# Contract design for V2G smart energy trading

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#### 1. Introduction

In the effort of transitioning to a net zero energy system, energy management V2X (Vehicle-to-Everything) is developing. V2X refers to the transfer of the electricity stored in the battery of Electric Vehicles to the grid (V2G), to buildings (V2B), to houses (V2H), to loads (V2L) or to farms (V2F).

The transition to a net zero energy system necessitates development in a number of directions including developing advanced electricity trading markets. Because electricity markets are responsible for a large portion of carbon emissions, improving the electricity markets' method for determining energy transactions could have a significant impact on carbon reductions and thus facilitate the transition.

V2X technology can be applied to regulate different energy markets, and thus reduce costs and carbon emissions by using the batteries in the electric vehicles to store energy during off-peak hours and export it during peak hours.

Specifically, during periods of high demand, back-up power plants are often needed to supply electricity demands. These back-up power plants are usually fossil-fuel powered generators which produce higher carbon emissions than most other types of power generation facilities. Thus, V2X can reduce carbon emissions in addition to increasing resilience and security of the electricity supply.

Furthermore, during Peak hours, additional electricity is sometimes needed to be purchased from the wholesale electricity market which raises electricity costs. For example, the top 1% of electricity demand account for 8% of electric energy costs. Thus, V2X can generate revenue by performing energy arbitrage – discharging (i.e. energy exporting) during expensive peak hours and charging (i.e. energy importing) during non-peak hours.

The energy market consists of three main markets:

- 1. The Forward market, where transaction are settled weeks, months or years in advance.
- 2. The Spot market, where transactions are settled between a day ahead, or up to 5 minutes in advance.
- 3. The Balancing market, which facilitates frequency balancing.

Energy transactions are based on contracts between energy suppliers (i.e. energy exporters) and energy importers.

By applying smart contracts which are based on algorithmic game theory for these energy transactions, V2X can reduce carbon emissions and prices stemming from all three markets.

The current understanding is that there exists no system in the market that optimizes V2X mechanisms along with algorithmic electricity trading by non-domestic customers.

In this research, we focus mainly on the Spot market and on the balancing market. We believe that the Forward market and balancing market may be developed further in a similar fashion to our suggested contract for the Spot market, but leave these open for future research. Particularly, we focus on fleets of Electric Vehicles, which export energy via a computerized system to the Grid, Micro-Grid, Houses, Buildings, or to Farms, through contract allocations. We refer to the computerized system as the *platform*. For simplicity, in this paper, we will consider this platform as the energy recipient.

We introduce a mechanism for electricity trading for the intra-day and day-ahead spot markets using smart contracts in a V2X setting that is relatively efficient, cost minimizing, and simple to implement. We also introduce a mechanism for exporting energy to support the balancing market.

Many proposed mechanisms for easing energy markets via V2X rely on Machine Learning or Statistical Analysis which aim to assess the demand and supply for electricity throughout the day and offer prices for importing and exporting electricity accordingly (Mustafa et. al 2022, Liu et. al 2013, etc.). These techniques require extensive data collection, which might not always be available. Specifically, companies and the public, who are strategic agents, might choose to be untruthful concerning their reports, in order to raise their profits. Companies' untruthful reports often lead the proposed mechanisms to select sub-optimal strategies which can result in extreme in-efficiency.

Other proposed mechanisms consider auctions such as first-price (where bidders pay their announced bid), and multi-stage (where the auction has multiple rounds and bidders are required to announce several bids), however these mechanisms, too, rely on extensive data collection, or do not align the EV's incentives of minimizing costs with those of the system, and thus do not always induce truthfulness or efficiency. Furthermore, the proposed mechanisms do not consider possible strategic manipulations participants may apply in order to affect their final payments, and thus are not efficient.

According to Holmstrom (1979) and Alon et al (2021), the only mechanisms that can induce players to announce their true valuations, and thus lead to efficiency are VCG-based mechanisms (Vickery 1961, Clarke 1971 and Groves 1973). Although many papers consider applying VCG-based mechanisms to V2G (Ma et al 2017, Anthony et al 2023, Li 2021, Guizni 2019, etc.), these papers do not take into account the different time periods possible for trading energy and their interrelated

effects on each other and on the EV's profits. Furthermore, they do not consider non-domestic customers.

#### 2. Methodology

We suggest the following two mechanisms:

- 1. A mechanism for exporting electricity to the platform in the day-ahead/intra-day markets. We call this the *Hour Scheduling mechanism*.
- 2. A mechanism for exporting electricity to the platform in the Balancing market. We call this the *Balancing-Exporting mechanism*.

The Hour-Scheduling mechanism extends the literature of the VCG auction (Clarke, 1971). As stated above, the VCG auction is the only type of auction that can simultaneously guarantee participants' truthful announcements and efficiency.

Due to these properties, throughout the years, there have been many applications to extensions of the VCG auction. Among these applications:

- E-bay participants bidding when buying a product.
- Google, twitter and Facebook payments for allocating adds.
- Spectrum auctions selling the rights to transmit signals over bands of the electromagnetic spectrum

The Hour-Scheduling mechanism, takes into account the different time periods possible for trading energy and their interrelated effects on each other, in addition it allows for having fleets with multiple EV's participate, instead of single EV's.

For example, consider a micro-grid from which non-domestic customers consisting of fleets of EVs, import energy for their consumption. Fleets, at times, have an excess quantity of kW in their EV batteries. By means of a *platform* the fleets can export excess energy back to the micro-grid. The platform allocates a set of contracts stating transactions between the fleets and micro-gird which determine the quantities of kW that will be exported from the fleets' EVs to the micro-grid, and the corresponding payment each fleet (the micro-grid) will receive (and pay) for each transaction. The platform determines these transactions via a mechanism which is an algorithmic procedure.

In our case, the platform is Q-Energy, and the mechanisms shall be the 'Hour Scheduling mechanism' and the 'Balancing-Exporting mechanism'.

#### 3. The Hour Scheduling Mechanism

The Hour-Scheduling mechanism can be implemented for intra-day or day-ahead markets by fleets interested in exporting energy from their Bi-directional batteries.

This approach can simultaneously guarantee truthfulness and limit the extent of inefficiency that can arise. It considers all hours of the day and their inter-dependencies, and not only a single hour. Furthermore, this mechanism's application is relatively simple and can be computed in polynomial time.

A lower bound for the probability of covering the expected demand for a specific period of time can be deduced from the announced bids of the fleets' offered contracts. Moreover, the more competition there is, the more efficient the allocation of contracts will be, and the lower the cost for the platform.

The mechanism is defined over a period of time.

In this paper, we consider a 24 hour period divided into half-hour period (hhp)'s.

Denote "T" as the set of all *hhp's* during a 24-hour period, and consider T's division into *peaks* and *valleys*, where a peak (or valley) describes a set of consecutive hhp's with high (or low) electricity demand.

Specifically, peaks and valleys of a 24-hour period can be can be determined through the relevant spot market prices. The precise division into peaks and valleys isn't essential, the main purpose is to divide the day into hour blocks of similar expected energy demand.

Consider for example the following division into peaks and valleys.



Denote the market prices:  $m^t_{day\ ahead}$ ,  $m^t_{intra-day}$ ,  $m^t_{balancing}$ : such that  $m^t_i$  describes the wholesale market price at hhp t  $\in \{0:00-00:30,...,23:30-24:00\}$ , where  $i \in \{day-ahead,intra-day,balancing\}$ .

We consider a set of fleets, where each fleet has a number of Electric Vehicles (EV)'s, and every EV has a schedule.

Each fleet has private information concerning it's:

- Schedule and schedule flexibility
- Energy costs
- · Probability of default for each of it's offered contracts
- Battery deterioration costs

Many mechanisms require fleets or EV owners to share their private information in order to enable efficient management. However, fleets often choose not to share this private information, or may choose to disclose deceitful information in order to enhance their final profits. For example, deceitful strategies naturally arise in mechanisms where the platform compensates fleets' based directly on their announced energy importing or exporting costs. Furthermore, a fleet may have some flexibility regarding their schedule, where different schedules generate different costs. If fleets receive a payment from the platform equal to their announced

costs, then clearly fleets have an incentive to act deceitfully and announce higher energy costs, higher rescheduling costs etc.

On the other hand, VCG-based mechanisms, by nature, induce participates to be truthful. This is because, if it is profitable (according to announcements) to have a transaction with a certain fleet, then the VCG-based mechanism determines that fleet's payment independently of it's announcements. The VCG-based mechanism will offer a payment to the fleet which will be equivalent to the 'extra value' they are adding to society (i.e. the platform and other fleets). Because the VCG-based mechanism's payment is independent of the fleet's announcement, by not announcing a true value, either the fleet's offered contract will not be accepted, or if it is accepted, it's announcement will have no effect on it's payment.

In the Hour Scheduling mechanism each Fleet n in the set of N fleets, offers contracts to the platform of the form  $j = (hhp, \ell, f_{\ell})$ , where: hhp states the hhp in which the energy transfer is to take place (for example 15:00-15:30),  $\ell$  is the quantity of kW planned for exporting, and  $f_{\ell}$  is the penalty if contract j is defaulted.

The platform chooses a subset of these offered contracts, aiming to maximize efficiency, while preserving truthfulness. The bids announced for the offered contracts are truthful (i.e. equivalent to the expected cost of attempting the contract for the fleet). The fleets' truthfulness stems from the fact that the payments the fleets receive for the contracts are aligned with the platform's aim for minimizing cost and maximizing efficiency; where efficiency is quantified by the ratio between the resulting social welfare and the optimal social welfare, and social welfare is the utility of all fleets and the energy recipients.

We shall describe this contract for the day-ahead market, although it can be applied to multiple intra-day markets as well or in succession.

#### The Hour scheduling contract proceeds as follows:

- 1. Each fleet offers a set of contracts in where they offer to export a quantity of kW at each hhp during each peak.
- 2. For each offered contract *j*, the platform determines the potential payment that contract *j* would receive if accepted. This payment is based on the additional value the contract adds to the social welfare by existing.
  - Specifically, consider for each hhp: the *demand covering set* as the set of offered contracts that minimize the sum of bids needed in order to cover the expected demand for that hhp. The bid of the contract which would have belonged to the covering set had the fleet that offered contract j not existed, will be the payment for contact j.
- 3. Order all hhps in peak, which still have positive expected demand that hasn't yet been covered by contracts, according to the maximum difference between payment minus bid per contract.
- 4. For the hhp with the highest value in (3): the platform accepts the contract with the lowest bid at that hhp.

- 5. When a contract is accepted, then all other offered contracts by the offering fleet for the same peek, and the same quantity of kW are eliminated and removed from the set of available contracts, as a fleet cannot export the same ℓ kW more than once per peak.
- 6. Return to (3)
- 7. Finally, the platform transfers the payments calculated is stage (2) to all fleets with accepted contracts.

For every accepted contract add the fine  $f_{\ell}$  to the contract in the event that the contract will not be honoured.

#### Claims:

- a. A fleet will announce a truthful bid b(j) for the contract j, i.e.  $b(j) f_{\ell} \cdot (1 p) = c_{hhp}(j)$ , where p is the probability of fulfilling contract j, and  $c_{hhp}(j)$  is the cost of attempting contract j at hhp and  $f_{\ell}$  is the fine if  $\ell$  kW are not exported at hhp (see section 3.1, below).
- b. A lower bound for the portability of fulfilling contract j is  $\frac{f_{\ell} b(j)}{f_{\ell}} = \hat{p}(j)$ .
- c. The algorithm is simple to implement with polynomial complexity.
- d. The algorithm reaches an efficiency level of at least approximately half the most efficient possible level.
- e. Every fleet n receives, for an accepted contract, a payment at least as high as their bid, i.e.  $Payment^n(j) \ge b^n(j)$ .
- f. The Hour Scheduling mechanism can result in every fleet receiving a different price.
- g. The more fleets there are: the more efficient the final allocation of contracts, and the lower the cost for the platform (see example 5).

Note that applying this mechanism to the public and to private EV owners, can be conducted by considering each private EV as a fleet with a single EV.

#### 3.1. Announcing a value equivalent to the true value:

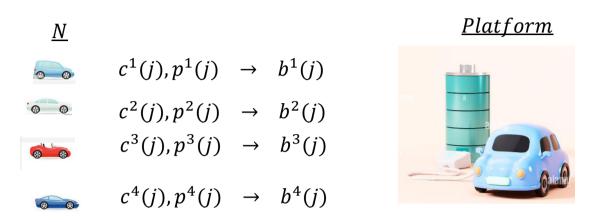
In this section, we will describe in more detail the intuition behind claim (a) above.

Consider fleet n offering a contract  $j = (13:30 - 14:00, \ell = 1, f_{\ell})$ .

<u>Claim</u>: The dominant strategy of a fleet n is to announce for any offered contract j a bid equal to:  $b(j) = c^n(j) + (1 - p^n(j)) \cdot f_\ell$ , where: (1)  $c^n(j)$  describes fleet n's cost for attempting the contract including battery deterioration, energy costs, etc., or alternative transactions; (2)  $p^n(j)$  describes fleet n's probability of fulfilling contract j; (3) and  $f_\ell$  is the fine if the contract is not fulfilled.

We will begin by showing this for individual EVs for a specific hhp, and subsequently expand to fleets with multiple EVs and all hhp's in over T.

Each EV  $n \in N$  announces a bid  $b^n(j)$  for contract j. Every EV n has private information consisting of their costs  $(c^n(j))$  and their probability  $(p^n(j))$  of fulfilling contract j. Each EV will announce a bid  $(b^n(j))$ , based on their private information, for exporting the quantity of kW described in the contract to the platform.



The platform perceives only the announced bids, and is not exposed to the private costs or probabilities of fleets. The platform chooses the contract with lowest bid.

The chosen EV n (with the lowest bid) will receive a payment equal to the lowest bid that would have been accepted had EV n not existed, in order to cover the demand  $D^{hhp}$ .

#### Idea of Proof:

We assume that an EV = n knows it's cost  $c^n(j)$  and it's probability of completing the contract  $p^n(j)$ : where, for example,  $c^n(j) + (1 - p^n(j)) \cdot f_\ell = 9$ . In fact  $c^n(j) + (1 - p^n(j)) \cdot f_\ell$ , is the true expected cost of contract j for EV n.

• Assume that EV-n announces  $b^{\rm n}=11>9$ , and assume that EV n' announced  $b^{n\prime}=10$ .

EV-n will not be chosen, and will result in zero utility.

Had EV-n announced it's true value  $b^n = 9 = c^n(j) + (1 - p^n(j)) \cdot f_\ell$ , then EV-n would have been chosen, and would have received the second lowest bid of 10=  $b^{n'}$  and attained expected utility of  $u = payment^n(j) - [c^n(j) + (1 - p^n(j)) \cdot f_\ell] = 10 - 9 = 1 > 0$ . So EV n would have been better off announcing it's true value.

• Assume that EV-n announces  $\mathbf{b}^{\mathrm{n}} = 8 < 9 = c^n(j) + (1 - p^n(j)) \cdot f_{\ell}$  .

Assume EV-n' offers a bid of  $b^{n\prime}=8.5$ . In such a case the contract of EV-n will be accepted, and EV-n will receive a payment equal to the second lowest bid of  $8.5=b^{n\prime}$ , and attain expected utility of  $u=payment^n(j)-[c^n(j)+(1-p^n(j))\cdot f_\ell]=8.5-9=-0.5<0$ .

Had EV-n announced it's true value  $b^n=9=v^n$ , then the contract offered by EV-n would not have been accepted, and EV-n would have received a utility of zero and been better off.

- An EV is always better off announcing a bid equal to their true expected cost, because:
  - either their expected cost is higher than the lowest bid in which case they are better off announcing their expected cost rather than announcing a lower bid, being chosen and receiving the second lowest bid (which would have been the lowest bid had they announced truthfully).
  - or their expected cost is lower than all other bids in which case they will be chosen if they announce their expected cost. In such a case their payment will be independent of their announcement and equal to the second lowest bid which will be higher than their expected cost.

Note that an EV has no motivation announcing non-truthful bids in order to export kW for a more profitable hhp in peak. This is because the algorithm always allocates the contracts for the most profitable hhps first, so by announcing the true value for all contracts in their respective hhp's, the fleet raises the chance of having their most profitable contract accepted.

Extending the concept from single EVs to fleets, will have each accepted contract generate a payment equal to the bid offered in the contract that would have been accepted if the fleet that offered the contract didn't exist.

Note that the hour scheduling mechanism entails every accepted contract j of fleet n offering the contract, to receive a payment  $Payment^n(j)$  equal to the external value their existence causes society.

## 4. Balancing-Exporting Mechanism

A situation may arise in which for certain hhps there will be a gap in real-time between demand (i.e., energy importing by the platform) and energy supply (i.e., energy exporting to the platform) that will not be covered by contracts that were either planned beforehand by the Hour-Scheduling mechanism, or through other mechanisms. In such cases, the remaining demand is covered through the Balancing market, which is often quite costly.

We introduce the *Balancing-Exporting mechanism* for exporting energy in the balancing market which enables EV owners who have excess kW, to export this energy for a profitable fee, and thus reduce costs at the Balancing Market.

#### The 'Balancing-Exporting mechanism:

This mechanism pays EVs for the time they are connected to the platform and for the kW they export.

- 1. Each EV can announce the electricity they have available for export at the hhp in which they connect to the platform, where  $x_{available}^m(hhp)$  is the quantity of available kW for export that EV m has at hhp.
- 2. The platform imports kW from all EV's that are connected via the Balancing-Exporting Mechanism.
- 3. Any remaining kW which are still not covered, will be supplement by importing kW from the grid at  $m_{Balancina}^{hhp}$  per kW.

We consider all pre-planned contracts (contracted through the Hour-Scheduling mechanism, or via other mechanisms) for exporting energy at time hhp, and denote them as  $J^{final}$ . Initially let  $J^{active} \leftarrow J^{final}$ , where  $J^{active}$  is the set of active contracts that have been accepted and haven't defaulted.

For every amount of y kW between 0 and  $D^{hhp}$ , given the expected electricity demand at hhp, and the set of active contracts  $J^{active}$ , there is a probability of  $p_{hhp}^{missing}(y,J^{active})$  that y kW should be lacking.

An upper bound for this probability of lacking *y* kW may be assessed through the existing kW exporting agreements, which were accepted in the Hour Scheduling mechanism.

Let  $c^{BD}$  - refer to battery deterioration cost for charging and discharging 1 kW, in addition to the cost of importing 1 kW during low-peak periods.

Offer an EV m that is connected to the platform, the following contract:

$$\begin{split} Payment^{m} & \big( x_{available}^{m}(hhp), hhp, x_{exported}^{m}(peak) = \\ & = \sum_{y \in [0, \dots D]} const \cdot p_{hhp}^{missing}(y, J^{active}) \cdot m_{Balancing}^{hhp} \cdot \\ & \cdot y \frac{x_{available}^{m}(hhp) + x_{exported}^{m}(peak)}{\sum_{q \in plugged_{hhp}} (x_{available}^{q}(hhp) + x_{exported}^{q}(peak))} + x_{exported}^{m}(hhp) \cdot c^{BD} \end{split}$$

#### Where:

 $x_{exported}^{m}(hhp)$  is the kW quantity that are exported during hhp by EV m.

 $x_{exported}^{m}(peak)$  is the kW quantity that have already been exported in the relevant peak before hhp by EV m.

 $x_{available}^{m}(hhp)$  is the kW quantity that are available for export during hhp by EV m. const is a predetermined constant.

 $plugged_{hhp}$  is the set of EVs that are connected to the platform at hhp.

We wish to avoid a situation in which a fleet should manipulate the platform by avoiding the 'Hour Scheduling mechanism, in order to attain a higher payment from the Balancing-Exporting mechanism (where there is no penalty). By adapting 'const', this manipulation becomes less profitable for fleets and EV owners.

#### 5. Applications and Potential Use

The Hour-Scheduling mechanism and the Balancing-Exporting mechanism may be adopted and applied widely for both domestic and non-domestic use.

For instance, these mechanisms may offer bus fleets a significant additional profit, enabling their participation in the energy market, while reducing energy costs. An outline of a strategy enabling this transition of electrifying busses and participation in the Hour-Scheduling and the Balancing-Exporting mechanisms, is described in 'The business case for V2X in bus fleets' (J. Southernwood (2023)).

### 6. Demonstrating the Hour Scheduling Mechanism

We demonstrate the Hour Scheduling mechanism through the following setting. We assume unless otherwise stated:

Six fleets, unless otherwise stated, where each fleet owns twenty EVs. We assume that each EV imports a certain amount of kW at each valley for consumption, and has approximately 100kW remaining for export during each peak period.

We assume that each fleet imports their energy during low price occurrences. We assume that fleets have additional costs (i.e. battery degradation, taxes, etc.) of three pence per kW, and therefore each fleet is willing to export their excess energy at the price they paid for it plus their additional costs of three pence per kW. That is, if 1 kW was imported by an EV belonging to a fleet at one pence in the preceding valley period, then that EV will offer a bid for exporting that kW equal to four pence. Specifically, they will not agree to receive less than four pence for the 1 kW.

We assume that the energy demand at each hhp (i.e. the energy demand not yet covered by existing energy transaction agreements) is 3000 kW.

Example 1 describes a weekday (2nd August 2023).

Example 2 gives us a closer look at a small set of contracts for a single hhp.

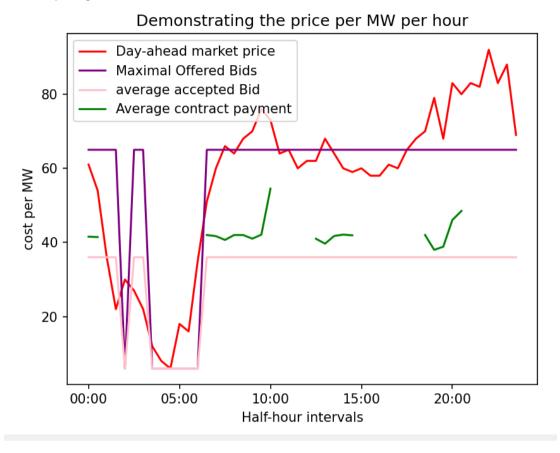
Examples 3 and 4 describe the setting during a weekend (4th August 2023), and in the event of negative prices (2nd July 2023).

Example 5 compares to instances of the mechanism with different levels of competition.

In these examples the energy is imported at low price occurrences throughout the 24 hour day, and not necessarily during the valley periods.

## **Example 1:**

The following example demonstrates the Hour-Scheduling mechanism according to the weekday August 2<sup>nd</sup> 2023.



The above graph demonstrates contracts offered during a 24 hour day. The red line depicts the day-ahead spot market (data from epexsport.com).

The pink line depicts the minimal bids of all contracts for every hhp in T, and the purple line depicts the maximal bids of all offered contracts for every hhp in T. All bids are based on the cost of mW in the day-ahead spot market during the preceding valley period.

The Green line describes the average payments of all accepted contracts that are paid to the fleets for every hhp.

Note that the average payment is always above the minimal bids, and always below the spot market.

The platform's profit is the area between the red line and the green line, and the fleets' profit is included in the area between the green line and the pink line.

The total platform profit is: 1,415 pounds (£) for a day

The total fleets profit is: 150 pounds (£) for a day (above the minimal profit required to cover costs, unless otherwise stated)

The average profit for the fleets for every KW is: 0.27 pence

The average profit for the platform for every KW is: 2.6 pennies.

The number of accepted contracts is: 500 contracts.

This profit may seem low but it is above the minimal profit the fleets require. Due to section 3.1, the fleet will state a bid equivalent to the minimal payment required to cover all expected or alternative costs. Specifically, the fleet will not bid lower than the minimum payment required to attempt the transaction. Therefore, in this case the profit of 0.27 pennies per kW is above the minimum payment required by the fleet in order to keep participation profitable.

# Example 2:

The following example demonstrates the mechanism for a fabricated set of contracts for the 30<sup>th</sup> of June 2023, at hhp 13:30-14:00 pm.

We assume two fleets: Keele University and NHS, each owning two EVs.

Serial Num	Fleet	Date	hhp	Bid - pence per kW	kW	Prob - $\hat{p}$
				perkvv		
1	NHS	30.06.2023	13:30-14:00	10	20	0.8
2	Keele Uni	30.06.2023	13:30-14:00	6	14	0.88
3	NHS	30.06.2023	13:30-14:00	9	16	0.82
4	Keele Uni	30.06.2023	13:30-14:00	20	9	0.6
6	Wholesale			29	1	1
	price					

- The estimated probabilities of the fleets honouring these contracts are calculated by:  $\hat{p}^n(j) = (f_\ell b^n(j))/f_\ell$ .
- Contract (6) is based on the corresponding day-ahead spot market price for exporting kW.

We assume that in expectation there is a demand of 35 kW for hhp 13:30-14:00 (determined according to statistical analysis of historical data). Therefore, the contracts that will be accepted will be:

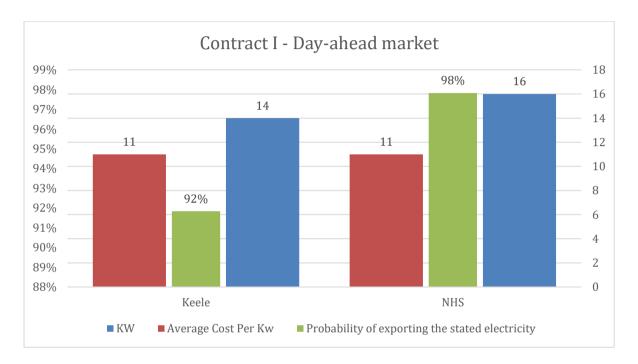
Table 1

Serial Num	Fleet	Date	hhp	Bid - pence per kW	kW	Prob - $\hat{p}$
1	NHS	30.06.2023	13:30-14:00	10	20	0.8
2	Keele Uni	30.06.2023	13:30-14:00	6	14	0.88
3	NHS	30.06.2023	13:30-14:00	9	16	0.82

Note that the chosen contracts state that 50 kW should be exported, and not 35 kW as demand requires. This discrepancy is due to the estimated probability of satisfying the contracts  $\hat{p}$  which lowers the expected fleets' quantity of exported kW. For the set of accepted contracts in table 1, the expected lower bound of the

quantity for energy export is 41 kW, because each contract has a probability of default equal to  $(1-p) \le (1-\hat{p})$ . For simplicity, we choose to accept a set of contracts which satisfies more rather than less of the expected quantity of kW, when the expected demand is not possible to cover precisely in expectation with the offered contracts.

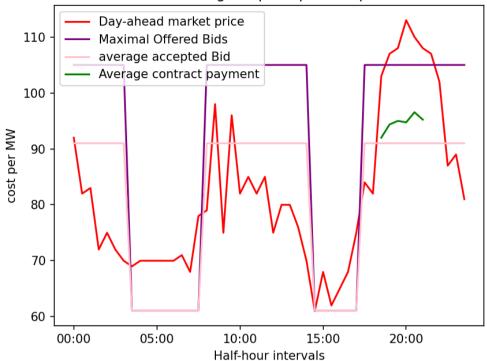
The following chart demonstrates the expected quantity of kW exported by each fleet, the average expected cost per kW for each fleet and the probability of exporting the contracted quantity of kW for each fleet.



# **Example 3:**

The following example demonstrates the mechanism during the weekend of 4th August 2023.





#### In this example:

The total platform profit is: 240 pounds (£) for a day

The total fleets profit is: 41 pounds (£) for a day

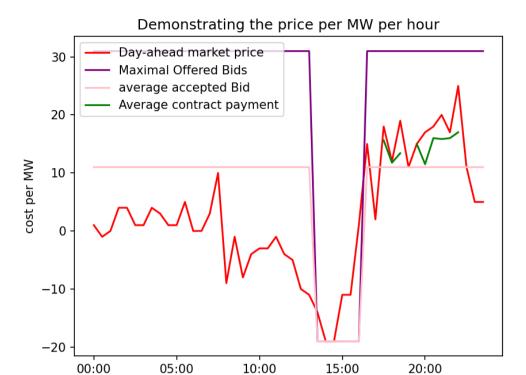
The average profit for the fleets for every KW is: 0.17 pence

The average profit for the platform for every KW is: 1 penny.

The number of accepted contracts is: 220 contracts.

# **Example 4:**

The following example demonstrates the mechanism during the weekend on the 2nd of July 2023, where there were negative prices.



In this example:

The total platform profit is: 75 pounds (£) for a day

The total fleets profit is: 40 pounds (£) for a day

The average profit for the fleets for every KW is: 0.17 pence

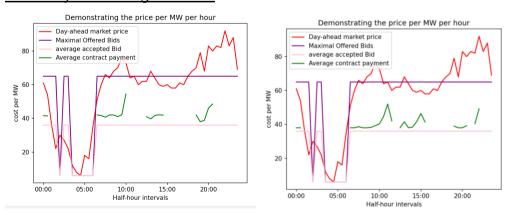
The average profit for the platform for every KW is: 0.32 pence.

Half-hour intervals

# **Example 5**

This example compares two instances with different levels of competition for the weekday market.

#### Weekday of 2th August 2023:



The above two graphs demonstrate the effect of competition on the Hour-Scheduling mechanism.

The graph to the left demonstrates the setting with 6 fleets, and the gaph to the right demostrates the setting with 8 fleets.

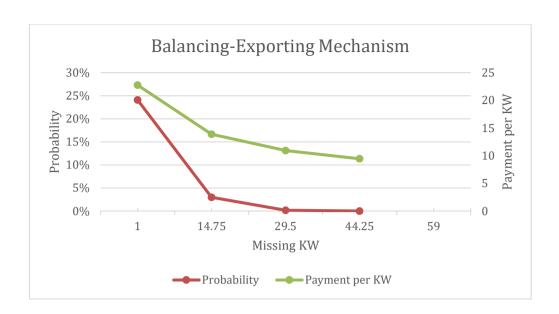
	6 fleets	8 fleets	
The total platform profit is	1,415 pounds (£)	1,915 pounds (£)	
The total fleets profit is	150 pounds (£)	83 pounds (£)	
The average profit for the fleets for every KW	0.27 pence	0.12 pence	
The average profit for the platform for every KW	2.6 pence	2.8 pence	
The number of accepted contracts	500 contracts	621 contracts	

As demonstrated, the graph on the right with a higher level of competition, has higher efficiency of contract allocations, and higher profit for the platform. Furthermore, as demonstrated, competition tends to reduce the fleets profits per kW, and raise the platform's profits per kW.

### 7. Demonstrating the Balancing-Exporting Mechanism

In this subsection we demonstrate the Balancing-Exporting mechanism. We assume the contracts depicted in table 1, with their estimated corresponding probabilities of success. The probability of exporting different quantities of kW are assessed through these contracts.

In the following graph, we consider the contracts chosen in table 1. The following graph depicts the relationship between probabilities of shortages of kW, and payments per kW,:



Note that the higher the deficient quantity of kW, the lower the payment per kW, and the lower the probability of such an occurrence.

## 4. Bibliography

Many related works concerning the electricity market have emerged. A partial list of these works includes the following:

- "Integrating electric vehicles as virtual power plants: A comprehensive review on vehicle-to-grid (V2G) concepts, interface topologies, marketing and future prospects" (Mustafa Inci, Murat Mustafa Savan, Ozgur Celik, 2022)
- "Using peer-to-peer energy trading platforms to incentivize prosumers to form federated power plants" (Thomas Morstyn2, Niall Farrell, Sarah J. Darby and Malcolm D. McCulloch (2018))
- "Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies" (y Chunhua Liu, K. T. Chau, Diyun Wu, Shuang Gao (2013))
- "Role of Vehicle-to-X Energy Technologies in a Net Zero Energy System" (Department for Business, Energy & Industrial Strategy (2021))
- "Contract Design for Energy Demand Response" (Reshef Meir, Hongyao Ma, Valentin Robu, 2017)
- "Bidding Strategy for Aggregators of Electric Vehicles in Day-Ahead Electricity Markets" (Gua et al (2017)): investigates a trading model based on auction, but

- considering a multi-auction based bidding strategy, thus complicating the process.
- "Day-ahead bidding strategy for electric vehicle aggregator enabling multiple agent modes in uncertain electricity markets. Appl Energy " (Zeng (2020)) analyze bidding strategy for EV's, which relies on agent bids, and statistical analysis.
- "Contract Design for Energy Demand Response" (Reshef Meir, Hongyao Ma, Valentin Robu, 2017): introduces contracts for buying electricity, based on a VCG mechanism. Efficient and minimal costs, however does not consider time preferences.
- "VCG-Based Auction for Incentivized Energy Trading in Electric Vehicle Enabled Microgrids" (Ifiok Anthony Umoren, Muhammad Zeeshan Shakir, and Hamed Ahmadi., 2023): They consider electricity trading via VCG-based auctions, where the trade takes into account the distance of the EV to the kW exporting platform.
- "Groves' Scheme on Restricted Domains" (Bengt Holmström, 1979): He shows that efficient truthful auctions must by based on a VCG type setting.
- "Incentive-based Location Privacy Preserving Electric Vehicle Charging Mechanism in Smart Grid" (Yuhao Ma, Donghe Li, Qinguy Yang, 2021): Introduce a contract that induces efficiency and preserves EV owner's privacy.
- " Multipart pricing of public goods" (Clarke, 1971): Introduced the VCG setting.
- "Double Auction Mechanisms For Dynamic Autonomous Electric Vehicles Energy Trading" (Abdulsalam Yassine, Shamim Hossain, Ghulam Muhammad, Mohsen Guizni, 2019): Introduces a double auction mechanism based on the VCG mechanism, that implements efficient dynamic pricing structures for energy trading.
- "An Online Continuous Progressive Second Price Auction for Electric Charging" (Zhang, Yang, Yu, An, Li, Zhao, 2019): Introduce an online continuous progressive second price auction enabling energy trading with low computational overhead.
- "Extended second price auctions for plug-in electric vehicle (PEV) charging in smart distribution grids" (S. Bhattacharya, K. Kar, H. Chow, A. Gupta (2014): Introduce two mechanism extending VCG mechanisms to allocating energy
- "Extended second price auctions for plug-in electric vehicle (PEV) charging in smart distribution grids" (S. Bhattacharya, K. Kar, H. Chow, A. Gupta (2014):

Introduce two mechanism extending VCG mechanisms to allocating energy efficiently in terms of prices and quantities.

- "An Incentivized Auction-Based Group-Selling Approach for Demand Response Management in V2G Systems" (M. Zeng, S. Leng, S. Mahargan, S. Gjessing, J. He (2015): Introduce a group selling mechanism for demandresponse between EV's and aggregators, and between aggregators and the grid.
- "The business case for V2X in bus fleets" (J. Southernwood (2023): Presents a strategy enabling bus companies to electrify their bus fleets while increasing profitability.