacked revenue values.

Table 14: Comparison of possible annual revenue per kW chargepoint power for different use cases and archetypes

At first glance these results look very positive for a V2G business case for electric vessels, with possible revenues in the range of £122 to £382 per kW. The values are also significantly higher than tariff optimisation revenue available from unidirectional (smart) charging alone.

Recreational vessel has the highest revenues. This archetype has a relatively large battery size and very few (100) operational hours in the year. It does, however, make the assumption that the vessel will be plugged in all of the rest of the year. This may not be realistic if the chargepoint needs to be shared with other vessels. However, it may be a sensible assumption for a vessel that is stored in a dry stack out of the usage season, provided electric connection provision is made whilst in dry stack.

The archetypes that have heavier use (Passenger ferry and river tours vessel) have the lowest revenue per kW. This is due to them having much more time in the year taken up by trips or charging for the next trip. As working boats, they are likely to require dedicated charging, so the assumption of being plugged in during any periods when they aren't used is likely to be more realistic.

Vessel-to-Marina tariff optimisation values are significantly higher than corresponding revenues in the Vessel-to-Grid use case. As mentioned previously, this is due to being able to offset very high import prices for the site on the Octopus Agile tariff. However, it is questionable as to whether this tariff would be the most suitable one for a marina, which without any V2G is likely to have a non-flexible demand. A fixed rate tariff may be more economic. When comparing tariff optimisation savings with a fixed rate tariff as a baseline, the savings would reduce.

9 Modelling of Revenue Streams with Archetypes

In 2021 Cenex completed the analysis from the world's largest domestic vehicle-to-grid trial, project Sciurus[16]. In the analysis the annual revenue for domestic EV V2G propositions were simulated. This resulted in an annual tariff optimisation revenue of £57/kW, and an additional annual revenue of £64/kW for the Dynamic Containment service, from a vehicle plugged in for 75% of the year. The results from the VBEV analysis show similar values for tariff optimisation revenue for the Vessel-to-Grid use case. But compared to the Sciurus results, the Dynamic Regulation revenue is significantly higher for most archetypes than the similar Dynamic Containment service. This is due in part to the higher prices of the Dynamic Regulation service, but also the higher availabiltiy of some of the archetypes in VBEV.

It should also be noted that for the period modelled (Aug 2022 to July 2023) energy prices exhibited high volatility (as shown in section 4.5). This is reflected in the tariff optimisation revenue (especially in the Vessel-to-Marina use case). Such revenue may not be possible with lower price volatility. Balancing Mechanism costs incurred by NGESO for the winter 22/23 are second highest recorded, being up to six times what they were during the previous decade. This results in higher revenue from the BM for V2G propositions. Whilst BM revenue has a positive outlook (from a V2G perspective), the value is not guaranteed.

The revenues from the BM in this modelling are high. However, the dynamics of the BM have not be accurately captured within this work. It is unclear how much of the potential revenue stated may be obtained in practice.

And finally, it should be remembered that due to the modelling approach used in this work, the revenues stated should be regarded as upper bounds on what revenue is possible given the input assumptions. In practice, market competition and forecasting error will reduce the value obtained. The value will then need to be shared between the various stakeholders (e.g., vessel owner, chargepoint operator, site owner, aggregator).

[16] *https://www.cenex.co.uk/news/worlds-largest-domestic-vehicle-to-grid-trial-reveals-customers-could-recover-the-majority-of-their-household-energy-costs/*

10 Conclusions

Regulations, energy, and flexibility markets are all in the midst of significant change. The Access Significant Code review has the potential to reduce connection charges significantly for some customers seeking upgraded or new connections.

Flexibility services are also changing. Newer response services are more suited to distributed and battery-based assets than the old services. This lowers barriers for V2G assets to enter the flexibility services market. NGESO's Enduring Auction Capability may make the provision of multiple reserve and response services easier to achieve from a single portfolio of flexible assets. DNOs are also increasing the volume of flexibility services they procure year on year. Whilst these are geographically dependent, they can provide a good income for assets sited in a distribution grid constrained area.

The price of response services can vary between seasons years and periods in the day. And whilst they can provide a significant income through provision today, it is likely that the value will reduce as the market reaches saturation in the coming years. Although reserve services have a more positive price outlook, they are less suited technically for V2G provision. With lower barriers to entry then previously, and a positive outlook, the Balancing Mechanism now provides a significant potential income for V2G propositions. There is likely to be significant price support for electricity wholesale prices over the coming decade, combined with higher volatility than in the last decade. These factors mean that both wholesale price optimisation, and time of use tariff optimisation (with smart tariffs, largely reflecting wholesale prices) are both likely to be strong revenue streams for V2G.

Whilst almost all revenue streams can be stacked in separate periods, very few can be stacked within the same period. The exception to this is the Capacity Market, with recent values of £60/kW per year, this is a useful addition to the revenue. It is likely that the best revenue propositions for V2G would access several different revenue streams at different points in the year as they become more lucrative. This, however, could lead to quite a complex operation to optimise which revenue stream to access at each point. There are also limitations with procurement timelines, as committing to one service will essentially lock out provision for most others. NGESO's Enduring Auction Capability will partly resolve this, at least from the perspective of the ESO services.

A summary of the revenue stream applicability assessment is provided in *Table 15* on the next page.

By modelling and accounting for a shortlist of the most applicable revenue streams (Dynamic Regulation, DSO Secure, Behind the meter tariff & renewable optimisation, Balancing Mechanism, Capacity Market) annual revenues for each archetype and use case were obtained. The Recreational Vessel had the highest revenues per kW of chargepoint power, whilst the working vessels (Passenger Ferry and River Tours Vessel) had the lowest.

When using a dynamic tariff (such as Octopus Agile) being able to offset behind-the-meter demand can be very valuable, with annual savings of up to £224/kW possible (in the Vessel-to-Marina use case). Without behind-the-meter demand to offset, revenue from tariff optimisation is much less, only up to £63/kW. Revenue from grid services, in particular Dynamic Regulation can be significant, with annual revenues of up to £131/kW.

The highest revenues come from combining the tariff optimisation, with either Dynamic Regulation or the Balancing Mechanism, and the Capacity Market, with total annual revenue of up to £382/kW.

10 Conclusions

Category	Revenue Stream/Market	Technical Requirements (Can V2G offer this?)	Market Accessibility	Potential Annual Revenue	Market Outlook
Reserve	Quick Reserve	Red	Amber	Amber	Amber
	Slow Reserve	Red	Amber	Amber	Amber
	Demand Flexibility Service	Green	Green	Amber	Amber
Response	Dynamic Containment	Amber	Amber	Green	Red
	Dynamic Moderation	Amber	Amber	Red	Red
	Dynamic Regulation	Green	Amber	Green	Red
	Static Recovery	Green	Amber	Red	Red
DSO Services	Sustain	Green	Amber	Red	Amber
	Secure	Green	Amber	Red	Amber
	Dynamic	Green	Amber	Amber	Amber
	Restore	Green	Amber	Red	Amber
Markets	Balancing Mechanism	Green	Amber	Green	Green
	Capacity Market	Amber	Amber	Amber	Unclear
	Electricity Wholesale Market	Green	Amber	Green	Amber
	Behind the meter tariff & renewables optimisation	Green	Green	Green	Green

Table 15: Summary revenue stream assessment

Revenues from V2G hinge on the vessel being plugged in and not needing to charge, for long periods of time. It is important for any V2G business case, to understand how realistic it is for each vessel to remain plugged in when not in use.

Alternatively, by performing a carbon optimisation with the V2G unit, annual carbon savings of up to 79kg. CO2/kW are possible.

From this analysis revenues of up to several hundred pounds per kW of chargepoint power appear possible for V2G, which is significantly higher than for smart charging alone. Whilst actual values obtainable in practice over the coming years may be less (due to factors such as forecast error and reductions in price volatility), it will likely still be a very good revenue stream for the best archetypes. Some marine archetypes are used for less than 10% of the year making them particularly applicable, these will obtain significantly higher V2G revenue values than road based EVs, which are in use more frequently.

The leading archetype (recreational vessel), numbers in the tens of thousands across the UK. With these numbers, it could provide a significant source of flexibility to the GB energy system, potentially to the scale of hundreds of MW. These results are sufficient to justify further research and development of V2G for the marine sector.

11 Recommendations

The following recommendations are drawn from analysis and modelling with regards to VBEV V2G use cases.

Customer Education:

Income is entirely reliant on vessels being connected to a charger whenever they are moored or not being used for a reasonable duration. Unlike the automotive market, vessels go through a mooring process, meaning that this behaviour should be more natural to the operators. However, it is still important to educate operators around this need.

First Target Customer Segment:

Recreational vessels are the logical first target market for V2G, provided they have a dedicated chargepoint.

Flexibility Service Tracking:

It is likely that the best revenue propositions for V2G would access several different revenue streams at different points in the year as they become more lucrative.

Flexibility Service Prioritisation:

Flexibility services have seen significant change over the past couple of years. The following recommendations are made for each of the key services:

- Behind-the-meter tariff optimisation is a valuable revenue stream with an appropriate dynamic tariff. It has low barriers to entry, and doesn't require many other stakeholders, and so should be targeted first.

- Dynamic Regulation is the most promising of the newer NGESO flexibility services for V2G, and so should be targeted and investigated in further projects/developments in this area.

- Capacity Market revenue can be stacked with other revenue streams within the same time window, increasing the overall revenue which can be achieved. This should there be targeted as a primary market for V2G.

- It is difficult to model the value obtainable from the Balancing Mechanism for V2G, but it shows high potential opportunity and should be investigated further as a potential source of income for aggregated V2G.

- DSO services, where they are geographically available should be considered, but cannot be relied upon for all business cases.

Appendix A – Marine Archetypes Assessment

This appendix is an initial consideration of archetypes for electric vessels in the UK with respect to V2G. It will require periodic reviewing and updating as both the industry accelerates its drive to net zero and V2G maturity in the wider transport sector improves.

Cenex conducted an initial internal workshop to generate a list of potential archetypes with some loose definitions. These were used as a seed in a follow-up consortium workshop and stakeholder interview process that further developed the initial archetypes and began to define the important identification criteria. Cenex continued to refine the criteria and populate the key fields through a desk based literature review. The resulting 36 vessel archetypes, shown in *Table 16*, are a UK centric view of the potential electric maritime sector.

Index	Archetype	Brief Description
1	The Responding to Danger Vessel	24-hour response vessel responding to those in danger.
2	The Supporting an Emergency Response Vessel	Diving and other emergency response.
3	The Royal Navy Frigate	The Type-23 military vessel is primarily an anti submarine warfare platform but is used in a more generic role.
4	The Recreational Vessel	Electric Vessels will be financially unavailable to many in the current market for leisure craft. Boat pooling companies are being trialled to run fleets of Electric Vessels that can be rented on a day by day basis.
5	The Mid-sized Passenger Ferry	Day trips and day cruising for foot passengers.
6	The Roll-on Roll-off Ferry	A vessel designed to carry passengers and cargo with their vehicles, rather than purely the cargo itself. This allows a faster turn-around at ports and so they're common across Europe, ranging from smaller intra region vessels to those designed to cross the North Sea.
7	The Sailing Club Support (at Sea) Vessel	A small, powered RIB, providing emergency support for sailing clubs.
8	The Sailing Club Support (Inland) Vessel	A small, powered RIB, providing emergency support for sailing clubs.
9	The Sailing Yacht (with a secondary electric power supply)	A typical small sailing boat, that traditionally would have a low powered ICE to navigate a marina.
10	The Large Research Vessel	Undertake activities such as sampling, scanning, monitoring and collecting data over a long time frame. Manned with a small crew and technical equipment. They have an irregular duty cycle but set route and geographical mapping pre departure.
11	The Small Research Vessel	Undertake activities such as sampling, scanning, monitoring and collecting data. Manned with a small crew and technical equipment. They have an irregular duty cycle but set route and geographical mapping pre departure.
12	The Aquaculture Vessel	Aquaculture and fish farm support vessels.
13	The Barge Work Boat	Modular vessels that can be used to transport goods around short distances along waterways.
14	The Border Force Vessel	A small vessel, typically less than 20 m, designed to help protect the border waters. They may also be used in other roles such as anti smuggling, fishery patrols and immigration law.

Appendix A – Marine Archetypes Assessment

Index	Archetype	Brief Description
15	The Canal Boat – Permanently Occupied	Houseboats operating on the inland waterways. They're typically stationary throughout the year, perhaps moving for a week or so during the summer holidays and also going to a workshop for annual maintenance.
16	The Canal Boat - Leisure	Narrowboat leisure craft operating on inland waterways (canals & navigable rivers). Up to 10 hours cruising per day (daylight hours), usage varies considerably by season.
17	The Coastal Trader	Smaller cargo vessels traditionally operating along coastal routes.
18	The Cruise Ship	Large passenger ships, mainly for holidays. Often used in round trip voyages, with multiple stop-offs at different ports.
19	The Deep-Sea Fishing Vessel	Deep sea fishing vessel with a small crew, larger hull for cargo and technical equipment such as a winch.
20	The Diving Support Vessel	Vessels with daily usage for passengers and technical equipment used for diving expeditions. They have irregular duty cycles, but set routes and geographical mapping pre-departure.
21	The Fuel Bunkering Ship	A vessel designed to carry fuel that is to be transferred to other vessels.
22	The Harbour Patrol Rib	Up to 10 m rib providing harbour patrol services.
23	The River Tours Vessel	Vessels used for river tours or similar inland leisure activities.
24	The Inshore Fishing Boat	Smaller, near-shore fishing vessel typically only used during daytime hours.
25	The International Freightliner	A container ship, designed to carry load in 1 TEU and 2 TEU ISO Standard Containers. These vary in size from a few thousand TEU capacity up to the largest ones that are able to carry over 14 500 TEU containers.
26	The Personal Watercraft	A small watercraft that typically carries one or two people that may either stand or sit like riders on a motorbike. The majority are used for personal entertainment, using an engine to drive a water jet.
27	The North Sea Crew Transfer Vessel	Vessel transporting goods, crew & supplies to platforms in the North Sea.
28	The Offshore Support Vessel	Vessel transporting goods, crew & supplies to platforms in the North Sea, also conducting maintenance and decommissioning of vessels and infrastructure.
29	The Leisure Boat in a Dry Stack	Smaller (<24m) leisure vessels that are wintered in a dry stack arrangement and on water moorings in summer.
30	The Pusher Boat	Pushes inland unpowered barges.
31	The Short Distance Transfer Ferry	A pedestrian and small automotive vehicle transfer ferry, typically chain operated.
32	The Short Sea Cargo Vessel	Small cargo vessels.
33	The Small Passenger Ferry	A commuter vessel for transporting foot passengers (around 147). It has a regular, well defined duty cycle, with daily usage up to 16 hours a day.
34	The Superyacht	The ultimate in exclusive vessels, typically the domain of multi billionaires. Requiring a sizeable staff to operate around the world.
35	The Trawler	Trawling fishing vessel, with a small crew, equipment, and cargo.
36	The Tugboat	Boat to assist larger vessel enter and leave port.

Table 16: Vessel Archetype Descriptions

Appendix A – Marine Archetypes Assessment

Analysis and Results

Once the archetypes had been identified, it was necessary to consider parameters that could be used to assist in ranking the V2G viability and those required for conducting modelling work. Expert opinion, based on experience in the automotive industry, was used to identify such parameters, including usage patterns, range between moorings and journey types. These are detailed in *Table 17.*

Parameter	Description	Possible Values
Range between Mooring	An estimate of the range between mooring activities. Key to sizing of propulsion system. Any vessel that travels over 200 nautical miles between mooring was scored one on the V2G suitability.	'0 10 nm', '10 50 nm', '50 100 nm', '100 200 nm', '200 500 nm', '500+ nm'
Journey Type	A description of the typical journey mode for the vessel. Point to point journeys are further segmented geographically.	'Destination to Destination (International)', 'Destination to Destination (National)', 'Destination to Destination (Local)', 'Return to Base', 'Variable'
Possible Trip Hours	The usage pattern across the day assists in determining the suitability of the vessel for V2G applications.	'0900-1800', 'All day', '1100-1600 Apr-Sep, 1100-1400 Oct-Mar', '0700-2000 Apr-Sep, 0700-1800 Oct-Mar'
Possible Trip Days	The usage pattern across the week assists in determining the suitability of the vessel for V2G applications.	'All days, 'Mostly Weekdays', 'Mostly Weekends'
Possible Trip Months	The usage pattern across the year assists in determining the suitability of the vessel for V2G applications.	'All Year', 'April to September', 'July and August'
On-call	Is the vessel on-call and can be used at a moment's notice and must be ready for use.	'Yes', 'No'

Table 17: Vessel Archetype Characterisation Data Points

The values of these parameters for each of the archetypes was then used to derive a V2G viability score. This score ranged from 1: unviable for V2G, 2: possibly viable for V2G (uncertainties remain), 3: immediately viable for V2G. The score for each archetype was determined using the following methodology.

Two initial filters were applied to the archetypes that resulted in scores of one; if a vessel was 'on call' 24 hours a day; and secondly any vessel that had an estimated range between moorings of greater than 200 nautical miles. The first filter is to recognise that an emergency vessel must have maximum range capabilities for as much time as is feasible. Therefore, the vessel is unable to partake in V2G. The second filter captures those vessels that are likely to require large very battery systems and so are more likely to use an alternative powertrain technology that means V2G isn't an option.

Appendix A – Marine Archetypes Assessment

The seasonality (possible trip months/days/hours) was quantified based on an estimation of the maximum likely number of hours the vessel may be used across the year, its effective annual duty cycle. Any vessel with an expected number of hours less than 1,000 was scored three, between 1,000 and 3,000 scored two and everything else scored at one.

An expert panel moderated the seasonality as a function of likely battery size and recharge time, journey type (which may preclude V2G if the vessel could complete a voyage at a non V2G enabled mooring) and the emergence of example electric vessels.

Table 3 shows the V2G Viability Score for each vessel archetype.

The long predictable dwell times and low energy demand voyages reflect the previously identified characteristics of suitable vehicles for automotive V2G, as reported in Project Sciurus in 2018. As in the automotive sector, vessels that can be connected to a charger for extended periods of time, in significant numbers, provide ideal conditions for the battery to be used for V2G services.

Six archetypes were selected (*highlighted in green in Table 18*) for further investigation. These were chosen to represent a range of potential vessels based on physical size, quantity in the fleet, seasonality and usage location, with all six scoring highly (mostly three) on the V2G viability. They are:

4. The recreational vessel
15. The canal boat – permanently occupied
16. The canal boat - leisure
23. The river tours vessel
26. The personal watercraft
33. The small passenger ferry

Index	Archetype	V2G Viability Score
1	The Responding to Danger Vessel	1
2	The Supporting an Emergency Response Vessel	1
3	The Royal Navy Frigate	1
4	The Recreational Vessel	3
5	The Mid-sized Passenger Ferry	2
6	The Roll-on Roll-off Ferry	2
7	The Sailing Club Support (at Sea) Vessel	1
8	The Sailing Club Support (Inland) Vessel	2
9	The Sailing Yacht (with a secondary electric power supply)	3
10	The Large Research Vessel	1
11	The Small Research Vessel	1
12	The Aquaculture Vessel	2
13	The Barge Work Boat	2
14	The Border Force Vessel	1
15	The Canal Boat – Permanently Occupied	3
16	The Canal Boat - Leisure	2
17	The Coastal Trader	1
18	The Cruise Ship	1
19	The Deep-Sea Fishing Vessel	1
20	The Diving Support Vessel	1
21	The Fuel Bunkering Ship	1
22	The Harbour Patrol Rib	1
23	The River Tours Vessel	2
24	The Inshore Fishing Boat	2
25	The International Freightliner	1
26	The Personal Watercraft	3
27	The North Sea Crew Transfer Vessel	1
28	The Offshore Support Vessel	1
29	The Leisure Boat in a Dry Stack	2
30	The Pusher Boat	2
31	The Short Distance Transfer Ferry	2
32	The Short Sea Cargo Vessel	1
33	The Small Passenger Ferry	2
34	The Superyacht	1
35	The Trawler	1
36	The Tugboat	1

Table 18: Ranking of Vessel Archetypes

These selected archetypes all have either low usage or predictable usage patterns, which are well suited to V2G operation.

Appendix B – The REVOLVE Model

The modelling for this work package has been performed using the Cenex REVOLVE model. REVOLVE is a perfect foresight optimisation model capable of simulating the charging/discharging behaviour of large numbers of EVs at half hourly granularity over a year.

Key Features:

- Simulates charging/discharging of up to a few hundred EVs
- Customisable constraints on max charging/discharging power to allow modelling of specific or generic V2G units
- Customisable constraints on max/min storage capacity of EVs to allow modelling of specific or generic vehicles
- Constraints on EV availability (plug-in times) and requirement to make journeys (energy demand)
- Modelling of:
  - charging/discharging losses
  - half-hourly varying import and export tariffs
  - flexibility of charging/discharging for the provision of grid services
- Simulation of local PV generation
- Optimises EV charging/discharging against behind-the-meter value streams and grid services
- Customisable warranty constraint modelling through optional limiting of maximum kWh of V2G provision per vehicle per day
- Evaluation of the impact of battery degradation costs on V2G revenue streams

The model optimises the charging/discharging behaviour of individual EVs on a minimum cost basis using the import and export tariffs available to the EV. Whilst the model covers an entire year, it does this by optimising weekly blocks one at a time. Each EV in the model has an associated driving energy and plug-in availability data set for the year. It also includes the local electricity demand for the site or building(s) the chargepoint is connected to. The chargepoint is assumed to be behind-the-meter and so, by discharging the EV, the local demand can be offset.

The chargepoints in the model can also be aggregated up and offered to provide grid services. The model stacks the available flexibility inherent in the chargepoints to build up the grid service product window requirements. To provide a grid service, a minimum capacity (in MW) must be held in either an upwards or downwards (or both) direction, for the specified grid service periods. During the entire service periods, the model must also hold sufficient stored energy/demand reduction (or battery headroom) to meet a minimum length of call of the grid service product. Note that whilst this headroom/footroom is held, the model does not currently simulate the actual calls due to the additional modelling complication this adds.

Appendix B – The REVOLVE Model

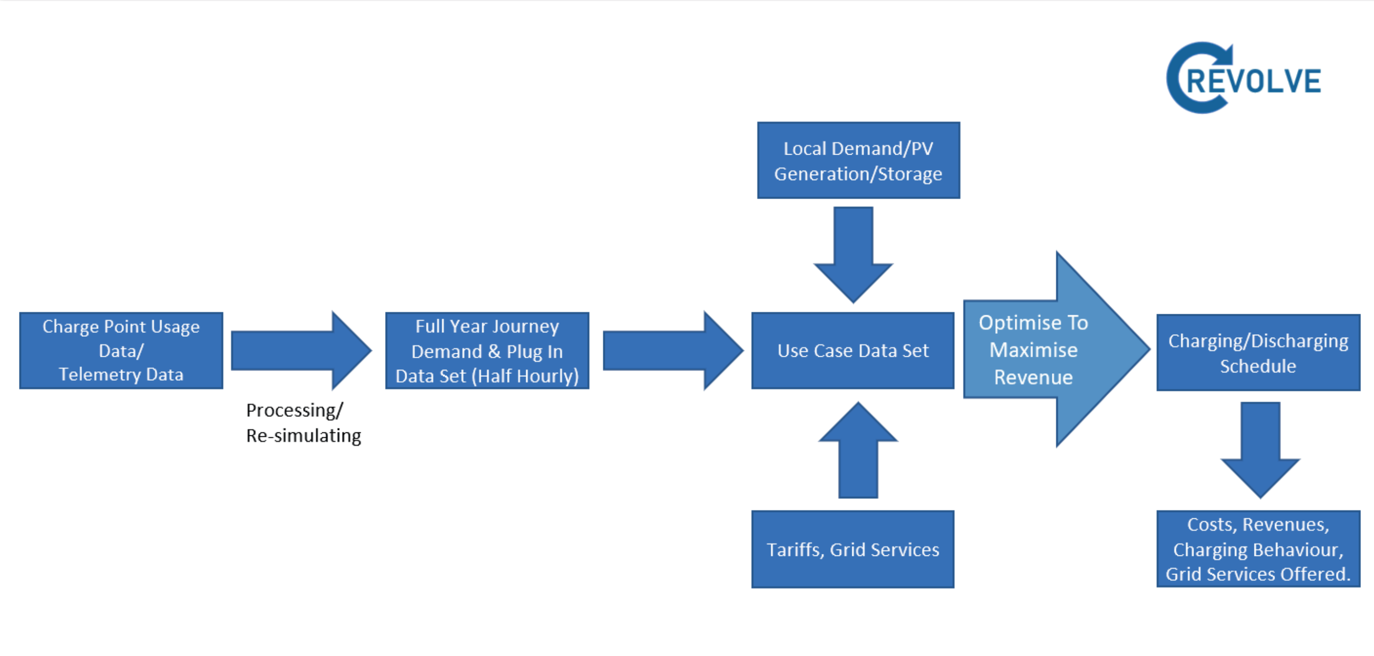


Figure 29: Cenex REVOLVE Model Diagram

Because the model is a perfect foresight model, it provides an upper bound on the revenue that can be earned through the V2G options modelled. In reality there will be deteriorations in the value through EV availability forecasting error and potentially price forecasting error.

In order to quantify the value provided by V2G, the model first performs an Unmanaged run. In this, all EVs charge up to full as soon as they are plugged in. This run is used to create an energy cost baseline. Subsequently, an Optimised run is performed. In this run the charging and discharging behaviour is optimised on the basis of minimum cost.

Appendix C – Vessel-to-Marina with Renewables Integration – Case Study Single Day

The following charts show the energy profile for a single day for the Vessel-to-Marina with renewables integration case study.

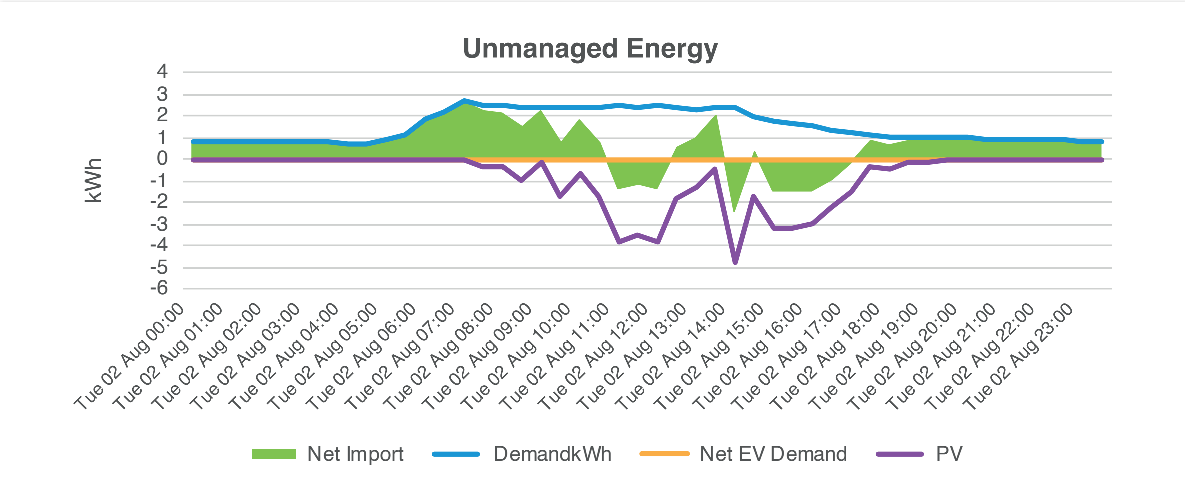


Figure 30: Vessel-to-Marina with renewables integration, example day for unmanaged run

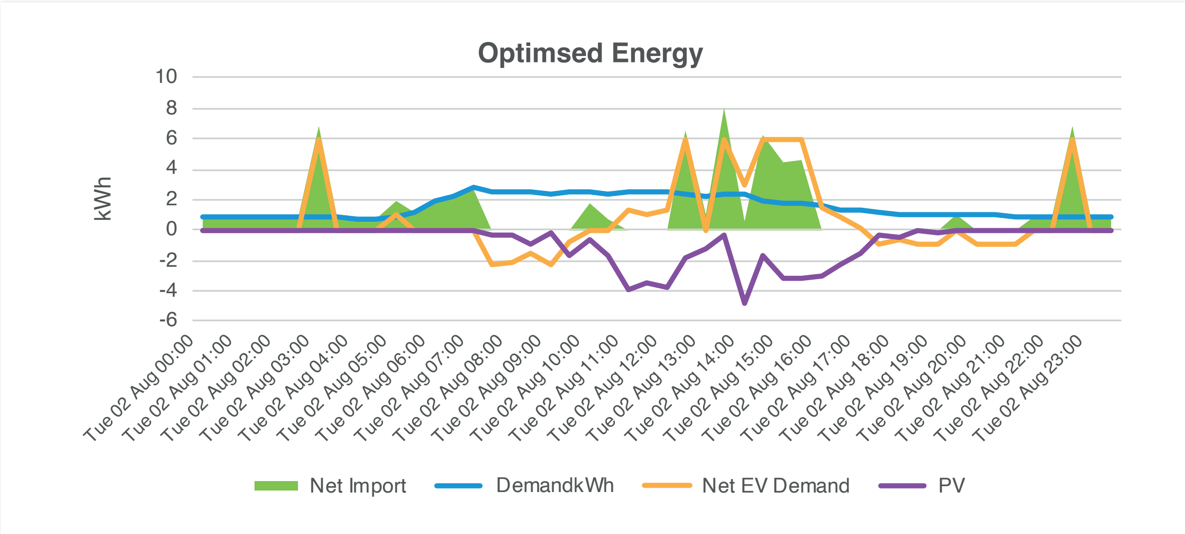


Figure 31: Vessel-to-Marina with renewables integration, example day for tariff and renewable optimised

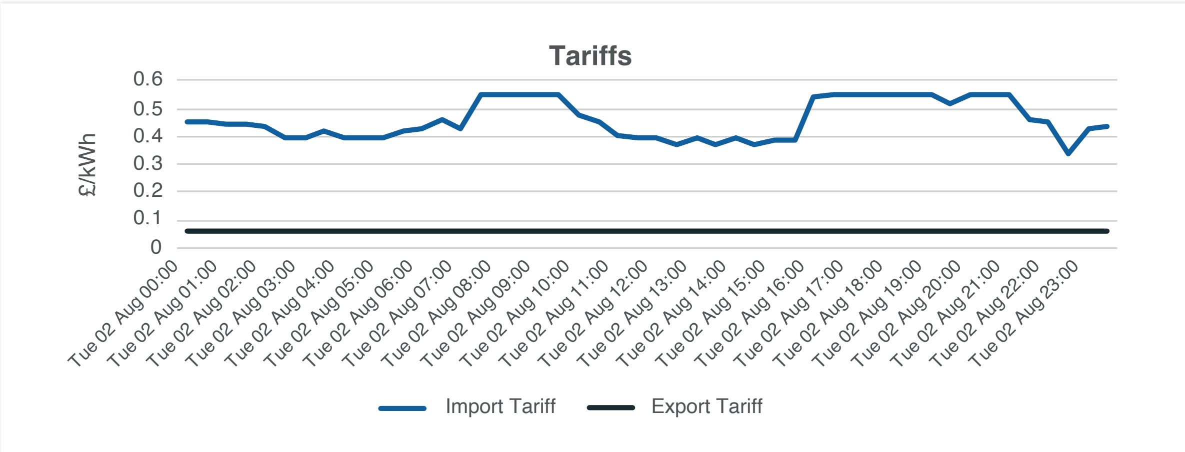


Figure 32: Tariffs for example day

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