Michael Lewis - 40444786

Multi-Agent Systems SET10111 Coursework 1

Word Count 3186,

Introduction

Global warming has increased at an alarming rate in our lifetimes leading to rising sea levels and floods, heat waves and droughts stated by non-profit organization Climate communication (Climate Communication | Overview, 2021). However, this is contradicted by the Intergovernmental Panel on Climate Change (IPCC) that claim although there is evidence that some extremes have changed as a result of the increase in greenhouse gas, it is challenging to attribute a single extreme event such as a cyclone to climate change ((Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation — IPCC, 2021) pages 112 and 9).

It is possible to view the data of greenhouse gas emissions on ourworldindata.org (Ritchie and Roser, 2021) where you can view the global average temperature increase per year (fig 1) and the per capita emission from the average UK citizen. (Fig 2). Due to the climate change issue renewable energy has become the main focus of controlling the change we created. Renewable energy can come in the form of solar photovoltaic arrays (solar panels), wind turbines and more. The electricity grid has for a long time been run as a top-down business with utilities and big power generators sending their energy to customers (Energy trading for fun and profit buy your neighbor's rooftop solar power or sell your own-it'll all be on a blockchain, 2021). The grid is now transitioning their business model to implement a two-way street approach. This is where my task of creating a peer-to-peer energy trading market using multi-agent systems shines.

Multi-Agent systems are perfect for this task as an agent can be placed inside smart meters which are being installed in almost every home in the UK and these agents will be able to handle the buying and selling of energy with or without human interaction. Agents are also very small and require little resources which is also a bonus for reducing the effects on global warming while making the implementation and resources required to run these agents very low.

In this report I will go on to discuss the design route I took with my approach to this problem and the results gathered from the system I created. To conclude the report I will talk about changes I would make to the program and further work that can be done once the project has ended.

Design

Auction style

As this task is aimed at global warming, I have designed my system to use all little bandwidth as possible by reducing the number of messages sent and making the agents as efficient as possible. One of the choices I made with this goal in mind is I opted to implement the Vickrey auction as my chosen buy and sell method. This is due to the fact that another auction style such as English or Dutch would continuously change the price at the auction until the item has been sold resulting in multiple messages being sent per auction. Since I am auctioning one kilowatt at a time, in a real system this may result in hundreds or even thousands of extra messages from the auctioneer. With my chosen implementation of the Vickrey model an agent will simply state whether they wish to buy or sell a certain number of kilowatts and they wish to set. This will result with the auctioneer only sending messages to the winner and the seller. I have also implemented lists to hold the names of the buyer and seller agents so that once they have no more use for the market, either they have no more bids or no more kilowatt to sell.

They will be removed from the market and not receive any more messages such as being notified of the markets end.

Market valuation

I have chosen my valuation with the goal of the household agent benefiting more by selling their extra kilowatt on the market meaning more households will gradually add more renewable energy increasing supply of renewable energy and lowering the cost of buying renewable energy on the market. First, I set the base valuation to sell for higher than what the utility is offering, and buying lower than what the utility is selling. This is so that there is incentive to use the system. The thought process is that since it is cheaper to buy on the market there will be less people buying energy from the utility. This will result in the utility companies having to lower their prices to compete with this market. On the other hand, since the utility buy price is so high the market price will almost be as high meaning you will get substantially more from selling to the market than selling to the utility. This will result in people introducing more renewable energy to make money while saving the environment. This will also result in more supply in theory meaning the price for buying on the market will also steadily drop. I went with this solution rather than setting the buy valuation as low as possible and the sale as high as possible as this will result in multiple kilowatts of energy not being sold, this is due to the sell price being higher than the majority market valuation. I believe this social aim will benefit the market much greater than the self-motivated target which would eventually cripple itself and buying for more than market price from the utility.

since I have chosen to implement a Vickrey style market I have chosen to begin the sale of the cheapest kilowatt first. I have chosen this style instead of having the most expensive sales first as this would result in the price being much higher at the beginning of the auction than the end of the auction resulting in a large price fluctuation. In my auction the agents with the highest valuation will buy first with the goal of keeping the price per kilowatt as stable as possible and not result in fluctuations such as the search engine keyword auction (fig 3). My theory is that while the market goes on the sell price will rise and the bid price will fall leading to a balanced true value. This may result in riskier trade strategies such as trying to have the lowest buy price to find the sweet spot of the true value which may result in you not being able to buy on the market then having to buy at a much higher price from the utility company. This does pose the problem of setting your price as the lowest to be sold first which is why I have chosen to implement a second price protocol.

Second price bid auction protocol

As my auction is a sealed bid auction. I have decided to use the second price bid protocol. This means that the winner will pay the price of the second highest bid. This will reduce the cost per kilowatt on the market making it more appealing to households looking to buy renewable energy instead of other energy sources from the utility company. I implemented this by having a single round for bidding since this is a Vickrey auction. At the end of this round, I created a new list of the bids that lost. This also included an if statement to make sure none of these lost bids include other bids from the winning bidder so that the second price is not set as the same price as another bid from the winner. I then simply ordered the list from highest to lowest and took the value of the first bid in the lost bids list. Alternatively, I could have used first price bid protocol but this would lead to higher prices which may result in less households looking to buy renewable energy on this market. Having a sealed bid auction may lead to some agents cheating the protocol by lying about their valuations. This would be combatted by using digital signatures on the bids.

Contract Net Protocol

The flow of my program has been made with Contract Net Protocol in mind with the five stages of the protocol being played out. The first stage is recognition, where the agent recognizes once it has received its values from the environment agent that is must either buy or sell a certain number of kilowatts should it not have the correct amount. As it realizes it cannot achieve the goal of acquiring or selling these kilowatts it moves to the second stage of announcement. The household agent announces to the market/auctioneer agent its demands and the valuation of the kilowatt it has set on. The auctioneer then carries out the next sections of the contract net protocol which is where we steer away from the standard contract net protocol due to the nature of my program. The latter stages of contract net protocol are bidding awarding and expediting. This is done through the market function which carries out the Vickrey auction and sends messages regarding the winner, seller and the end of the market. The first two sections of the protocol may be assigned to the auctioneer but due to my program not using announcements to start the market this becomes irrelevant.

Agents

I have chosen to use as little agents as I could in this program. I have an agent that will be for the individual households. And an agent designed to handle the market. I have done this so that implementation of my system in the real world would be easy as possible and that should there need to be any changes made to the system it is easy to find the separate sections of the program.

Action selection and messages sent

For the agents in my system, I have the following action selection based on message it receives and the corresponding messages the agent will send based on the action selection. This will be visualized using a sequence diagram (fig 4)

<u>Household Agent</u>

- **Inform**: When the agent receives an inform message which will be sent from the environment agent the variables of the household agent is set. These variables include the kilowatts of energy required and that have been generated and so on. This is done by a settings method in which these variables are sent through the parameters and based on the information set for each agent they will calculate whether they need to message the auctioneer market to buy or sell on the market. Should they have the correct kilowatts the agent will stop as it is no longer needed.
- **Sold:** This message is sent from the auctioneer whenever a kilowatt belonging to the agent has been sold on the market. The message will contain the value of the price that each kilowatt has been sold at and take away this kilowatt from the agents' total kilowatts to calculate the remaining kilowatts held by the agent. Should they sell all their extra kilowatts the total will match the kilowatts needed stated by the environment agent and the agent will stop as it has completed its goal.
- **Win:** This message comes from the auctioneer whenever the agents bid on the market has won a kilowatt. The logic is the same as the sold function with the difference being the kilowatt won on the market is added to the kilowatt total to calculate and determine whether the agent has the correct kilowatts. The agent will stop should the total match the kilowatts needed set by the environment agent.
- **Finish:** This message is sent from the auctioneer to state that there is either no more kilowatts being sold or bought on the market. This finish message will be sent if the agent is still looking to

either buy and there are no more sellers on the market. Or sellers should there be no more buyers on the market. The agent will then call a method to calculate how much extra or how much more kilowatts are needed and a message will be displayed on the console showing what the agent needs to do such as buying or selling to the utility company.

Auction Agent

- **Buy:** This message will add the sender of this message to the buyers list and for each kilowatt that the sender wishes to buy a new sale will be added to the sale list.
- **Sell:** The same logic is used here as with the buy action except the sender and kilowatts stated for sale will be added to the sellers list and the sales list.

The auction agent has a default action that is carried out once it has received messages from the household agents. This will set the market in motion and the agent will carry out the market function. This function loops as long as there is at least one buyer or seller on the market and sends buy and sold messages to the highest bidder and the seller of the kilowatt being sold in each market cycle. Once there are no more buyers and/or sellers the agent will send the finish message to the remaining agents on the market. The program is visualized in the sequence diagram (fig 6.) with the sequence ending with the agent either buying or selling if they do not have the correct kilowatts.

Evaluation

To test my system, I have included a feature that you can select how many agents you would like in the system. For testing I have decided to keep the number of agents low so that the testing is easy to understand. For the first test I will use five agent and the second I will use seven agents. (fig. 4,5 and table 1,2)

Experiment 1:

Setting agent variables and market stance.

For the first test of the system, I chose to use five agents. The randomize response from the environment ended with their being two agents that had the correct kilowatts so they stopped functioning as they were no longer required. The environment was left with three agents that did not have the correct kilowatts. This resulted in one buying agent that required one kilowatt and had a valuation of fourteen due to the price to buy from the utility would be fifteen. There were two agents that needed to sell excess kilowatts. The first had one to sell for a price of three which was one more than the price to sell to the utility and the other had four kilowatts it needed to sell with the valuation being five which was one more than to sell to the utility. With these results this shows that the inform and setting methods worked correctly and the messages were correctly sent to the auctioneer.

Market cycles and results

Once the household agent has carried out the tasks above the auctioneer will run the market matching the highest bids to the lowest sales. As there was only one buyer this test resulted in this buyer having bought for its original price so the second bid function could not be carried out but the kilowatt bought from the agent was the cheapest on the market showing the main function of the market was working. The correct sold and win messages were sent to the corresponding agents with a finish message being sent to the final agent who was left on the market.

Final results

Once the auctioneer agent had sent the messages back to the agents the household agents had to calculate whether their goal had been accomplished. For the two agents who bought and sold their single kilowatt on the market they responded with a statement saying they have the correct final kilowatts which shows that the program worked. For the agent that did not have the correct kilowatt total, once they received the finish message from the auctioneer agent, they calculated how much kilowatts they needed to sell to the utility which was further evidence that that the test was a success.

Experiment 2

Setting agent variables and stance

This test resulted in seven agents all without the correct starting kilowatts needed. There were two sellers, both selling two kilowatts each both with the valuation of four per kilowatt which doesn't show the market cycling through cheapest kilowatt first but this is shown in the first test. There were five sellers looking to buy fifteen kilowatts between them with prices ranging from eleven to twenty. Each agent sent their market stance and valuation to the auctioneer correctly meaning this section of the test was a success.

Market cycles and results

The auctioneer agent performed its task perfectly by selling all four kilowatts on the market to the highest bidder. Evidence of the second-bid protocol is shown as the kilowatts were sold to the highest bidder with the price being set of that of the second highest bid price. The auctioneer then sent the correct messages to each agent regarding the market state such as sold messages to the selling agents, win messages to the agent who had bought a kilowatt on each cycle and market end once all kilowatts had been sold. This shows that the auctioneer agent performed its task correctly with the market method also working correctly with the second-bid protocol being evident.

Final results

The test resulted in the agent looking to buy all four kilowatts for sale on the market at the highest price finished with the correct kilowatts along with both sellers selling all their kilowatts on the market and a message stating that these three agents had the correct kilowatts at the end of the test. Once the market had ended and the finish message had been sent to all remaining buyers, they all returned with a message in the console stating how much kilowatts they have remaining to buy from the utility. This function was shown to work in test one but is backed up in this test.

Conclusion

I believe that it is evident in the test that my program runs perfectly according to the protocols I have chosen to implement. I have focused on reducing the messages displayed which works well with the case of reducing energy consumption and bandwidth. Next time I would spend more time looking into market structure and game theory so that I may expand my knowledge on implementing the best market protocols possible. Further work could be done as made evident by Morgen E and David Wagman who state that the buying and selling could be done using blockchain technology. My only concern with not only that idea but the peer to peer selling and buying of energy in this proposed way is that how do we guarantee that the agents have the energy that they are selling or have the funds to buy the energy the need. How do we know that once the agent has bought the energy, they will receive the energy owed. This may do through a blockchain as mentioned with a smart contract handling the transactions which would be made publicly available should any problems arise (Energy trading for fun and profit buy your neighbor's rooftop solar power or sell your own-it'll all be on a blockchain, 2021).

Figures and tables

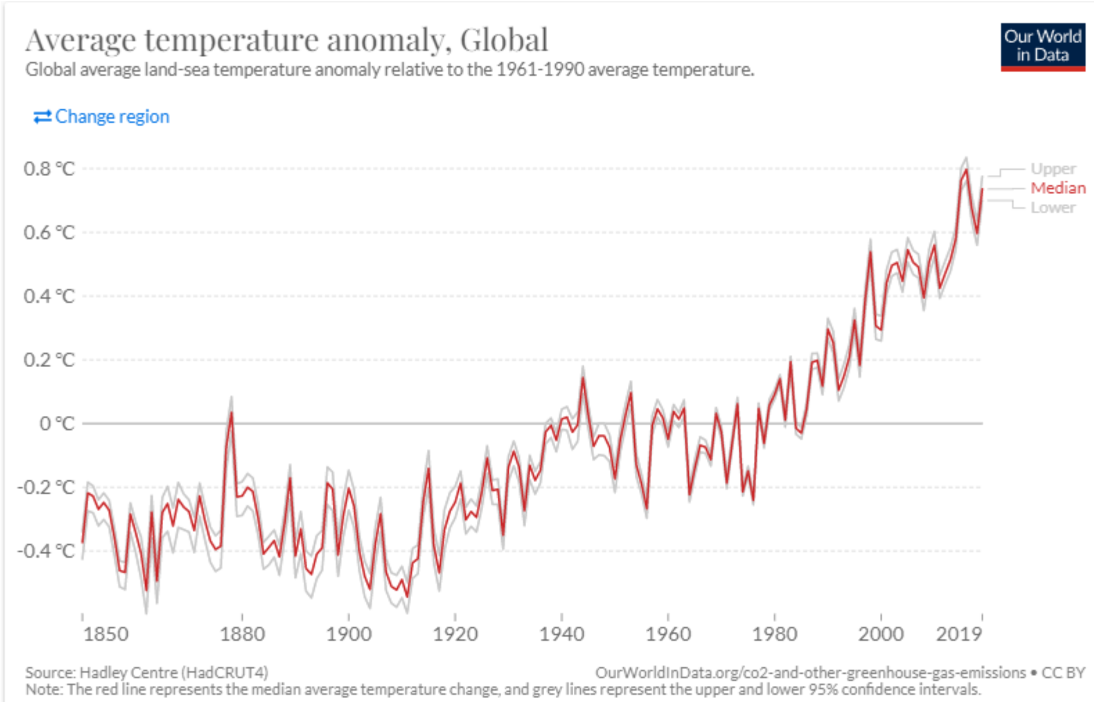

Fig 1. Average temperature anomaly – Our Word in Data

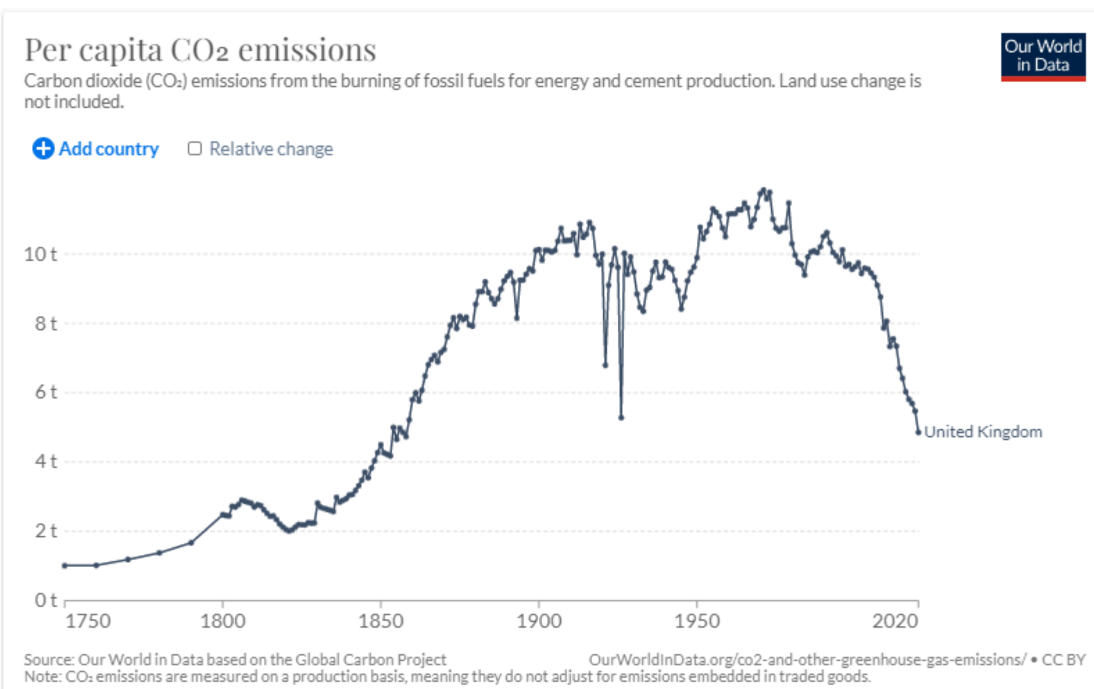

Fig 2. Average co2 emissions per capita – Our Word in Data

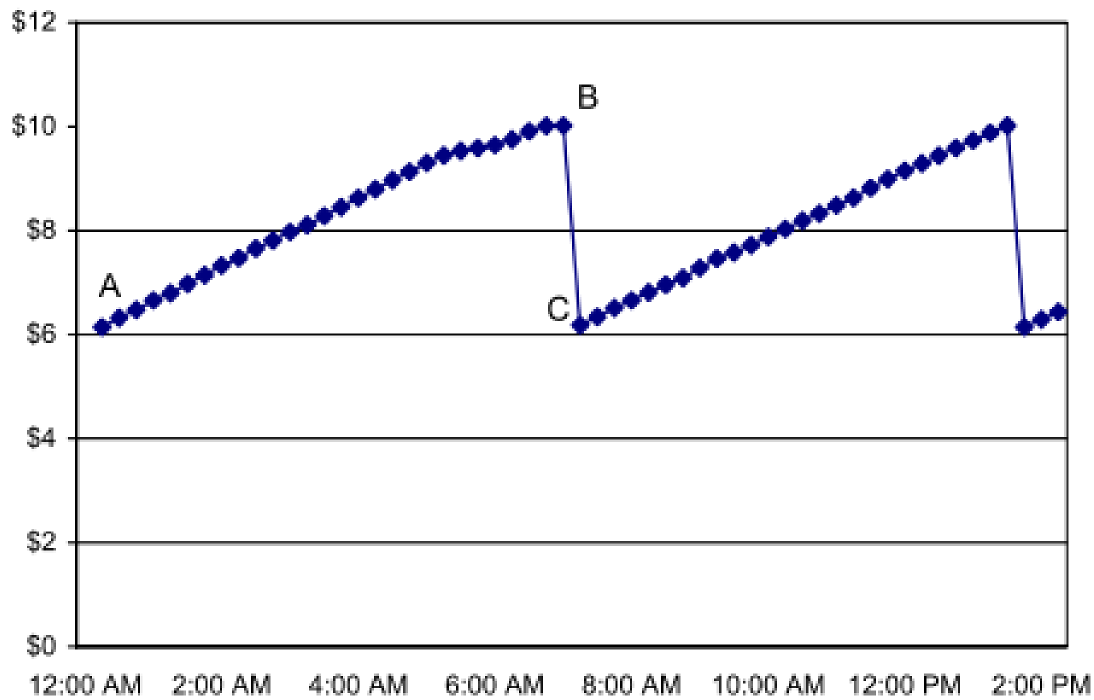

Fig 3. Price fluctuations in search engine keyword auctions - Edelman & Ostrovsky 2005

```
how many agents would you like?
5
        [enviroment -> agent05]: inform 11 11 16 3
        [enviroment -> agent01]: inform 11 11 15 2
        [enviroment -> agent02]: inform 8 12 13 4
        [enviroment -> agent04]: inform 10 11 17 2
        [enviroment -> agent03]: inform 11 10 15 2
        [agent04 -> auctioneer]: sell 1 3
        [agent02 -> auctioneer]: sell 4 5
        [agent03 -> auctioneer]: buy 1 14
removed agent03
        [auctioneer -> agent02]: finish
        [auctioneer -> agent03]: win 14
        [auctioneer -> agent04]: sold 14
[agent04]: I have correct kwh
[agent02]: I need to sell 4 to utility
[agent03]: I have correct kwh
        [auctioneer -> agent04]: finish
```

Fig 4. Results for test one

```
how many agents would you like?
7
        [enviroment -> agent04]: inform 11 10 15 2
        [enviroment -> agent05]: inform 12 8 12 3
        [enviroment -> agent02]: inform 13 12 15 3
        [enviroment -> agent03]: inform 11 6 15 4
        [enviroment -> agent01]: inform 10 6 21 3
        [enviroment -> agent06]: inform 7 9 12 3
        [enviroment -> agent07]: inform 12 14 14 3
        [agent04 -> auctioneer]: buy 1 14
        [agent07 -> auctioneer]: sell 2 4
        [agent02 -> auctioneer]: buy 1 14
        [agent03 -> auctioneer]: buy 5 14
        [agent06 -> auctioneer]: sell 2 4
        [agent05 -> auctioneer]: buy 4 11
        [agent01 -> auctioneer]: buy 4 20
removed agent01
        [auctioneer -> agent04]: finish
        [auctioneer -> agent03]: finish
        [auctioneer -> agent02]: finish
        [auctioneer -> agent07]: sold 14
        [auctioneer -> agent05]: finish
[agent04]: I need to buy 1 kwh from utility
        [auctioneer -> agent01]: win 14
[agent05]: I need to buy 4 kwh from utility
[agent03]: I need to buy 5 kwh from utility
[agent02]: I need to buy 1 kwh from utility
        [auctioneer -> agent06]: sold 14
        [auctioneer -> agent07]: sold 14
        [auctioneer -> agent06]: sold 14
        [auctioneer -> agent01]: win 14
[agent07]: I have correct kwh
[agent06]: I have correct kwh
        [auctioneer -> agent01]: win 14
        [auctioneer -> agent01]: win 14
[agent01]: I have correct kwh
```

Fig 5. Results for test 2

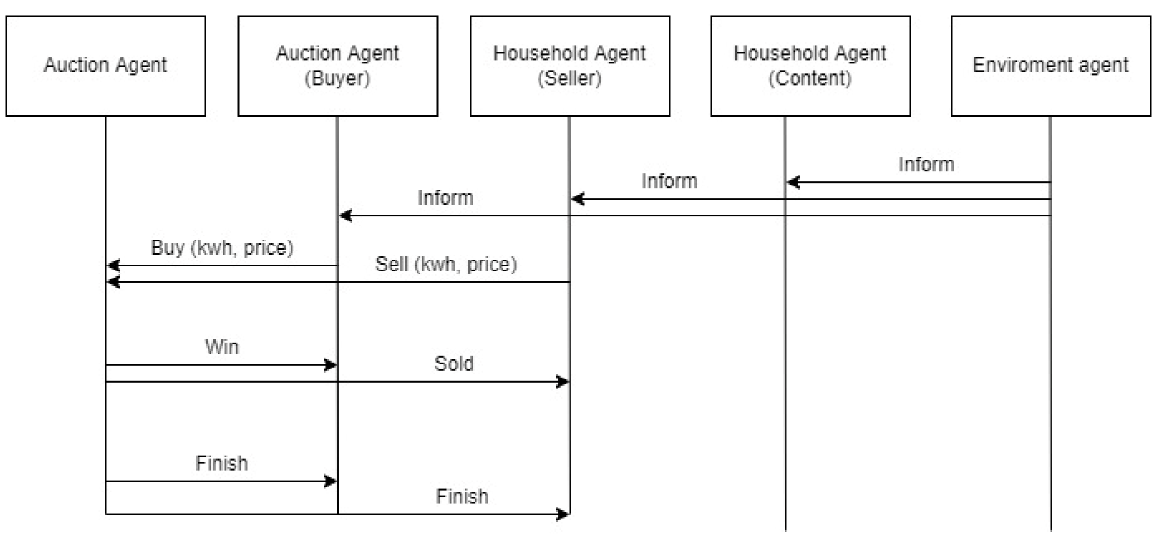

Fig 6. Sequence diagram

Agent Name	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5
KWH generated	11	12	10	11	11
KWH needed	11	8	11	10	11
Utility buy price	15	13	15	17	16
Utility sell price	2	4	2	2	3
Verdict and valuation	Correct kwh	Sell 4kwh for 5	Buy 1kwh for 14	Sell 1 kwh for 3	Correct kwh
Market result	N/A	Sold 0	Bough 1 for 14	Sold 1 for 14	N/A
Final results	Correct kwh	4KWH needed from utility	Correct kwh	Correct kwh	Correct kwh

Table 1. Test 1 results

Agent Name	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5	Agent 6	Agent 7
KWH generated	6	12	6	10	8	9	14
KWH needed	10	13	11	11	12	7	12
Utility buy price	21	15	15	15	13	13	14
Utility sell price	3	3	4	2	3	3	3
Verdict and valuation	Buy 4 KWH for 20	Buy 1 KWH for 14	Buy 5 KWH for 14	Buy 1 KWH for 14	Buy 4 KWH for 22	Sell 2 KWH for 4	Sell 2 KWH for 4
Market result	Bought 4 for 14	Bought 0	Bought 0	Bought 0	Bought 0	Sold 2 for 14	Sold 2 for 14
Final results	Correct kwh	1 KWH needed from utility	5 KWH needed from utility	1 KWH needed from utility	4 KWH needed from utility	Correct kwh	Correct kwh

Table 2. Test 2 results

References

1. Climatecommunication.org. 2021. *Climate Communication | Overview*. [online] Available at: <https://www.climatecommunication.org/new/features/extreme-weather/overview/> [Accessed 3 December 2021].
2. Ipcc.ch. 2021. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation — IPCC*. [online] Available at: <https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/> [Accessed 3 December 2021].
3. Ritchie, H. and Roser, M., 2021. *CO_2 and Greenhouse Gas Emissions*. [online] Our World in Data. Available at: <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions?source=post_page-----47fa6c394991-----------------------> [Accessed 3 December 2021].
4. Xplqa30.ieee.org. 2021. *Energy trading for fun and profit buy your neighbor's rooftop solar power or sell your own-it'll all be on a blockchain*. [online] Available at: <https://xplqa30.ieee.org/document/8048842/> [Accessed 3 December 2021].