Campus solar roads: Optimization of solar panel and electric charging station location for university bus route

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1 INTRODUCTION

We explore the prospect of replacing conventional university campus buses powered by fossil fuels with ones using solar energy. The proposed research investigates the emerging technology of solar powered road panels within a stochastic framework in order to optimally determine the corresponding infrastructure requirements for a university circulator line. More specifically, an optimization model is developed in order to determine the optimal locations for solar-powered roadway segments and electric charging stations for the existing university campus bus route. Since the availability of solar energy is linked to sunshine levels, we explore the possibility storing the energy to depots to allow operation in days with no sunshine. Three scenarios are being developed for the collection and use of solar energy: a) bus stations covered with solar panels b) cover open spaces with solar panels and c) pave the road with solar panels. In order to account for the uncertainty associated with the system inputs, the transportation demand for the campus route and the availability of solar energy over the campus area are simulated using stochastic methods. The capital cost and energy consumption of the selected buses, charging stations and solar panels are also investigated in a case study for the NTUA campus.

2 SCENARIO 1: SOLAR BUS STOPS

The route of electric buses is the same as that of conventional ones. The number of conventional bus routes is 66 per day. The route is cyclical and joins the M3 metro line to the university. There are **19 bus stops**, some of them outside the campus. In this scenario, bus stops are covered with solar panels that collect and transport the energy to the buses. So we are looking at whether the energy produced by the solar panels is sufficient to carry out these 66 routes per day.

Images 1 & 2: Display of solar bus stops (zdnet & www.alibabab.com)

The area of each bus stop is 11,875 m² and the area of a commercial solar panel is 1,937 m². Thus, six solar panels can be installed in each bus stop (11,875/1,937=6,13), 114 solar panels at all stops. Average solar radiation at the campus per year is 1,169 MWh/m², therefore **the solar energy per year** at the area of all bus stops (11,875*19=225,625 m²) is **263,75 MWh**. The performance of a panel is 13%, hence the production of electricity in the year is 34,29 MWh. The itineraries are 239 days a year, so for each day of operation are required 34,29/239 = 0,143 MWh = **143 kWh.** An electric bus requires an average of 1.35 KWh/km, the 66 routes per day are 495km, that means that the total amount of energy required is 495*1,35= **668,25 kWh/day**. We conclude that the solar panels at the bus stops **do not** provide enough energy to operate the buses.

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3 SCENARIO 2: OPEN SPACE WITH SOLAR PANELS

There is an abandoned open parking inside the campus with a size of 3014 m². The area of a commercial solar panel is 1,937 m², therefore the total number of panels installed in the area is 1555. Average solar radiation at the field per year is 1,1 MWh/m² and the solar energy per year at the area is 1,1* 3014=3315,4 MWh. The performance of a panel is 13%, so in one year 431MWh can be produced. For 239 days of operation, the photovoltaic park can **generate** 431/239= 1,803MWh/day or **1803 kWh/day**. The total amount of energy required for 66 routes a day, that is 420 km, is 143 kWh. That means that the produced energy is enough to cover the consumption of the buses. We examine two possible ways of charging the fleet.

Image 3: Display of charging area (www.proterra.com)

First one is charging them **overnight**. In this method, solar energy is collected in the daytime, converted to electric power and stored in depots. The buses charge overnight and are ready to go the next day. An average time of charging through a 60 kW depot is 6 hours. It requires a big battery for the bus which causes extra weight. This scenario ensures **credibility** in running the routes but it requires a lot time for the charging, which in this case it's not a problem, because all the itineraries are through the day time. We suppose a fleet of **6 buses**, that means 11 routes and 82,5km per bus. The itineraries are 15 hours a day, so the whole fleet **needs 1671 kWh/day**, an amount the solar park can produce.

The second way of charging is **stationary**. In this scenario, we form 3 groups of 2 buses. Each bus runs for 2,5 hours and each group for 5 hours. This is accomplished by overlapping the itineraries of the 2 buses. An average time of charging is 2,5-4 hours depending on the depots. A 125 kW power charger can achieve full charge in under 3 hours. In this case we can charge the first group the day before and the second one during the operation of the first. As for the third group, we can charge the first two buses during the operation of second ones, in this way we eventually use **4 vehicles** but in the same amount of time, saving money from buying six buses. The energy required is the as the first scenario because the covered kilometers are the same.

4 SCENARIO 3: SOLAR ROADS

The third scenario considers the selection of parts of the whole road network of the NTUA Campus, in order to build solar roads to collect solar radiation and power the bus network. To select these parts, we created a GIS Map, which shows the percentage of solar radiation annually on the roads.

Image 4: GIS map displaying solar radiation at the roads of the campus, red color for the highest and yellow for the lowest.

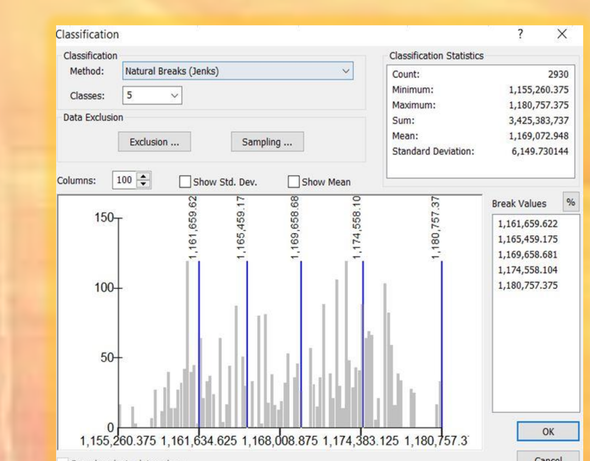

Image 5: Levels of radiation annually per m² at the campus.

Based on that map, we chose **4 parts of 300 meters in length and 8 meters in width** (the area is 2400 m²) at the parts of the road where the solar radiation is the highest. The area of a commercial solar panel is 1,937 m², therefore the total number of panels installed in the each area is 1238. Average solar radiation at the campus per year is 1,169 MWh/m² and the solar energy per year at the area is 1,169*2400= 2805,6 MWh. The performance of a panel is 13%, so in one year 364.728 MWh can be produced. Adding the performances of all 4 areas, we have a total of **1458.912 MWh** per year. For 239 days of operation, the solar roads can produce 1458.912/239= 6.104 MWh/day or **6104 kWh/day**. The electric buses will be charged as they drive on the solar roads by induction. The solar energy will be stored in depots by the solar road parts. There is a depot that will be placed close to the start of the route and it will charge the buses, so they can have the energy to reach the solar road and charge by deduction. Hybrid buses would be the best solution, in order to account also for the days of no sunshine and solve the problem of the first dead kilometers.

Image 6: Display of a solar road in France (www.theconversation.com)

5 COMPARISON OF THE THREE SCENARIOS

Starting with the solution concerning the solar panels on bus stops, the energy required for the system is not provided by the number of panels. The solution with the parking area is the most cost efficient one, if we consider the energy provided, which is enough to feed the system. Stationary charging allows the most effective use of the buses, as we can use 4 of them instead of 6 that we use in overnight charging. The technology of solar roads is groundbreaking and provides a great amount of energy but also has many flaws, such as being really expensive not only to build but also to maintain. The panels on the road can be easily broken or ruined and the dust that will cover the surface of the panels will lower the percentage of radiation absorbed. Therefore, the open space scenario has the most advantages, as it combines efficient cost and high energy generation.

Indicatively the costs for each of the three scenarios amount to:

SOLAR PANELS	m^2	€ /m^2	RESULTS (€)
Open space	3014	270-330	843920
Solar bus stops	226	270-330	63280
Solar roads	2400	400-500	1080000

Table 1

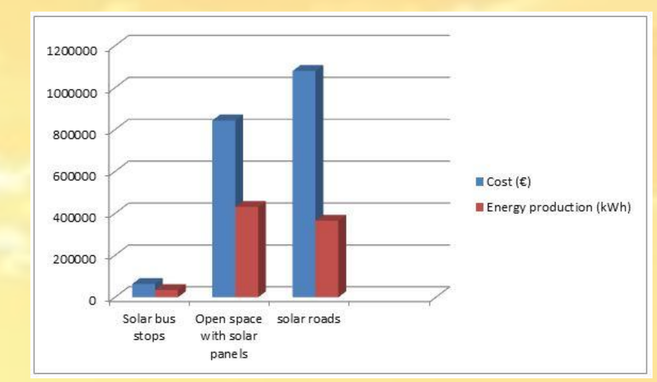

Image 7: Comparison of cost and energy generation/year

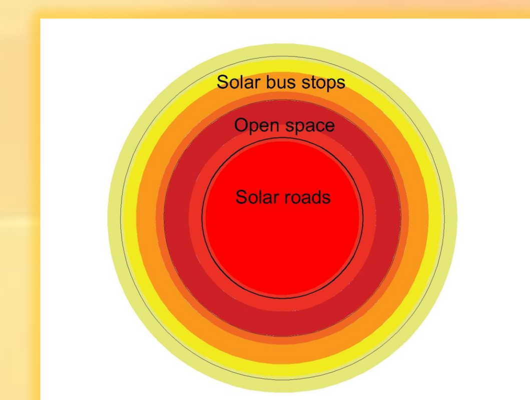

Image 8: Representation of the generation of energy for each scenario. The color represents the amount of the energy. Red for the highest generation, light red for sufficient and yellow for the lowest generation.

6 CONCLUSIONS

Solar energy is an important source of renewable energy but the capabilities of today's technologies to convert it into electricity are small. The electric buses require a dedicated charging equipment and infrastructure for their operation, in difference to diesel buses. Despite the high construction and operating costs, it is important to turn to alternative ways of producing energy, as oil reserves are decreasing and environmental impacts due to fossil fuels use are increasing.

The results of the project show that a **large area is needed so that the energy produced suffices for the bus route**. Of the three scenarios **the best in terms of energy generation is the solar roads**; however, it is very costly, which makes this scenario infeasible with current conditions. **Solar bus stops deliver minimal energy**, while the scenario of **solar panels in open space looks more cost-effective and energy efficient**. However, the high procurement costs and the lack of funds won't make it easy to happen until the technologies have become less costly.

Nonetheless this project helps the student community to familiarize with renewable energy sources and sustainability. Also, the development of infrastructure for electric buses has an additional advantage as a **pilot project showcasing pros and cons of this technology**.

7 REFERENCES

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This work is part of a collaborative student project and was conducted with those in References [5,6].