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Womanium Quantum Hackathon 2022

Green Qupermarket

by Deloitte Quantum.Link

Figure 1: an example illustration of the Quantum.Link challenge[1]

1. Goal of the Green Qupermarket Challenge

The goal of the Green Qupermarket challenge is to analyze how quantum technology can optimize the energy consumption model of supermarkets in regard to its CO_2 emissions. The challenge scenario features a supermarket, multiple electric vehicles, and various weather conditions. The energy management of the supermarket is to be optimized so that the total CO_2 emission is minimal by using the green decentrally generated energy out of electric vehicles. The batteries of the electric vehicles can be used as additional storage capacity. A detailed problem motivation as well as a description of the constraints is presented below.

Please be aware that assumptions and simplifications were made for this challenge to enable the creation of a concept and a quantum-based algorithm within the given time frame.

2. Background

In this chapter the background information about solar power systems for supermarkets, electric vehicles, and the challenge itself are given.

[1] Image source, *GreenBuddies News*, GreenBuddies

2.1 Solar Power and Supermarkets

Solar power plays an important role regarding sustainability. Supermarket operators spend 1.6% of their annual net sales on energy[2]. Through the usage of a solar power plant supermarkets can generate their own renewable electricity. The supermarket can not only generate energy but also save their energy within a battery system, sell their solar power to customers such as providing charging stations, or providing the excess electricity to the grid provider and thus increase the share of renewable energy within the grid. Thus, our hypothesis is that the utilization of solar power systems can minimize operating and energy costs.

2.2 Charging Station as A Key Factor reducing CO_2 Emissions

In Germany, electric mobility is getting more popular because it can reduce the emissions of greenhouse gas and particulate matter[3]. Charging infrastructure plays an import role in incentivizing the usage of electric vehicles. Since 2018, the German Federal Ministry for Economic Affairs and Climate Action has provided a range of measures to accelerate the development of electric mobility: purchase grant (environmental bonus), support for the roll-out of charging stations, more electric vehicles in the public-sector vehicle fleet, and extension of the vehicle tax exemption[4]. For the spread of charging infrastructure, many German discount supermarkets have put massive efforts: Lidl has set up a charging network with 400 charging stations, Aldi Süd has set charging points in 100 locations, and Kaufland has set up 200 charging stations[5]. Therefore, using these charging stations for a supermarket's energy management is not only feasible but also attractive to utilize decentralized power generation.

2.3 The Quantum.Link Challenge

In the Quantum.Link challenge scenario, you play the role of an energy manager of the Qupermarket located in Quremberg in Germany. In Quremberg, local residents drive electric vehicles in which 20% of them charge from plug at home and 80% of them using the solar power system as energy source. In the Qupermarket, there are several charging stations that can be used to charge or discharge electric vehicles. To make an efficient usage of energy in environment friendly way, your mission is to optimize the usage of electricity because the Qupermarket can get electricity from their solar system, when residents discharge their vehicles, and use electricity directly from plug. The CO_2 emissions of these options increase in order.

3. Data

This chapter presents the information of the weather data, the Qupermarket data, the electric vehicles data, and the CO_2 emissions. The data of this challenge represent a forecast based on the experiences of Qupermarket.

3.1 Weather data

The sheet "General Data" in the attached excel file presents the weather data of March in Quremberg. The average of sunshine hours in March in Quremberg is 6 hours, which affects the produced electricity. The cells E11, F11, G11, and H11 show the different values of produced

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[2] Source: *Why Supermarkets Should Switch to Renewable Energy*, SMA

[3] Data source: *Anteil der Elektroautos am Bestand der Personenkraftwagen in Deutschland von 2012 bis 2022*, statista

[4] For the details, see *Electric mobility in Germany*, German Federal Ministry for Economic Affairs and Climate Action

[5] Source: *Charging Networks for Electric Vehicles*, MARKETS

electricity in kilowatt (kW) based on the weather condition. The weather conditions are night (0 kW), rain (50 kW), cloudy (80 kW), and sun (180 kW).

The sheet "Weather Data" in the attached excel file presents a series of weather data in terms of weekday. Each weekday contains 48 half-hourly weather data to work with.

3.2 Qupermarket Data

The Qupermarket is a supermarket, which has a shopping area of 2000 m² and a parking area of 1500m²; contains its own solar plant with 3500 m² covered by panels, batteries for the storage of electricity with a capacity of 500 kilowatt-hour (kWh) and DC fast charging stations. The opening hours of the Qupermarket are 8.00 am to 10.00 pm, Monday to Saturday.

The solar power system of the Qupermarket produces on average 70 kilowatt (kW). Consequently, Qupermarket's Solar Power Plant generates 1680 kWh per day. For the daily operation such as lighting, freezing and frozen storage and cashier system, the Qupermarket needs 0.86 kWh per square meter for each day[6] on average. Therefore, it needs 1720 kWh per day. In this respect, the Qupermarket requires 120 kWh per hour in the opening hours and 24 kWh per hour in the rest hours. The data of the Qupermarket can be found in the sheet "General Data" of the attached excel file.

3.3 Electric Vehicles Data

For the simplification, we assume the residents in Quremberg drive same model of electric vehicles. The specifications of this model are as follows:

- battery capacity: 60 kWh,
- charging and discharging rate (by DC fast charging station): 120 kW,
- full charging time (by DC fast charging station): 30 mins.

The data above can also be founded in the sheet "General Data" of the attached excel file. The sheet "Car data" in the attached excel file presents the numbers of consumer vehicles per day. Each of the electric vehicles has an arrival time (column C), battery status on arrival (column D), departure time (column E), and minimum battery status on departure (column F).

3.3 CO_2 Emission Data

In Quremberg, the Qupermarket has three options to get the electricity: (1) use solar power system (2) get electricity from plug (3) use electricity from discharging.

The following tables lists the CO_2 of different energy sources:

	CO_2 Cost (g/kWh)
Plug	420[7,8]
Electric Vehicle (discharging)	84
Electric Vehicle (charging)	-84
Solar Power System	0[9]

[6] Data Source: Stromverbrauch im Lebensmitteleinzelhandel in Deutschland in den Jahren 2016 bis 2021, statista

[7] Data source: *Entwicklung des CO2-Emissionsfaktors für den Strommix in Deutschland in den Jahren 1990 bis 2021*, statista

[8] Data source: Entwicklung der spezifischen Treibhausga-Emissionen des deutschen Strommix in den Jahren 1990-2021, Umweltbundesamt

[9] Data source: *Emissionsbilanz erneuerbarer Energieträger 2020*, Umweltbundesamt

In the scope of this Quantum.Link challenge, the generated CO_2 emissions in terms of the installation are ignored for all energy types. Since 80% of electric vehicle owners use solar power systems to charge their car while 20% owners use energy from the plug and Qupermarket has no way of distinguishing these two. Therefore, we assume this mix for every car.

The Qupermarket also has the option to charge electric vehicles. Vehicles charged by Qupermarket don't use the general energy mix in cars. Since the cars will still use the same amount of energy, Qupermarket prevented them from using the usual electric vehicle energy mix so 84g CO_2/kWh are not generated. This leads to the Qupermarket saving this amount if it uses solar energy to charge the car or increase this amount by 336g CO_2/kWh if it uses energy from the plug.

If the surplus of energy is not used to charge the Qupermarket's battery, charge vehicles of customers or balance the Qupermarket's consumption will be lost.

4. Mathematical Description

In this chapter, we provide a mathematical formulation of the Quantum.Link challenge and its description.

4.1 Cost Function

The cost function for the total CO_2 emissions is defined as:

$$f = \sum(C_{Plug} + C_{Electric\,Vehicle\,(discharging)} + C_{Electric\,Vehicle\,(charging)} + C_{Solar\,Power\,System}),$$

where C_{Plug} is the resulting CO_2 emission by using electricity from plug, $C_{Electric\,Vehicle\,(discharging)}$ is the resulting CO_2 emission by using electricity through discharging, $C_{Electric\,Vehicle\,(charging)}$ is the CO_2 emission for the charging of electric vehicles, and $C_{Solar\,Power\,System}$ is the resulting CO_2 emission by the using solar power system.[10] The aim of this challenge is to minimize the cost function f in terms of energy utilization.

5. Challenge Tasks

To successfully complete this challenge please complete one of the following task sets (Quantum Tasks or Business Tasks). The evaluation for both task sets will be independent from each other and there will be a winning team announced for one task set each.

5.1 Quantum Tasks

1. Create a quantum algorithm, a quantum hybrid solution or a quantum inspired solution addressing the optimization of the utilization of electricity with respect to a minimum CO_2 emission. The solution shall be able to build optimized charging/ discharging schedules of electric vehicles so that the utilization of energy by Qupermarket is efficient.
2. Demonstrate a (scale down) version and present the concept of your quantum solution, which can be executed on a quantum computer or simulator.
3. Compare your quantum solution to a classical approach and describe advantages and disadvantages of both approaches. Evaluate the performance difference of your solution vs a classical approach.

[10] In our case CSolar Power System will always be 0.

4. Discuss the requirements for your solution to be implemented in real life and give an estimation of the time horizon. Requirements can e.g. be the number of logical qubits needed, necessary coherence times.
5. Give an overview of your research and the resources used during the challenge.

5.2 Business Tasks

1. Develop a price model for charging and discharging of electric vehicles taking into account CO_2 emissions and dependency of demand and supply on weather conditions.
2. Develop a corresponding business model based on your price model, which should consider the infrastructure of quantum hardware, e.g. quantum as a service fee (QAAS).
3. How many tons of CO_2 emissions are expected to be reduced by your business model?
4. Analyze the following aspects in terms of your business model:
    a. Scalability of your business model
    b. Who will be your target customers?
    c. How large is the size of the total addressable market (TAM) in energy industry? How large is the serviceable available market (SAM)? How large is the serviceable obtainable market (SOM)?
    d. Market entry barriers
    e. Who will be your competitors?

5.3 Evaluation Criteria

The challenge will be evaluated using the following evaluation criteria:

- Number, comprehensiveness, and adequacy of fulfilled tasks considering the challenge aim and setting. – 20%
- Degree of innovation of the approach, concept, and algorithm including creativity and originality. – 25%
- Feasibility, usefulness and functionality of the approach, concept, and algorithm –25%
- Quantum community impact – will your solution lead to progress within the quantum community e.g. create new applications or projects, spark discussions, increase public interest and knowledge about quantum? - 15%
- Presentation and structure of the results – 15%