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Report on Component 2 of the Project: "E-micromobility in Ghana - Promoting Local Business Models for Electromobility and Decentralized Energy Systems " (81274624)

10.12.2021

Dear Mrs. Krieger,

We present to you and your team the fulfillment of work packages pertaining to the second component of the E-micromobility in Ghana project which covers the feasibility of various sustainable mobility offers on the Tema Export Processing Zone Enclave.

We firstly express our gratitude to the team for the opportunity to work together on this pilot project and envision a longer-term cooperation in the development of sustainable mobility in the industrial development of Ghana. The report focusses on the objective of analyzing the feasibility of providing an alternative mobility offer to the processing enclave powered by renewable energy sources with the following sub-components as detailed in the project description:

- Analysis of local conditions in the processing enclave and determination of user requirements for mobility devices.
- Quantification of the environmental and economic benefits of the sustainable mobility product system
- Analysis of the potential use of a sustainably powered electric bus system on the processing enclave.
- Feasibility study of the enclave for the installation of solar mini grids for the energy needs of office buildings, low energy applications and electrically powered mobility devices.
- Feasibility study on the use of light electric vehicles for the delivery of materials, food and staff with stand-alone solar charging stations on the processing enclave
- Qualification and maintenance concepts for electromobility devices, charging stations and associated equipment.

It is our hope that the submitted report addresses these thematic areas and provides a roadmap for sustainable mobility for the processing enclave and other such industrial parks in Ghana. We look forward to the implementation of these concepts to further embed sustainable mobility in Ghana´s industrial development.

Warm regards,

Frederick Adjei

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Introduction

About the E-micromobility in Ghana Project

The population and prosperity of the Republic of Ghana is growing. With the economic development, the demand for mobility services is increasing, which exists mainly for cars and mopeds. At the same time, these vehicles cause and add to high environmental pollution, which creates opportunities for more environmentally friendly alternatives through e-mobility. However, in order to improve the environmental impact, it is important that the energy required for supply is obtained from a renewable source.

Despite the positive economic development, unemployment and especially youth unemployment is both a societal and political problem in Ghana. The problem is particularly pronounced in the formal sector where economic growth across board has not translated into increased number of jobs. It is therefore prudent to look at solutions that cover the needs of mobility, energy access and supply whiles having a positive impact on employment.

Objectives

The E-micromobility in Ghana project aims at finding solutions to growing mobility demands and environmental stress by deploying solar charging stations to power Light Electric Vehicles (LEVs) on the project site Kwame Nkrumah University of Science and Technology-Kumasi and the University of Energy and Natural Resources. Additionally, makerspaces dedicated to the research and application of electromobility topics will be established on both campuses. A further objective of the project is the deployment of LEVs on the Tema Industrial Processing Zone for which feasibility studies are currently underway.

Approach

As a starting point for up-scaling, the project would be first implemented on the campuses of the partnering universities (KNUST and UENR). Here the universities would provide the e-mobility offer to students, staff and visitors, making it possible to develop a suitable business model and to create the necessary job positions for administering and managing the product system. Alongside the implementation of the shared LEvs; sustainable mobility workshops, student exchanges, thesis research, guest lecturing will also take place between the three partner universities to ensure knowledge exchange and transfer. Construction of makerspaces on electromobility research will bring together academia, private sector and government to create the environment to foster the growth of business models and value chains in the e-mobility sector.

In the Tema Industrial Processing Zone, the first steps would be to assess the feasibility of replacing energy sources for offices and facilities with solar mini grids that can be used by all represented companies on the park. Feasibility studies on the use of LEVs and eBuses with off-grid solar charging stations to foster sustainable mobility of staff and industrial materials will also be conducted. Additional information and updates are available on the project's website here

Media from field trips undertaken by the research team can as well be accessed here

Report on the results of Work Packages

Overall Objective: To extend an alternative mobility offer to the Industrial Park area Tema, powered by renewable energy sources.

The Tema Export Processing Zone is located in Tema, Ghana's major residential and industrial city. Tema has the largest seaport in Ghana and is located about 24 kilometers from the international airport in Accra. There are many industries located in the Tema Industrial Park where there is also a concentration of skilled labor. The Tema EPZ, with a total area of 1,200 acres (480 hectares), offers investors a favorable and conducive environment for manufacturing, service and commercial export activities. It is currently operated by the Ghana Free Zones Authority and a private firm LMI Holdings Limited. The enclave has 70 registered companies with 58 currently in operation. About 9.000 people work currently across these manufacturing entities. Tema's Free Zone enclave is also linked to the airport and seaport by a road network. It is largely developed into a multipurpose industrial park to enable non-free zone investors to have access to the industrial site to boost their production capacities.

The provision of an alternative mobility offer is intended to be achieved through procurement of eBuses as they allow for safe and sustainable transportation of workers within the industrial park. The buses are to be powered by solar grids to ensure reliable and sustainable energy provision. In order to ensure reliable functioning, accordance with local conditions as well as with user requirements, several analyses were conducted as part of work package 1. A detailed description of each analysis can be found in the following chapters.

By providing a stable and reliable mobility offer, transportation within the industrial park will be facilitated, allowing people to move freely and safely. Workers will also benefit from the saving of time as they will be enabled to reach their workplace faster. These advantages will make the Industrial Park a more attractive place to work, which holds the potential to not only boost employment, but also to incentivize businesses to move their offices/production sites to the park. The employment of electric buses will further help combat air pollution and benefit Ghana's efforts to reduce their carbon emissions 15% by 2030 as well as to scale up sustainable mass transportation (Republic of Ghana 2015).

A: Analysis of Local Conditions

In order to analyze local conditions in the target location as well as user requirements for mobility devices, a survey was conducted at Tema Industrial Park. The survey was based on acceptance research methodologies with a focus on technology acceptance, and included a set of social, technical and economical questions, as well as questions that would allow conclusions regarding ecological relief and social acceptance.
The survey included a total of 20 questions and was answered by 61 participants. This group can be subdivided into 32 females and 29 males. The age division is depicted in Figure 1.

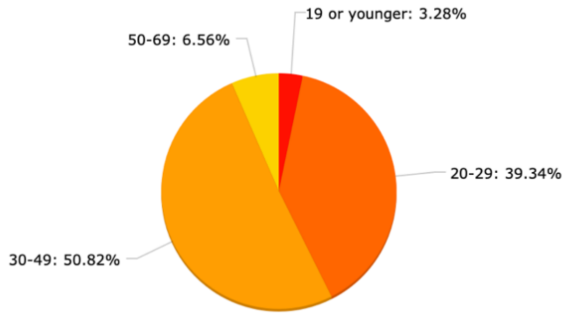


Figure 1: Age division among the survey participants (source: umfrageonline.com)

Among others, the survey showed that the majority of the participants are using trotros to get to Tema Industrial Park. Other means of transport include cars, buses, motorbikes and bicycles. Approximately seven per cent of people walk to work.

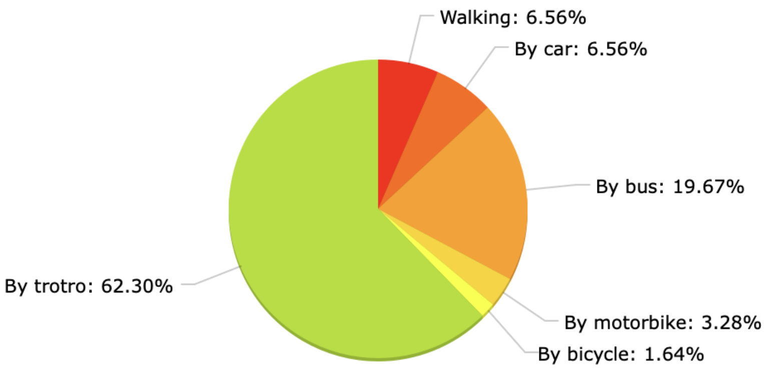


Figure 2: Selected modes of transport (source: umfrageonline.com)

The participants were also asked why they chose this particular mode of transport. It becomes evident that most participants chose the respective mode of transport due to financial reasons, or because they do not have any alternative. Only approximately sixteen per cent of the participants is able to prioritize comfort or time over costs, as shown in Figure 3.

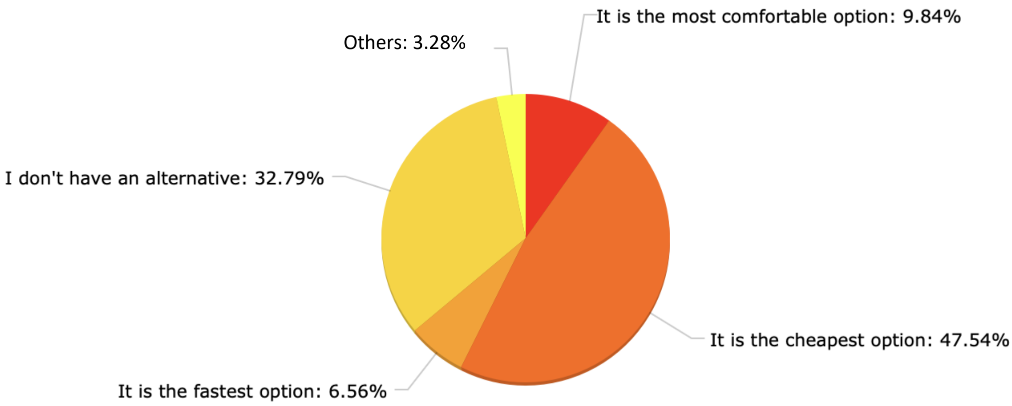


Figure 3: Reasons for using particular means of transport (source: umfrageonline.com)

The results of the survey question "Do you think a shuttle bus service in Tema Industrial Park will improve your daily transport experience?" strongly support the core idea of the *E-micromobility in Ghana* project. The responses indicate that more than 80% of participants approve, while only about 5% of participants are of the opinion that a shuttle bus service would not improve their daily transport experience.

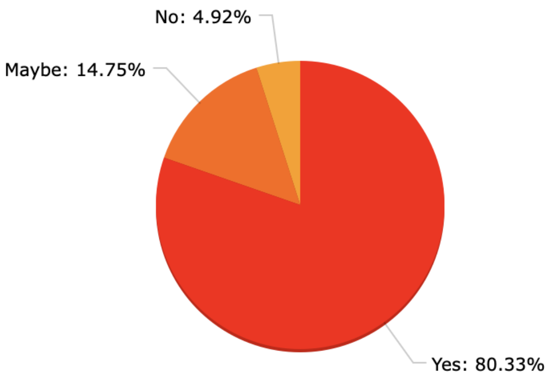


Figure 4: Do you think a shuttle bus service in Tema Industrial Park will improve your daily transport experience? (source: umfrageonline.com)

Participants were also given the opportunity to explain their response to this question. The provided answers indicate that most people assume that the shuttle bus service will come with a decrease in transportation costs. The financial incentive becomes even more evident when looking at the results of the following question: *"Assuming the costs for the shuttle bus service were as high as your current transportation costs, would you still consider using the shuttle bus service?"*

The willingness to use the shuttle bus service without any kind of financial incentive differs significantly from the responses provided to the previous question:

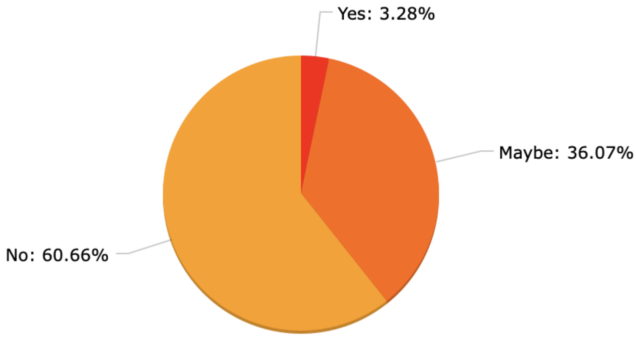


Figure 5: Willingness to use the shuttle bus without a financial incentive (source: umfrageonline.com)

The assumption that financial reasons strongly influence the willingness to use the shuttle bus service are further supported by the results to the two questions *"How much does transportation to work currently cost you per day?"* and *"How much would you be willing to pay for one ride with the shuttle bus to your workplace?"*.
The outcome of the first question is as follows:

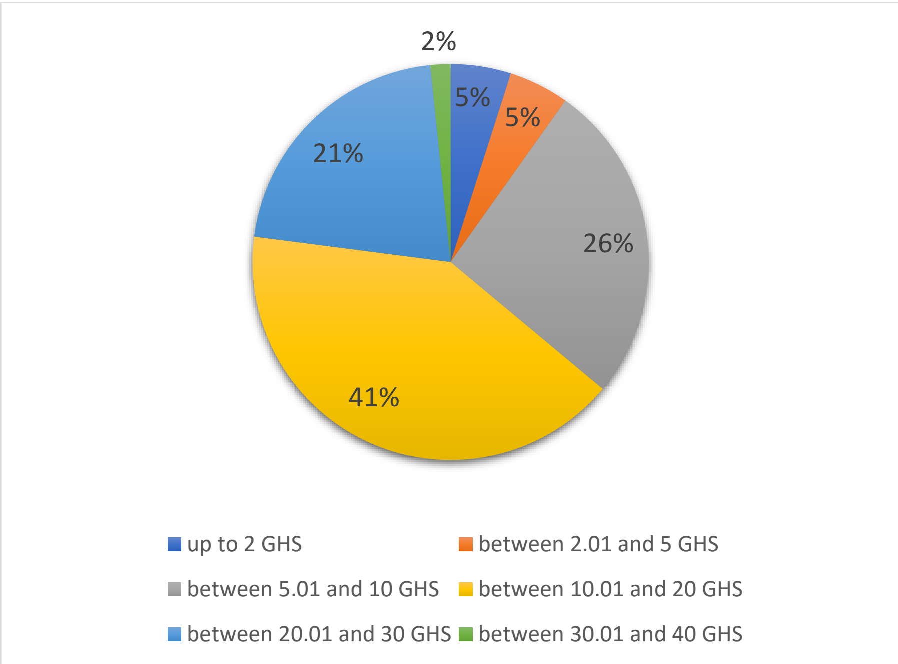


Figure 6: Current transportation costs to work (source: own illustration based on umfrageonline.com)

The responses show that more than three quarters of all participants pay 20 GHS or less for their daily transport to work. When comparing those responses to the ones provided to the question how much they would be willing to spend on the shuttle bus, it becomes clear that people are counting on a strong reduction in transportation costs when using the shuttle bus:

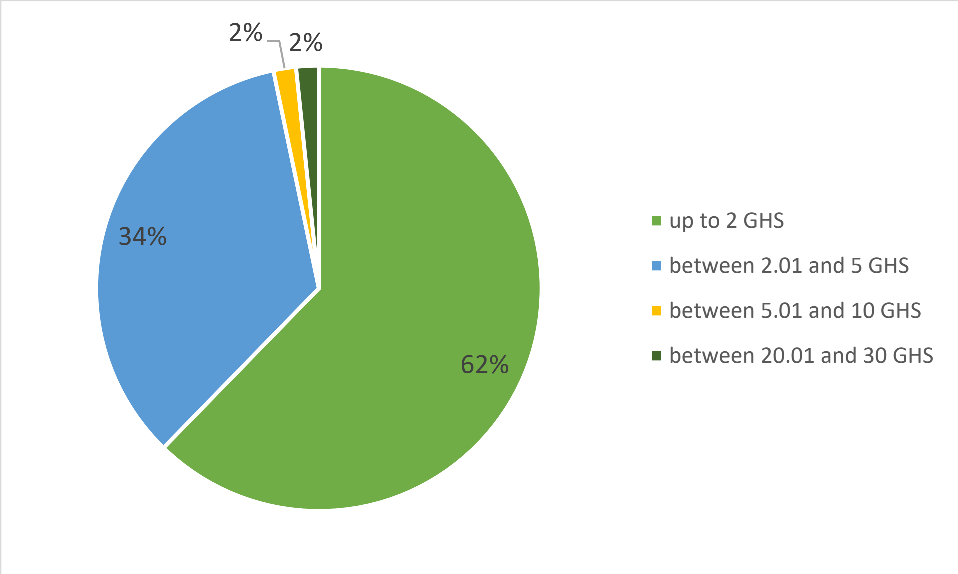


Figure 7: Willingness to pay for shuttle bus (source: own illustration based on umfrageonline.com)

The full report including all results can be found in Annex 2.

B: Analysis on the use of electric-powered buses and solar mini grids

WP 1.2	Conduct an analysis of the industrial park for solar mini grids for the energy needs of office buildings and low energy applications

This section of the report covers the feasibility study which intends to identify the local conditions in Tema Industrial Park. For this, we elaborated a collaboration with our partner Green Power Brains. A first draft of their analysis can be found attached to this report (Annex 3). Only GPB's part on possible collection points and routes is included below, as the content is relevant for further parts of this report.

Possible collection points and routes

Two routes have been identified as interesting for a pilot project. Collection points of interest are:

1. Free Zone Enclave Entry
2. Kpone Barrier Road Junction (Kpone Junction)

The first one running only within the Enclave. The second one having an additional collection point outside the Enclave.
A motorcycle taxi station is located close to the entry to the Enclave. The motorbike taxis are used both to arrive to the TEPZ entrance as well as starting point for motorcycle taxi rides to destinations inside the TEPZ.
The Kpone Junction is outside the Enclave, on the junction between the N1 Accra – Aflao Road and the Kpone Barrier Road. The Kpone Junction is a destination and stop of many Accra and Tema transportation services and is widely used by employees of TEPZ located companies.

Route 1

Starting point	Free Zone Enclave Entry
Main collection point	Free Zone Enclave Entry
Route length	10 km
Driving time without stops	30 minutes
Expected driving time with stops	45 minutes
Risk for delays	Low
Proposed serving time	5 a.m. – 8 a.m. and 17 p.m. – 19 p.m.
Route description	Route completely within the TPFZ.
Expected number of runs	Morning (5 a.m. – 8 a.m.): 4 times Evening (17 p.m. – 19 p.m.): 3 times
Total km	Morning: 40 km Evening: 30 km

Table 1: Route 1

Figure 8: Bus route 1 - short route

Route 2

Starting point	Free Zone Enclave Entry
Main collection point	Kpone Junction
Route length	16 km
Driving time without stops	30 minutes

Expected driving time with stops	60 minutes
Risk for delays	Medium (N1 Accra – Aflao Road)
Proposed serving time	11 a.m. – 1 p.m.
Route description	Route with collection point outside of the TPFZ.
Expected number of runs	3 times
Total km	48 km

Table 2: Route 2

Figure 9: Bus route 2 - long route

C: Feasibility study on the use of light electric vehicles with stand-alone solar charging stations on the processing enclave

This section of the report will cover two forms of sharing concepts, illustrating the potential of implementing a dock based and solar powered fleet of electro micro-mobility vehicles within the premise of the Tema Export Processing Zone Enclave.

1. Meal delivery vehicles for the on-site canteen
2. Employee shared mobility concept for on-site transit

Both concepts will incorporate vehicles provided by SolarTaxi and charging infrastructure provided by SunCrafter GmbH who were contracted as external consultants for the achievement of the work package. A detailed report is attached to this report (Annex 4).

D: Quantification of environmental and economic benefits

1.4	Quantification of environmental and economic benefits of the product system.

In order to quantify the economic and ecological impact of the eBuses, a literature-based Life Cycle Assessment (LCA) as well as an economic assessment using the Total Cost of Ownership (TCO) model were conducted. The aim of these analyses was to identify the potential benefits that can be achieved by substituting diesel powered buses, which are currently in use, with electrically powered buses. Please note that detailed information about the used buses and their specifications is not available at this point. Hence, this study is designed as a screening study to give an indication about economic and ecological impact of eBuses compared to diesel-powered buses. A verification of the assumptions and the calculated data will prove necessary for reliable results. Collection of real-life data is required, which could be done as part of this project at a later point in time. Once the bus has been procured, more reliable data can be collected and the results can be verified.
The approach as well as assumptions and results are described in the following chapters.

Environmental assessment

Lifecycle assessment (LCA)
Life Cycle Assessment "is an instrument for quantifying the environmental impact of technical systems (e.g., product systems) or services throughout their entire life cycle" (Schelte, et al., 2021). All production, use and end of life phases are considered in this assessment. When looking at different transport modes, an LCA encompasses among others:

- "the manufacture of the vehicle, raw materials and components (cradle to gate), including the manufacture of the vehicle itself (gate to gate),
- the use phase of the vehicle (well-to-wheel), including the generation provision of the drive energy (well-to-tank) and the conversion into kinetic energy to operate of the vehicle (tank-to-wheel),
- and the treatment or recycling of the vehicle and its components to recover raw materials (end-of-life)." (Schelte, et al., 2021)

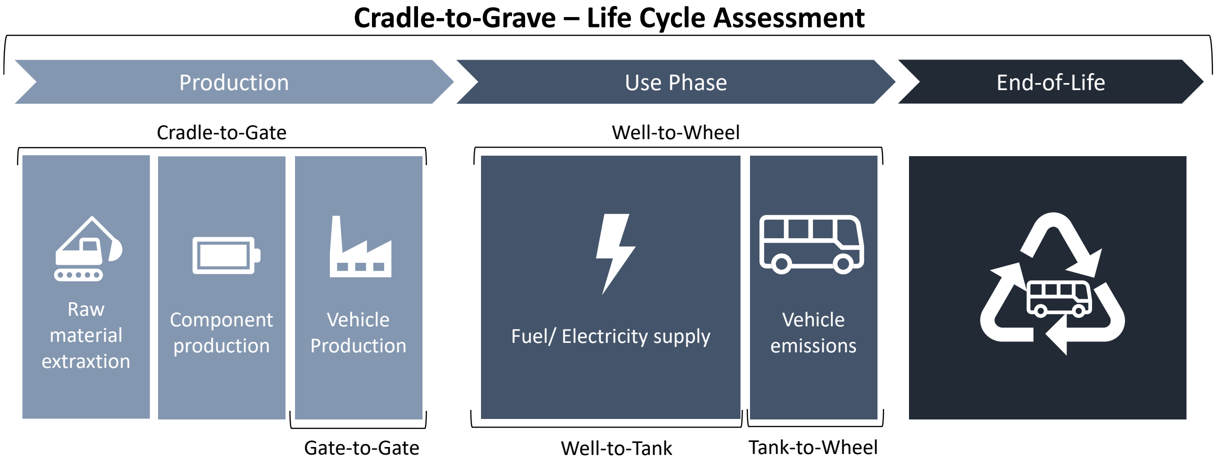


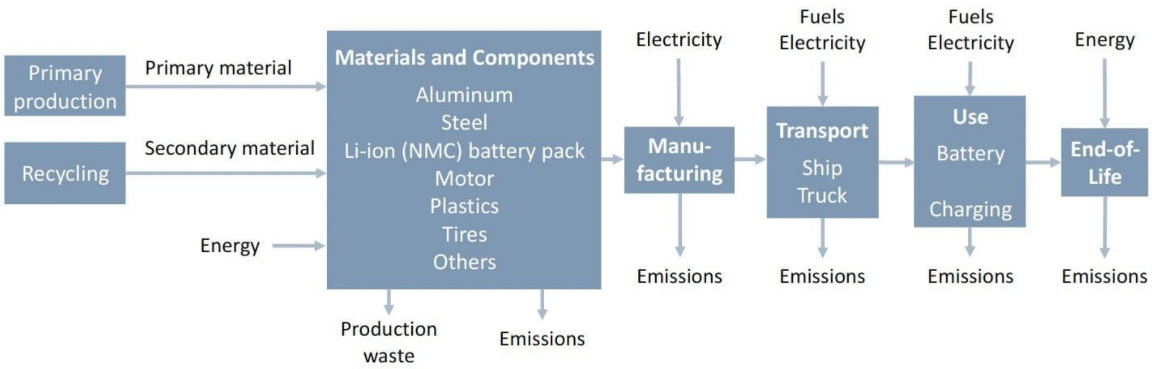
Figure 10: Phases of a cradle to grave Life Cycle Assessment of vehicles (Schelte, et al., 2021) based on (Howe & Jacobsen, 2019))

Goal and Scope

The goal of this study is to examine the life cycle environmental impact of the eBus service in Tema Industrial Park in comparison to a diesel-powered bus. Hence, this analysis looks at environmental impacts caused by different operating modes in an existing system.
The functional unit is passenger km (pkm). The main technical characteristics of the analyzed eBus and diesel bus shown in Table 3 are derived from (Anders Nordelöf, 2019).

	EBus	Diesel Bus
Vehicle Length [m]	12	12
Size Traction Battery [kWh]	76	none
Consumption [kWh/km; l/km]	1.1	0.45
Pkm per Vkm	16	
Consumption [kWh/pkm; l/pkm]	0.07	0.03
Weight w/o passengers [t]	12.8	12.5
Transport distance DE-GH [km]	8,452	
Max. passengers []	105	95

Table 3: Main technical characteristics of the analyzed eBus (Anders Nordelöf, 2019)



shows the system boundaries. We used pkm as the functional unit, and the Global Warming Potential over 100 years represented by CO_2 equivalents (CO_2e) was used as method of impact assessment.

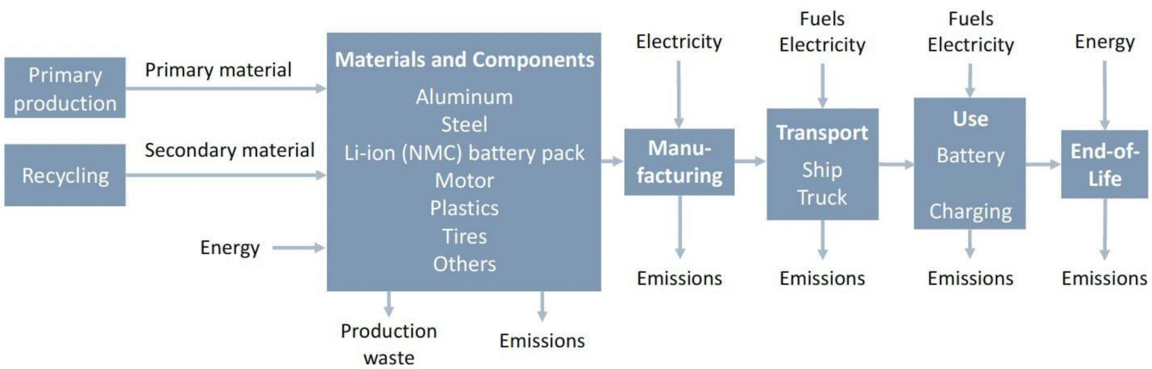


Figure 11: System boundaries

Assumptions

The analysis was conducted based on a set of assumptions. Firstly, all relevant data for the materials, the manufacturing, the maintenance, the End of Life (EoL) and the fuel consumption derives from (Anders Nordelöf, 2019). Nordelöf further assumes one battery replacement in the entire lifetime of the bus.
The transport to Ghana (Hamburg to Tema, 8,452 km) by a cargo ship was modelled using (GaBi, 2021). For the country specific Ghana grid mix a CO_2 intensity of 389 g CO_2e/kWh, for the Ghana Diesel Mix WtT emissions of 396 g CO_2e/l and for the Mini-Grid a CO_2 intensity of 55 g CO_2e/kWh was determined using (GaBi, 2021) and own calculations. The functional unit is pkm, but we also included an example using vehicle km (vkm) below.

Main Findings

Figure 12 shows an overview of the environmental impact of eBuses (both running on electricity from the solar mini grid, from the Ghanaian grid as well as the Tema Industrial Park specific mix of 31.5% Hydro and 68.5% Diesel-fuel) and of a diesel bus. While the emissions caused during manufacturing, transport to Ghana and end of life do show significant differences when comparing diesel and electric buses, the strongest driver of the overall environmental impact was found to be the emissions that occur during the tank-to-wheel phase:

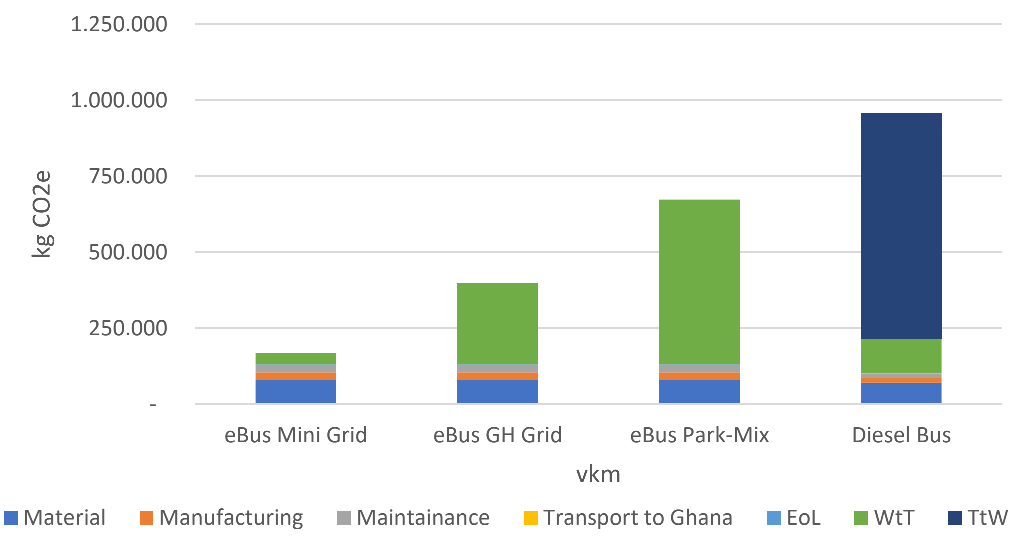


Figure 12: CO_2 emissions of diesel bus vs. eBus using the mini-grid or the Ghanaian grid mix after 10,000,000 pkm (own source based on own calculations (GaBi, 2021) and (Anders Nordelöf, 2019))

Figure 12 shows that while electric buses cause a significantly higher environmental impact during the production phase (103,750 kg CO_2e vs. 85,000 kg CO_2e for diesel buses), the emissions can be compensated during the use phase as no tank-to-wheel emissions occur. After 10,000,000 pkm, an eBus will have emitted approximately 30% less CO_2 with the Park-Mix and 58% less CO_2 with the Ghana Grid-Mix. If the bus is charged using solar power, more than 82 % of emissions can be saved.

The break-even point, however, is reached significantly earlier than after 10,000,000 pkm, as shown in Figure 13.

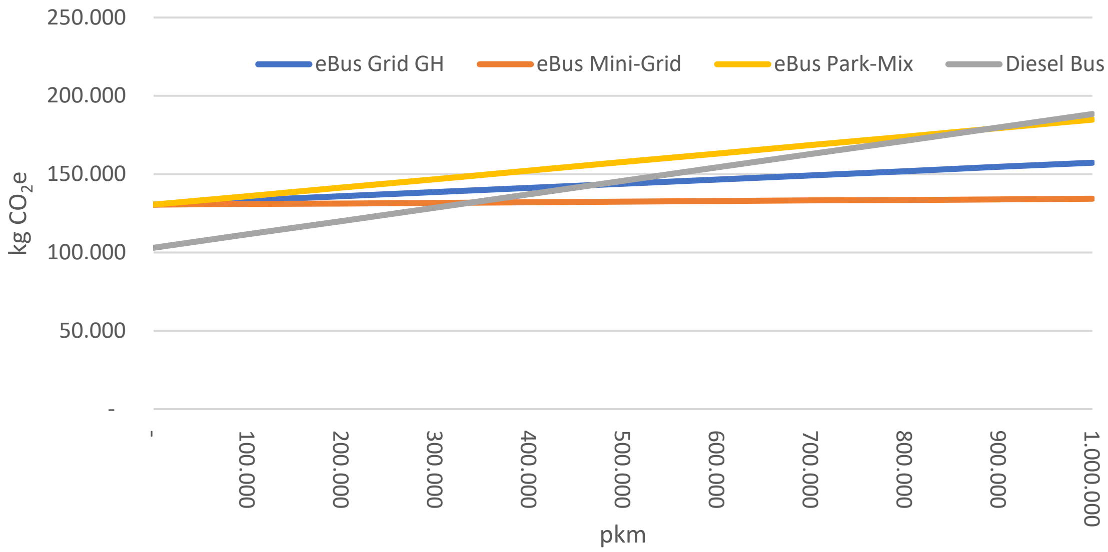


Figure 13: CO_2 emissions with increasing kilometrage in pkm (own source based on own calculations, (GaBi, 2021) and (Anders Nordelöf, 2019))

Figure 13 shows that the high emissions during production of an eBus are compensated after approximately 350,000 pkm when using electricity from the solar Mini-Grid, after approximately 500,000 pkm when using the Ghanaian Grid-Mix, and after approximately 900,000 pkm when using the Park-Mix.

To illustrate a different functional unit, Figure 14 depicts the case in vkm:

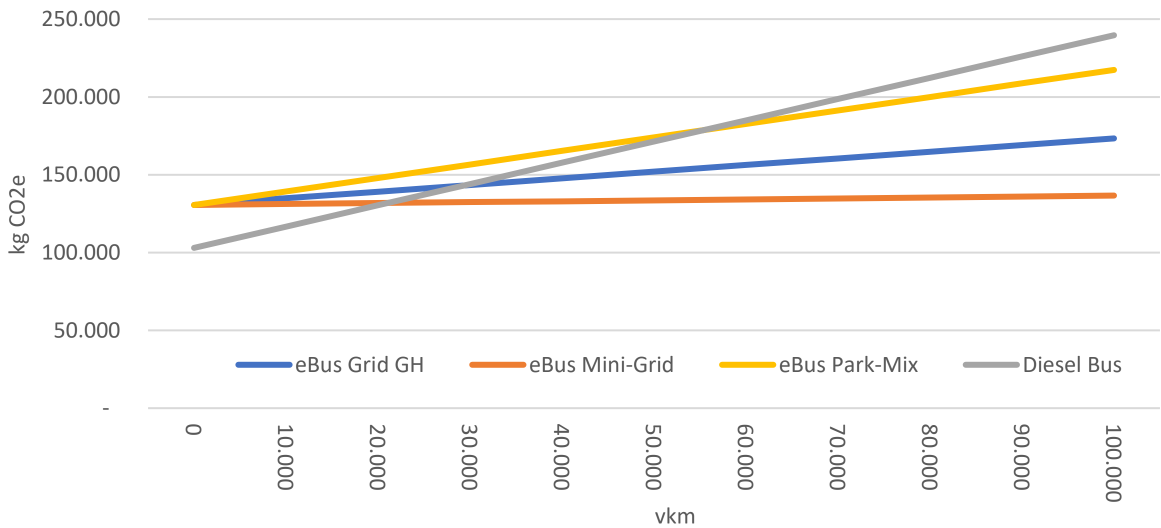


Figure 14: CO_2 emissions with increasing kilometrage in vkm

As one can see, the break-even point is reached after approximately 22,000 km when using a Mini-Grid, after 32,000 km when using the Ghanaian Grid-Nix and after 55,000 km when using the Park-Mix.

Recommendations

The results show that an eBus powered by electricity from the mini grid overall causes the lowest environmental impact. The highest emissions are caused during production and depend strongly on the size of the battery: Generally speaking, it can be said that the larger the battery, the higher the environmental impact. It is therefore crucial to find the right balance between the size of the battery that is required in terms of range and the CO_2 emissions it causes.
The emissions during the production phase of an electric bus can, however, be compensated during the use phase. The longer the bus is used, the better the overall environmental impact of the electric vehicle.
For this reason, we recommend deploying an electrically powered bus in conjunction with a mini grid. If used for at least 22,000 vehicle km (maximum two years if one of the suggested bus routes is used), this will allow for a lower-emission transport system in comparison to a diesel bus.

Economical Assessment

The Total Cost of Ownership (TCO) model served as a base for the quantification of the economic benefits of the shuttle bus service. This model looks at the purchase as well as running costs over the estimated time of ownership and divides the costs into three different stages: Acquisition Phase, Operation Phase, and Disposal Phase. Costs that amount during the Acquisition Phase include purchase costs, taxes, registration fees etc., while the Operation Phase includes running costs for electricity/fuel, maintenance, and insurance. Finally, costs that arise during battery recycling as well as salvage value credits are considered in the Disposal Phase.

Assumptions

Acquisition Phase
Following an extensive market research, the purchase price will be estimated at 300,000 € for electric buses/ 200,000 € for ICE buses for this analysis. The registration fee will amount to approximately 77 € (544 GHS) for both options. Further fees and levies that apply during this phase include Import Duty, VAT, ECOWAS, EDIF (Ghanaian Export Development and Investment Fund), NHIL, an exam, a processing fee (Ghana High Commission, 2016) and the GETFL (Ghana Education Trust Fund Levy) (KPMG, 2020). As there is no information available on the GETFL, those fees will not be considered in this analysis. It is to be assumed that the costs will not differ between an EV and an ICEV.
Interests are assumed to be 0% and are therefore excluded from the calculations. All costs including their respective value can be found in Table 4.

Operation Phase
Commercial operators of shared vehicles are obliged to pay the so-called Vehicle Income Tax (VIT). Payments are due every three months (Ghana Revenue Authority, 2021), hence the annual rate is divided by four. For a bus of up to 38 passengers, the annual rate costs approximately 23 € (160 GHS).

The electricity price currently amounts to an average of 0.14 € per kWh from the Ghanaian grid (PUBLIC UTILITIES REGULATORY COMMISSION (PURC) - PUBLICATION OF ELECTRICITY TARIFFS), while diesel prices are as high as 0.91 € (6.43 GHS) per liter (german cooperation, 2020). For the assessment, we assumed a consumption of 1.1 kWh/km and 0.45 l/km respectively. Additionally, a service fee of 10.01 € is charged monthly for using the electricity grid. This corresponds to a fee of 353.46 €/100,000 km.
Maintenance costs are expected to amount to 0.074 €/km for the electric buses and 0.13 €/km for combustion engine vehicles (Potkány, Hlatká, Debnár, & Hanzl, 2018). However, the electric bus will require a battery replacement at some point during its lifetime. These costs are assumed to amount to 19,000.00 € (Jefferies & Göhlich, 2020).
Lastly, the Operation Phase also includes running insurance costs. We assume these costs to remain unchanged between electric and fossil-fueled bus and will therefore not consider these costs in our calculation.

Disposal Phase
Once the vehicles have reached the end of their lifetime, further costs will emerge. However, these costs cannot be assumed at this stage, as it is unclear in which condition the buses will be disposed of. For this reason, these costs and credits will not be considered in further calculations.

Table 4 shows a summary of all costs described above and allows for a direct comparison between an electric and an internal combustion engine vehicle.

		EBus (Ghanaian grid)	Diesel bus
Phase	**Factor**	**Costs (€)**	**Costs (€)**
Acquisition Phase	Purchase price (including charging station)	300,000	200,000
	Registration fees	77	77
	Import Duty	0% if bus is "designed to carry thirty (30) or more persons" (Ghana High Commission, 2016) → 0	0% if bus is "designed to carry thirty (30) or more persons" (Ghana High Commission, 2016) → 0
	VAT	12.5% of purchase price → 37,500	12.5% of purchase price → 27,500
	ECOWAS levy	0.5% of purchase price → 1,500	0.5% of purchase price → 1,100
	EDIF	0.5% of purchase price → 1,500	0.5% of purchase price → 1,100
	Exam	1% of purchase price → 3,000	1% of purchase price → 2,200
	Inspection fee	1% of purchase price → 3,000	1% of purchase price → 2,200
	NHIL	2.5% of purchase price → 7,500	2.5% of purchase price → 5,500
	GETFL	Will not be considered	Will not be considered
Total Acquisition Phase		369,077	259,677
	Vehicle Income Tax	23 (per year)	23 (per year)

Operation Phase	Electricity/fuel consumption	0.14 €/kWh + service charge (= 10.01 €/month; 353.46 €/100,000 km)	0.91 €/km
	Maintenance	0.074 € per km	0.13 € per km
	Insurance	Will not be considered	Will not be considered
Disposal Phase	Vehicle salvage costs	Will not be considered	Will not be considered
	Battery recycling	Will not be considered	Will not be considered

Table 4: Cost overview

Main Findings

The economic assessment showed that the Total Cost of Ownership of an electric bus using the Ghanaian grid will amount to 482,402 € for the first 1,000,000 vehicle km, while the TCO of a diesel-powered bus will be as high as 651,127 €. The development of the costs is depicted in Figure 15.

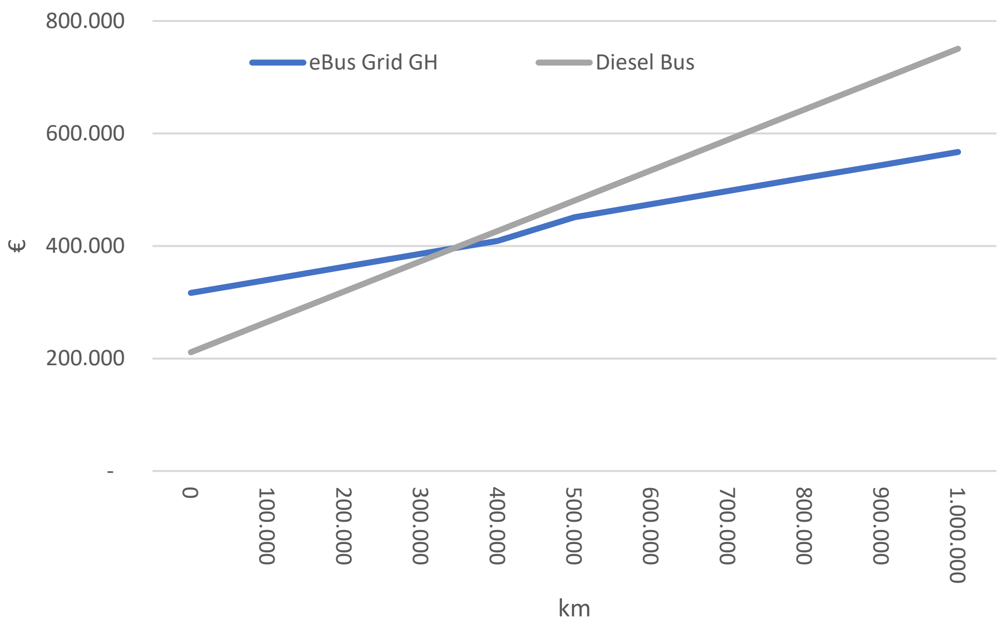


Figure 15: Development of TCO of a diesel bus vs. eBus (own source)

According to our calculations, the break-even point is expected to be reached after approximately 320,000 vehicle km. Looking at the two routes suggested in work package 1.2, the breakeven point can be reached after 9.42 years.

	Route 1	**Route 2**	**Total**
Route (km)	10	16	
Rides per day ()	7	3	10
km per day	70	48	118
km per month	1,680	1,152	2,832
km per year	20,160	13,824	33,984
Breakeven point (a)			9.42

Table 5: Overview distance travelled and breakeven point in route 1 and 2

If the bus is to run on more than six working days per week, or more times/more km per day, the calculations need to be adjusted accordingly.

Recommendations

As mentioned before, the short amount of time only allowed for a brief study, as important data could not be collected within the given time frame. We recommend verifying the information illustrated in this report by means of a more extensive research and long-term data collection, in order to carefully revise and verify the costs.

Annexes

Annex 1: Overview Vehicle Income Tax

Class of vehicle	Description	Rationalized annual rates (GH₵)	Quarterly rates (GH₵)
C1	Commuter (up to 15 persons)	80.00	20.00
C2	Commuter (16-19 persons)	100.00	25.00
C3	Ford buses, commuter (up to 23 persons)	80.00	20.00
C4	Tour operator (up to 15 persons)	320.00	80.00
C5	Commuter (up to 38 persons)	160.00	40.00
C6	Tour operator (16-23 persons)	400.00	100.00
C7	Commuter (39-45 persons)	200.00	50.00
C8	Tour operator (24-38)	280.00	70.00
C9	Tour operators (above 45 persons)	600.00	150.00
C10	Commuter (46 and above persons)	240.00	60.00

Annex 2: Report on survey results

RESEARCH REPORT ON IMPLEMENTING A SHUTTLE BUS SERVICE IN TEMA INDUSTRIAL PARK

NOVEMBER 2021

Inhalt

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1.0 Introduction

Transportation plays an important role in the mobility of people, goods and services from one location to another. Most mobility devices used fossil fuel to power their engines. Most of the by-product of these engines is largely exhausts which contain hydrocarbons, carbon monoxide, nitrous gases, etc, which are harmful to the environment. The promotion and usage of e-mobility devices have come to a time that climate change has become an important global topic that world leaders, research organisations, academia, and the business community are all investing resources and time to find a lasting solution to this global menace. The surest way to secure the future of the next generation against the adverse impact of climate change is to research sustainable adaptation and mitigation strategies and more importantly reduction of emissions to the barest minimum. One of the most important components of the COP26 meeting in Glasgow is to make world leaders commit themselves to the reduction of CO2 emissions and also finance the climate change mitigation and adaptation projects and programs across the globe. This research aims at reducing the usage of internal combustion engine vehicles in the Tema Industrial Park enclave in Ghana by replacing them with an electric bus which will take its power from a renewable energy source (solar power). This bus is intended to transport workers from the enclave entry to fixed bus stops near their workplace and back.

1.1 Research objective

The objective of the research is aimed at implementing a shuttle bus service within the Tema Industrial Park using an electric-powered bus. The aim will be addressed using the following specific objectives;

1. To analyse the local conditions in Tema Industrial Park, to allow for a tailored mobility offer
2. To determine the user requirements for mobility vehicles in the study area.

The survey was conducted on 9th November 2021 at the Tema Industrial Park enclave which started after a meeting with the management of the park from 11:00 to 18:00 GMT. The survey targeted mostly the workers who have no personal cars and who have to rely on company busses or public transport (trotro) to meet their mobility needs from the house to the factory or offices in the enclave. This is because these are the very people who will be using and benefiting from the electric bus shuttle if it is implemented to work in the park and their response will be pivotal to this research. The study employs a random sampling method in selecting 61 respondents to respond to semi-structured questionnaires.

2.0 Analysing local conditions to the usage of an electric bus in the Tema Industrial Park

In analysing the local condition to the usage of electric bus or shuttle in the Tema Industrial Park, socio-demographic characteristics of respondence, as well as the conditions of the enclave, were recorded and results are presented in Table 2.1.

2.1 Gender distribution of respondents

Respondents used for this study were 61 in general. This comprises 32 females and 29 males representing 52.5 per cent and 47.5 per cent respectively.

2.2 Age distribution of respondents

The majority of the respondents (50.8 per cent) are within the age bracket of 30-49, followed by 39.3 per cent within the 20-29 age bracket. However, 6.6 and 3.3 per cent represent age bracket of 50-69 and less than 19 years respectively.

2.3 Mode of transport and reason for choosing such mode to work

Most of the companies within the park have a staff bus that conveys workers from designated bus stops within the city to the company premises each day both before and after work, however, some companies don't have such a mode of transport and workers have to rely on their own choice of transportation to work every day. Also, if a worker missed the company bus, that worker has to find an alternative mode of transport to work. The majority of the respondents rely on the usage of trotro as a means of transportation to work each day. This majority correspond to 62.3 per cent of the respondents interviewed while 19.7 per cent also use the company bus to work each day. Additionally, 6.6 per cent of the respondents either walk or use their car to work while 3.3 per cent and 1.6 per cent use a motorbike and bicycle to work each day.

In finding out the reason for the choice of transportation to work, almost half of the respondents (47.5) per cent aid it is the cheapest mode of transport (mostly those that used commercial vehicles (trotro)) while 32.8 per cent said they don't have any other choice of transport. Another 9.8 per cent said it is the most comfortable option while 6.6 per cent said it is the fastest option (mostly those who used company buses and or drive their car or motorbike). Two respondents representing 3.3 per cent choose to walk to work since they don't live far from the industrial park and consider walking beneficial to their health.

2.4 Mode of transport within the Tema Industrial Park

Currently, the Tema Industrial Park has no legally recognised transportation mode that operates within the park. Workers and management have to rely on the usage of company and personal mobility devices to transact businesses each day in the park. There is a group of youth, mostly men, that offers motorbike services (*Okada*) to any part of the park at a fee. However, the usage of those motorbikes (*Okada*) as a commercial mobility device in Ghana is illegal and this makes the management of the Tema Industrial Park not recognise their services. Most female respondents mention their fear of being transported on the back of a motorbike, which is why they prefer to walk when they need to move from one point to another in the park. Also, the charge or cost of using the *Okada* services is high which discourages most workers from using their services. Instead, they walk to their preferred destinations within the park although tiresome. From the survey, nearly half of the respondents (49.2 per cent) used a motorbike (*Okada*) to move from one point to another within the park. This is followed by 45.9 per cent of respondents who walk to their preferred location within the park to transact businesses. Furthermore, 3.3 per cent and 1.6 per cent rely on company buses and bicycles to move within the park.

2.5 Time of starting and closing from work

The majority of the workers (86.9 per cent) start work between 6:01 am and 8:00 am daily. These workers are the factory workers, janitors and supervisors of the majority of the factories in the park. Those that start work before 6:00 am are mostly the security officers representing 8.2 per cent of the workers, while 4.9 per cent of the management start work after 8:01 am daily. This means if a bus shuttle is implemented within the park, it must start work before 6:00 am daily because this is the time workers in the part start reporting to work. Closing from work starts at 4:00 pm to 6:00 pm daily, and a majority of the respondents (91.8 per cent) leave their various homes from this time. Only 3.3 per cent of the workers close from work before 4:00 pm whiles 4.9 per cent close after 6:00 pm. These are mostly management which most use their car to work daily.

Furthermore, the operations of the bus shuttle will be busier during the early hours of the day (6:00 am – 8:30 am) and late hours (4:00 pm – 6:30 pm) daily. This means the bus has to be available mostly during these hours. However, since customers, visitors and other services providers (food vendors) also visit the park to transact business, the bus could still be working but not busily during the hours of the day from the entry point to other parts of the park.

Table 1.1: Socio-demographic characteristics of respondents

Variable	Frequency	Per centage
Gender		
Male	29	47.5
Female	32	52.5
Age bracket		
< 19	2	3.3
20-29	24	39.3
30-49	31	50.8
50-69	4	6.6
>70	0	0.0
Mode of transport to work		
Walking	4	6.6
Car	4	6.6
Bus	12	19.7
Motorbike	2	3.3
Bicycle	1	1.6
Trotro	38	62.3
others	0	0
Reason for choosing a mode of transport to work		
Comfortability	6	9.8
Less costly	29	47.5
Fastest option	4	6.6
No other available option	20	32.8
other	2	3.3
Mode of transport within the Industrial Park		
Walking	28	45.9
Car	0	0
Bus	2	3.3
Motorbike	30	49.2
Bicycle	1	1.6
Trotro	0	0
others	0	0
Work starting time		
Before 6:00 am	5	8.2
6:01 – 6:30 am	25	41
6:31 – 7:00 am	6	9.8
7:01 – 7:30 am	12	19.7
7:31 – 8:00 am	10	16.4
After 8:00 am	3	4.9
Work closing time		
Before 4:00 pm	2	3.3
4:01 – 4:30 pm	5	8.2

4:31 – 5:00 pm	2	3.3
5:01 – 5:30 pm	39	63.9
6:31 – 6:00 pm	10	16.4
After 6:00 pm	3	4.9
Total	**61**	**100**

Source: Author's computation from field survey data, November 2021

2.6 Cost of transportation to work

Respondents were asked how much money they currently spend on transportation to work each day. Out of the total number of respondents interviewed, 25 representing 41 per cent spend at most 20 cedis whiles 16 representing 26.2 per cent spend up to 10 cedis daily. However, 13 respondents representing 21.3 also spend up to 30 cedis on transportation daily. The respondents spend at least up to 2 or 5 cedis daily representing 4.9 per cent with only a respondent that spend up to 40 cedis a day. The amount of money spent on transportation each day is largely dependent on how far a worker home is from the Tema Industrial Park or how close the company bus stops is to the home of workers.

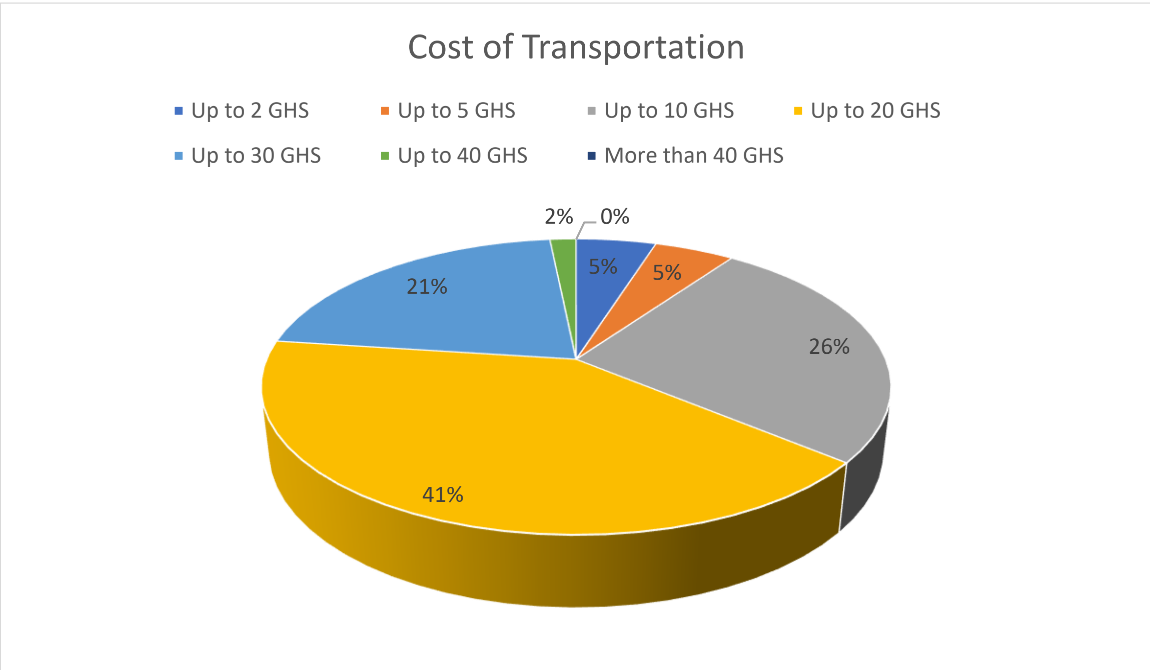

Figure 2. 1: Respondent's cost of transportation to work

2.7 Importance of a shuttle bus service in improving transport experience in Tema Industrial Park

The majority (80.3 per cent) of the respondents said *YES* a shuttle bus service will play an important role in the life of workers in the Industrial Park, while (14.8 per cent) said *MAYBE* and (4.9 per cent) said *NO* to improvement in transportation in the park. Among the reasons that were given by respondents for their approval, prominent were *reduction in the cost of transportation within the enclave, reduction in tiredness as a result of walking in the park and easy movement within the park*. For those that said no or maybe, the reason was that they *stay close to the park and will not need a shuttle bus.*

Table 2: Socio-demographic characteristics of respondents

Variable	Frequency	Per centage
Importance of a shuttle bus service in improving workers transport experience in the park		
Yes	49	80.3
Maybe	9	14.8
No	3	4.9
Total	**61**	**100**

Source: Author's computation from field survey data, November 2021

3.0 Determining user requirements for mobility vehicles in the study area

3.1 Usage of a shuttle bus within the Tema Industrial Park

Respondents were asked whether they will patronise the service of a shuttle bus in the Tema Industrial Park. From Figure 3.1, the majority of respondents (86.9 per cent) responded affirmatively to the usage of the bus if it is implemented in the park, (8.2 per cent) said they might use the shuttle bus while 4.9 per cent said no to the usage of the bus. The great number of respondents affirming their desire to use the bus is a clear indication that the shuttle bus service in the park is welcome by the workers.

Furthermore, respondents who said no to the usage of the shuttle bus were asked to give their reasons, the first said that the usage of the bus will depend on the time he gets to the entrance of the park. That is, he will take it when he is running late but will resort to walking when he has ample time to reach the office. The second reason was that he uses walking from the park entrance to the office as an exercise and that is the reason, he will not use the bus. The other two reasons were that he stays just close to the park and the other one has a personal motorbike that he uses as a medium of transportation to work daily.

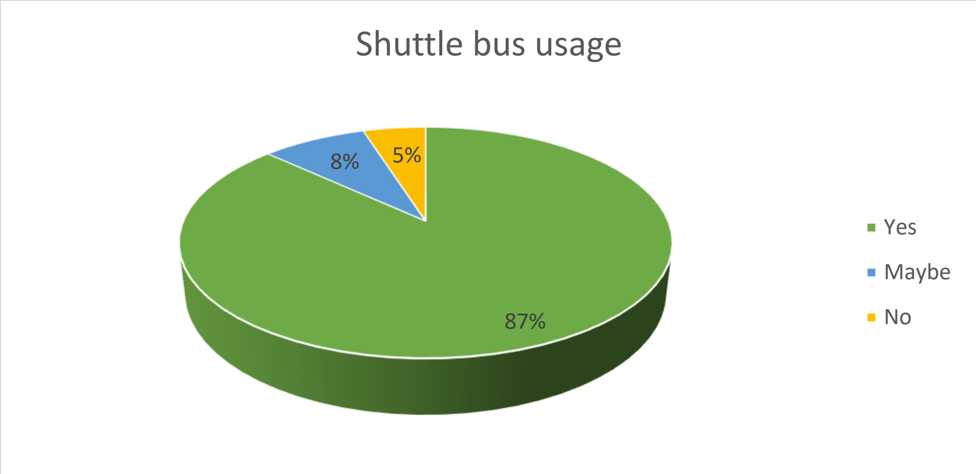

Figure 3. 1: Respondent's usage of shuttle bus service

3.2 Waiting time for the next bus

The majority of respondents (55.7 per cent) would be willing to wait between 5-10 minutes for the next bus followed by 23 per cent willing to also wait between 11-15 minutes. However, 21.3 per cent are willing to wait less than 5 minutes for the next bus.

3.3 Walking time from the bus stop to the office

Since companies or offices within the park are located at different places, the shuttle bus has to have designated bus stops scattered in the park. Workers have to be dropped at various bus stops and then walk to their offices or factory. The distance that workers are willing to take from the bus stops to the office will influence the usage of the shuttle bus. Workers were asked how many minutes of walk will they be willing to take from the bus stop to the office. The majority of respondents (62.3 per cent) indicated that they would be willing to walk 2-5 minutes to the office followed by 36.1 per cent willing to walk less than 2 minutes to the office. Only 1.6 per cent was willing to walk between 6-10 minutes to the office after being dropped off at the bus stop.

3.4: Willingness to pay for a trip to the office

In evaluating how much workers are willing to pay for a single trip to their office from the entrance of the enclave, workers were asked how much they would pay for a ride with the shuttle bus from the entrance to the office or vice versa. The majority of the respondents (62.3 per cent) indicated that they will pay up to 2 cedis for a ride while 34.4 per cent of the respondents are also willing to pay up to 5 cedis. However, only 1.6 per cent are willing to pay up to 10 and 30 cedis respectively for a single ride.

Table 3: Usage of shuttle bus service

Variable	Frequency	Per centage
Waiting time for next bus		
Less than 5 minutes	13	21.3
Between 5-10 minutes	34	55.7
Between 11-15 minutes	14	23.0
More than 15 minutes	0	0
Walking time from bus stop to the office		
Less than 2 minutes	22	36.1
Between 2-5 minutes	38	62.3
Between 6-10 minutes	1	1.6
More than 10 minutes	0	0
Willingness to pay		
Up to 2 GHS	38	62.3
Up to 5 GHS	21	34.4
Up to 10 GHS	1	1.6
Up to 20 GHS	0	0
Up to 30 GHS	1	1.6
Up to 40 GHS	0	0
More than 40 GHS	0	0
Total	**61**	**100**

Source: Author's computation from field survey data, November 2021

4.0 Factors regarded by respondents to the use of shuttle bus service in Tema Industrial Park

Factors that are considered very important by respondents to the use of shuttle bus service in Tema Industrial Park are presented in (Table 4.1). These factors were ranked by respondents on a Likert scale from 1-5 (1= absolutely important, 2= important, 3= somehow important, 4= not too important, and 5= not important at all. To find which of these factors is considered important by the rankings of the respondents, Kendall's Coefficient of Concordance was used. The Kendall's Coefficient of Concordance used in the analysis has a test statistics Kendall's 'W' which measures the agreement between respondents ranking.

Kendall's Coefficient was found to be 0.300 and significant at a 1% level. The 1% significance level implies that the model is 99.99% correct and not misspecified. The null hypothesis (i.e., Ho: No agreement among respondents ranking) was rejected in favour of the alternate hypothesis (i.e., Ha: There is agreement among respondents ranking) in the factors considered important to the usage of shuttle bus service in the industrial park. The Kendall's 'W' of 0.300

implies that there was 30% agreement between the respondent in the ranking of factors considered important to the usage of shuttle bus service in Tema Industrial Park. This further implies that respondents ranking of the factors

The four most important factors ranked by respondents are price per ride, reliability, safety, and comfort. These factors are very important to the usage and smooth running of shuttle bus services in the Industrial Park not forgetting the other factors.

Table 4: Ranking of factors that influence the usage of shuttle bus

Factors	Mean Score	Ranks
Price per ride	2.84	1st
Reliability	3.15	2nd
Safety	3.70	3rd
Comfort	4.15	4th
Load capacity	4.30	5th
Quality	4.89	6th
Design	4.98	7th
Diagnostics		
Number of observations	61	
Kendall's W	0.300	
Degree of Freedom	6	
Chi-square	109.683	
Asymptotic significant	0.000	

Source: Author's computation from field survey data, November 2021

4.1 Ranking of statements on the usage of a shuttle bus service by respondents

Kendall's Coefficient was also used in analysing respondents' agreement on the following statement. Kendall's Coefficient was found to be 0.291 and significant at the 1% level. The null hypothesis (i.e., Ho: No agreement among respondents ranking) was rejected in favour of the alternate hypothesis (i.e., Ha: There is agreement among respondents ranking) in the statements considered important to the usage of shuttle bus service in the Industrial Park. Kendall's 'W' of 0.291 implies that there was 29.1% agreement between the respondent in the ranking of statements considered important to the usage of shuttle bus service in Tema Industrial Park.

The three most important statements ranked by respondents regarding the usage of shuttle buses are positive effects on their economic situation, an improvement on their flexibility and lastly a positive influence on their life in general. These factors are very important to the usage and smooth running of shuttle bus services in the industrial park not forgetting the other factor.

Table 5: Ranking of statements that will influence the usage of shuttle bus

Statements	Mean Score	Ranks
A shuttle bus service can affect my economic situation in a positive way	1.88	1st
A shuttle bus service can improve my flexibility	2.33	2nd
A shuttle bus service would have a positive influence on my life in general	2.64	3rd
A shuttle bus service leads to better access to public services	3.16	4th
Diagnostics		
Number of observations	61	
Kendall's W	0.291	
Degree of Freedom	3	
Chi-square	53.331	
Asymptotic significant	0.000	

Source: Author's computation from field survey data, November 2021

Annex 3: Report Green Power Brains

Electromobility in Ghana – Promoting Local Business Models for Electromobility and Decentralized Energy Systems

Component 2 (E-Mobility in Industry)

Feasibility study for the introduction of e-mobility in the Ghana Free Zone in Tema

Organization and author:

Green Power Brains
Michele Velenderić

Version: 1.0

Green Power Brains

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List of stakeholders

The list of stakeholders included stakeholders involved and interviewed for this feasibility study. It does not necessarily contain all the stakeholders in the project “Electromobility in Ghana – Promoting Local Business Models for Electromobility and Decentralized Energy Systems”.

Involved companies, NGOs and institutions

1. Ghana Free Zones Authority
2. LMI Holding
3. Enclave Power

4. GIZ
5. Bochum University of Applied Science
6. Solar Taxi

Consulted partners

Company/NGO/Institution	Person
Dana Krieger	GIZ
Ebenezer Owosu	GIZ
Patience Agbleze Acorlor	GFZA
Boli Dziewornu	GFZA
Dela Kpe	GFZA
Robert Takyi	LMI Holding
Jesse (LMI Technician)	Enclave Power
Janis (LMI Solar Manager)	Enclave Power

List of terms and abbreviations

Enclave	Tema Export Processing Zone
GFZA	Ghana Free Zones Authority
Kpone Junction	Junction between N1 Accra – Aflao Road and the Kpone Barrier Road Junction (see Figure 1: TEPZ area (based on Google Earth 2021))
HSBO	Bochum University of Applied Science (Hochschule Bochum)
TEPZ	Tema Export Processing Zone
WLTP	Worldwide harmonized Light Duty Test Procedure

1 Abstract

This study handles the introduction of an e-mobility offer in form of an e-bus in the Tema Export Processing Zone (TEPZ) in Tema, Ghana. The current status of transportation to and within the TEPZ are analyzed and possible routes and operation times are proposed after interviews with stakeholders and empirical route evaluation on site.

The focus of this study is on the usage of an e-bus, on the required energy for daily operation and on the options for charging: using the utility grid or using a solar power system. The advantages both in terms of lifetime cost as well as of lifetime CO2 emission and the potential for emission reduction have been quantified as break-even points. From the financial point of view, two scenarios have been examined, leading to a financial break-even reached between 10 and 13 years of operation. In addition to that, usage of the surplus electricity produced by a solar power system and not needed to recharge the e-bus batteries for office buildings in the TEPZ lead to additional savings in the range of up to 5000 €/year.

From the emission side, CO2 break-even is reached after less than three years of operation.

Both show a great advantage of solar power systems in financial as well as in CO2 emission terms, compared to the utility grid at the TEPZ.

Principles and opportunities for the creation of a solar microgrid have been listed and have the potential to generate further advantages both financially as well as in the emissions-wise. Solutions for energy micro-trading and demand side management have been presented and have the potential for boosting investments of companies within the TEPZ in solar installations, due to the possibility of income generation and the reduction of the CO2 emissions of the investors and users of the solar generated energy, while at the same time, generating well qualified local jobs.

2 Introduction

The overarching objective of the Tema Industrial Park Project is to promote local business models for electromobility and decentralized energy systems. The focus of the project is to provide an alternative mobility offer to the Industrial Park area, powered by renewable energy sources.

The desired effect of interventions and activities is to promote job creation along various business models up and down the electromobility value-chain whiles achieving the environmental benefits of a sustainable mobility offer.

The enumerated aims of the project are:

1. Feasibility of electric-powered buses to be used for internal mobility in the industrial park.
2. Reduce dependence on fossil-fueled transport modes in the Tema Industrial Park.
3. Creating sustainable jobs in the fields of electromobility and decentralized energy systems.
4. Development of a mobility offer for a food delivery service consisting of cargo bikes and e-scooters adapted to the onsite requirements of the Tema Industrial Park, with an upscale opportunity to implement a sharing system for personnel of the park.

5. Feasibility of solar mini-grid deployment using facilities of the industrial park with blockchain integration to ensure transparency in energy use and cost distribution.

Industrial Enclave Focus: The second component of the project focuses on the use of industrial parks as starting point for the integration of sustainable mobility solutions in large scale industrial applications.

Figure 1: TEPZ area (based on Google Earth 2021)

3 Current status of transportation

The Tema Export Processing Zone (TEPZ) is an area of about 480 hectares, located in Tema, Ghana. The area hosts companies that are eligible for tax exemption due to a high export rate. The TEPZ is a fenced area, shown in the picture above.

The area is partly operated by the Ghana Free Zones Authority, a government authority, and partly by the LMI Holding Ltd., a privately held company.

Entry to the TEPZ by car or by motorbike is possible. A fee of 2 GHC is charged at the entry.

Currently there is no organized area-wide transportation service within the TEPZ Enclave.

Employees come by their own means, by car, motorcycle, walk into the TEPZ or take a motorcycle taxi. A motorcycle taxi station if located close to the “Free Zone Enclave Entry”.

Some companies provide transportation for their employees.

3.1 Need for transportation

Interviews with GFZA lead to the supposition that a transport service offered by the GFZA would be used by the employees of the companies in the Enclave. The price should be similar or lower to the price of the existing motorcycle taxis. Companies could possibly cover for some of the costs, for the benefit of their employees.

3.2 Operation times

Employees start working as early as 4 a.m. The morning rush hour is between 5 a.m. and 8 a.m.

In the afternoon, employees leave mostly between 5 p.m. and 7 p.m.

Around noon there is a minor rush hour between 11 a.m. and 1 p.m.

The main two rush hours are in the morning and in the evening. The GFZA recommends to start testing the transportation service running in that period of time. During this time, transportation should be made available as often as possible, thus leading to a possibly short route to reach a possibly high frequency of runs.

During the minor rush hour around noon, a longer route with a collection point outside the TEPZ is possible.

3.3 Possible collection points and routes

Two routes have been identified as interesting for a pilot project. Collection points of interest are:

1. Free Zone Enclave Entry
2. Kpone Barrier Road Junction (Kpone Junction)

The first one running only within the Enclave. The second one having an additional collection point outside the Enclave.

A motorcycle taxi station is located close to the entry to the Enclave. The motorbike taxis are used both to arrive to the TEPZ entrance as well as starting point for motorcycle taxi rides to destinations inside the TEPZ.

The Kpone Junction is outside the Enclave, on the junction between the N1 Accra – Aflao Road and the Kpone Barrier Road. The Kpone Junction is a destination and stop of many Accra and Tema transportation services and is widely used by employees of TEPZ located companies.

3.3.1 Route 1

Starting point	Free Zone Enclave Entry
Main collection point	Free Zone Enclave Entry
Route length	10 km
Driving time without stops	30 minutes
Expected driving time with stops	45 minutes
Risk for delays	Low
Proposed serving time	5 a.m. – 8 a.m. and 17 p.m. – 19 p.m.
Route description	Route completely within the TEPZ.
Expected number of runs	Morning (5 a.m. – 8 a.m.): 4 times Evening (17 p.m. – 19 p.m.): 3 times
Total km	Morning: 40 km Evening: 30 km

Table 1: Bus route 1 (morning and evening route)

Figure 2: Bus route 1 - short route

3.3.2 Route 2

Starting point	Free Zone Enclave Entry
Main collection point	Kpone Junction
Route length	16 km
Driving time without stops	30 minutes
Expected driving time with stops	60 minutes
Risk for delays	Medium (N1 Accra – Aflao Road)
Proposed serving time	11 a.m. – 1 p.m.
Route description	Route with collection point outside of the TEPZ.
Expected number of runs	3 times
Total km	48 km

Table 2: Bus route 1 (midday route)

Note on traffic situation:

Traffic on the N1 Accra – Aflao Road from the TEPZ to the Kpone Junction can be heavy. However, traffic jams usually occur in the direction Kpone Junction to TEPZ main entrance. The planned route runs in the opposite direction, from TEPZ main entrance to Kpone Junction. To avoid the potential traffic jams the alternative entrance to the TEPZ will be used (see Figure 1: TEPZ area (based on Google Earth 2021)). The alternative entrance lies diagonally to the main entrance to the TEPZ.

:

Figure 3: Bus route 2 - long route

4 Options for mobility solutions

Introduction of a mobility offer for the TEPZ is possible by using combustion engine or electric busses. In the following sections, both options will be considered to compare financial and environmental aspects.

4.1 E-bus

The chosen e-bus has the following specifications:

Electric motor power	90 kW
Battery capacity	76 kWh
Battery composition	Lithium ion, lithium metal polymer or lithium iron posphate
Charging power	min. 20 kW AC, min. 50 kW DC
Consumption	1.1 kWh/km
Range	69 km
Max. passengers	105

Table 3: E-bus specifications

4.2 Diesel bus

Comparable diesel bus:

Consumption	0.45 l/km
Max. passengers	95

Table 4: Diesel bus assumptions

5 Charging

Three options for charging of e-vehicles are considered:

1. Grid
2. Photovoltaic power system
3. Hybrid system

For all options, following the assumptions above regarding the routes have been used. For the needed energy, following assumption has been used:

Total distance morning runs	40 km
Total distance midday runs	48 km
Total distance evening runs	30 km
Bus battery capacity	76 kWh
WLTP range	69 km
Reduced range (temperature, stop and go, battery degradation,…)	50 km
Electric consumption	1.1 kWh/km

Table 5: E-bus assumptions

Out of the assumptions in the table above, the following energy is needed for charging:

Run	**Distance**	**Specific consumption**	**Total consumption**	**Charging time**
Morning	40 km	1.1 kWh/km	44 kWh	Night (before morning run)
Midday	48 km		52.8 kWh	Day (between morning and midday run)
Evening	30 km		33 kWh	Day (between midday and evening run)
Total	**118 km**		**129.8 kWh**	

Table 6: Energy demand for e-bus operation

Running and charging times both at day and night are assumed to be as follows:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
night							day											night					
charging					run			charging			run		charging				run		charging				

Table 7: E-bus run and charging times

5.1 Charging through utility grid

Charging through grid is the simplest solution. Following information about price and CO2 footprint of the used energy are known:

Price of electricity (Enclave Power "Low Voltage Tariff")	0.14 €/ kWh (0.16 USD/kWh, exchange rate 1 USD = 0.8731 €, as of 14.11.2021)
Electricity generation mix	31.5% hydro, 68.5% thermal (oil)

Table 8: Utility grid electricity cost and specific CO2 emissions

With the electricity generation mix from the table above, the specific CO2 emissions sum up to 0.789 kgCO2/kWh, determined by HSBO models.

The cost for a daily, monthly and yearly operation as well as the CO2 emissions result to:

Total daily consumption	Cost		CO2 emissions	
	daily	yearly (365x daily)	daily	yearly (365x daily)
129.8 kWh	18.17 €	6632.78 €	102 kgCO2	37380 kgCO2

Table 9: Cost and CO2 emissions of charging through utility grid

5.2 Charging through a photovoltaic solution

5.2.1 Solar irradiation

Ghana averages a solar irradiation of roughly 5,5 kWh/day. In July, the month with the lowest monthly solar irradiation, the long term average solar irradiation is of 4,4 kWh/day.

The monthly solar irradiation is shown in the following graph:

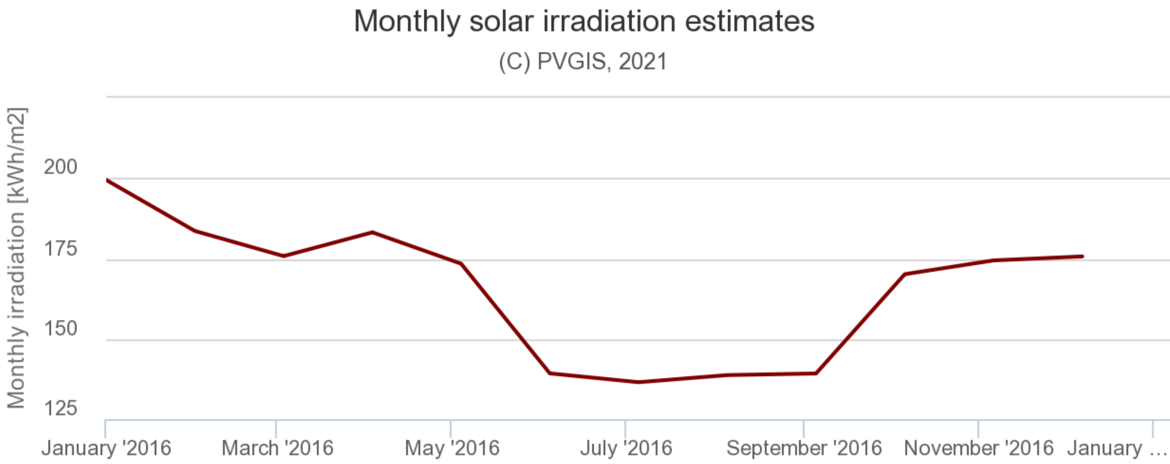

Figure 4: Monthly solar irradiation estimates for Tema, Ghana (Source: PVGIS)

The monthly figures from the graph above are shown in the table below, together with the average daily irradiation.

Monthly solar energy estimates

Month	**kWh/m²/Month**	**kWh/m²/Day**
Jan	199.44	6.43
Feb	**183.55**	**6.56**
Mrz	175.73	5.67
Apr	183.13	6.10
Mai	173.37	5.59
Jun	139.22	4.64
Jul	**136.47**	**4.40**
Aug	138.69	4.47
Sep	139.19	4.64
Okt	170.1	5.49
Nov	174.39	5.81
Dez	175.63	5.67
Average	**165.74**	**5.46**

Table 10: Monthly solar irradiation estimates for Tema, Ghana (Source: PVGIS). February, the month with the strongest irradiation marked in green, July, the month with the weakest irradiation marked in red.

The figures above also represent the so called equivalent sunshine hours for a month or for a day, meaning that an installation of 1 kWp will produce 6.43 kWh/day in average in January and 4.40 kWp in average in July.

The data are long term average values. Actual values can differ significantly for the given months or days.

5.2.2 Photovoltaic generator estimate using irradiation data

Using the solar irradiation estimate of 4.4 kWh/day for the month with the lowest irradiation, July, a solar generator of 29.5 kWp is needed to produce the needed 129.8 kWh energy a day. This figures follows the long term average solar irradiation and does not take into consideration days of lower solar irradiation due to clouds or the influence of the dust brought by the harmattan wind. Furthermore, it only takes into consideration the monthly solar irradiation estimate, without considering system losses within a photovoltaic power system.

Nevertheless, the generator of 29.5 kWp represents a lower boundary when sizing a photovoltaic power system for charging the considered e-bus.

5.2.3 Slope and azimuth of the photovoltaic generator

The theoretically ideal slope and azimuth angles vary depending upon the used historical irradiation data. Data from the PVGIS-SARAH[1] solar radiation database as well as from the CMSAF[2] database have been evaluated. Following slope and azimuth angles have been calculated using the PVGIS solar irradiation tool[3]:

Database	Ideal slope	Ideal azimuth
PVGIS-SARAH	8°	21°
PVGIS-CMSAF	7°	9°

Table 11: Ideal slope and azimuth angles for PVGIS-SARAH and CMSAF solar radiation databases

The PVGIS-SARAH solar radiation data at the slope and azimuth angles of 8° and 21° as written in the table above. With this angles, the solar production of a 29.5 kWp solar generator amounts to the following:

[1] https://ec.europa.eu/jrc/en/PVGIS/downloads/SARAH
[2] https://www.cmsaf.eu/EN/Home/home_node.html
[3] https://re.jrc.ec.europa.eu/pvg_tools/en/

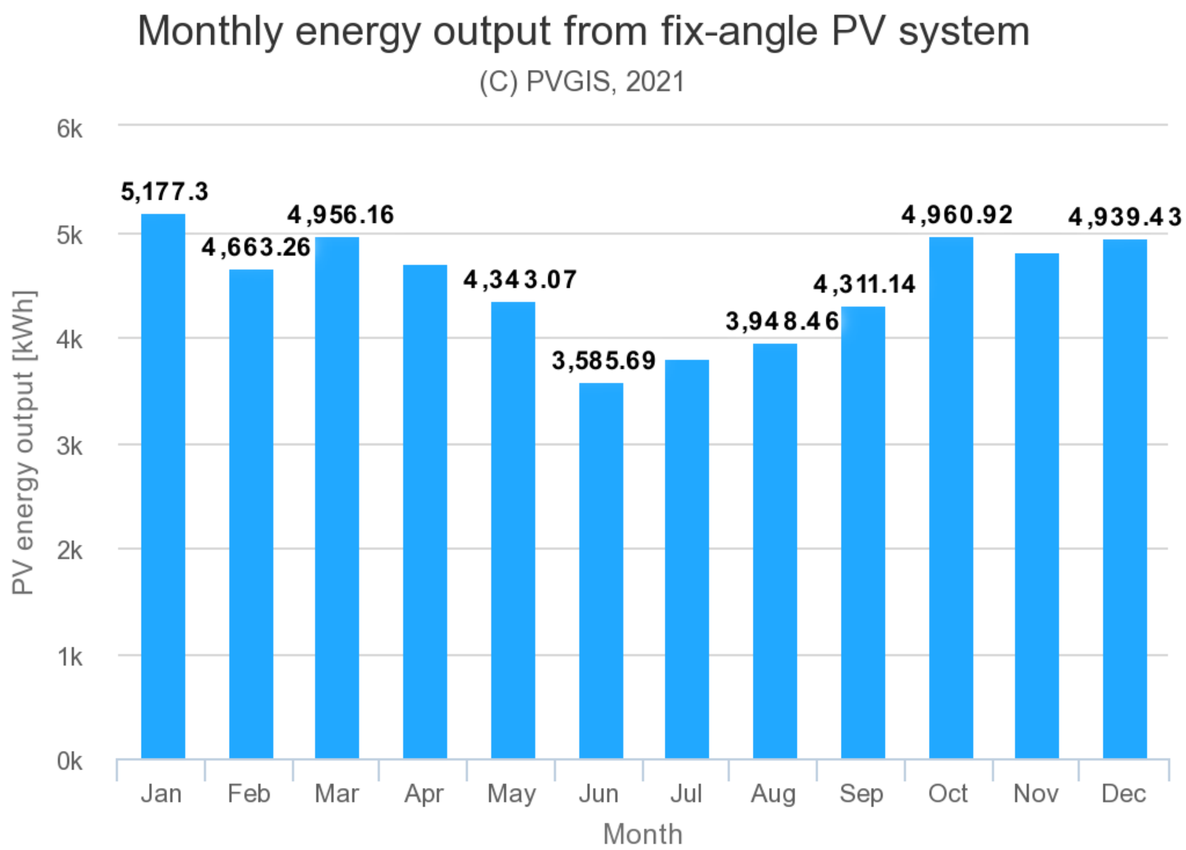

Figure 5: PV energy output for 29,5 kWp solar generator at 8° slope and 21° azimuth, using PVGIS-SARAH data

The daily production varies between 134 kWh in July and 169 kWh in February:

Solar radiation database	**PVGIS-SARAH**	
Slope/Azimut angle	**8°/21°**	
Month	**kWh/Month**	**kWh/Day**
Jan	5202.01	167.81
Feb	**4749.19**	**169.61**
Mrz	5040.09	162.58
Apr	4769.33	158.98
Mai	4356.13	140.52
Jun	3712.05	123.74
Jul	**4155.31**	**134.04**
Aug	4424.3	142.72
Sep	4702.9	156.76
Okt	5265.74	169.86
Nov	5040.86	168.03
Dez	5074.77	163.70
Total	**56492.68**	

Table 12: PV energy output for 29,5 kWp solar generator at 8° slope and 21° azimuth, using PVGIS-SARAH data

Using the CMSAF data leads to an optimal slope of 7° and an azimuth of 9° for the solar generator:

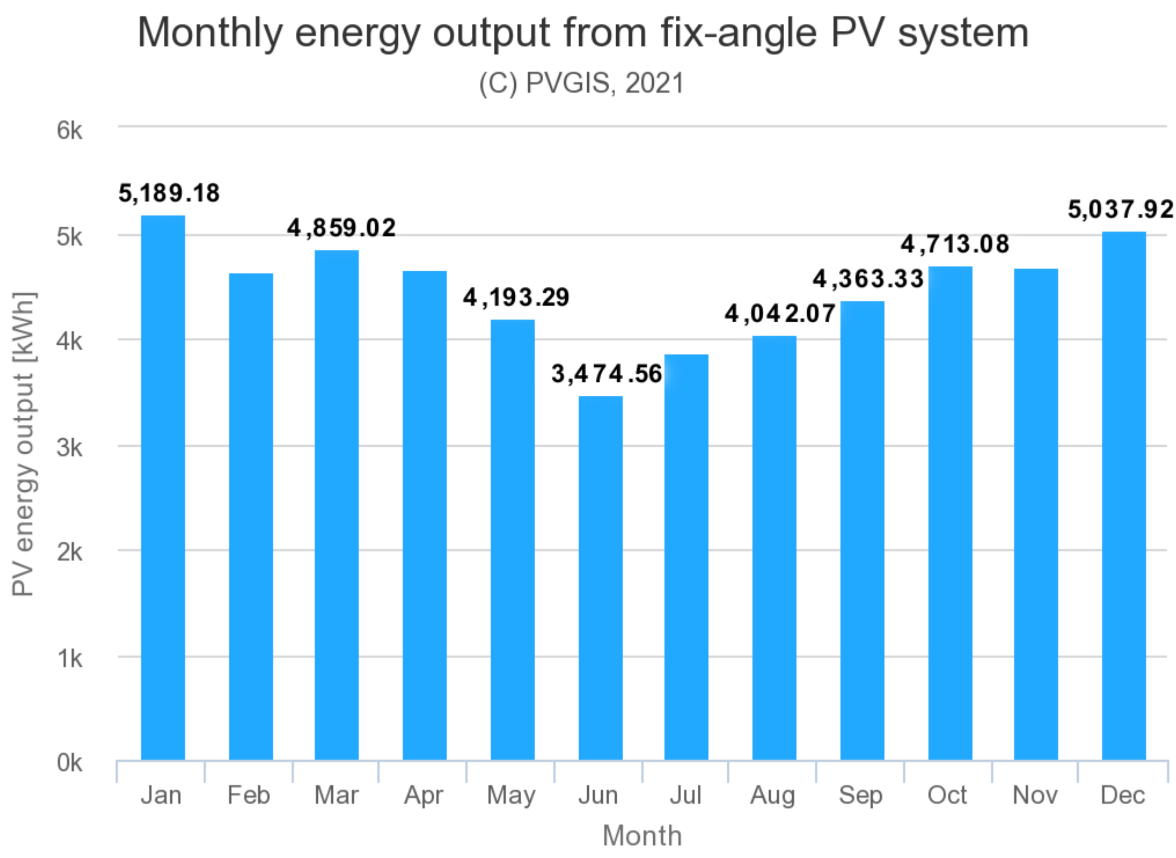

Figure 6: PV energy output for 29,5 kWp solar generator at 7° slope and 9° azimuth, using CMSAF data

Analogous to the PVGIS-SARAH data, the CMSAF data also deliver a maximum in February and a minimum in July:

Solar radiation database	**PVGIS-CMSAF**	
Slope/Azimut angle	**7°/9°**	
Month	**kWh/Month**	**kWh/Day**
Jan	5225.93	168.58
Feb	**4687.38**	**167.41**
Mrz	4953.05	159.78
Apr	4748.1	158.27
Mai	4290.24	138.39
Jun	3629.17	120.97
Jul	**4099.48**	**132.24**
Aug	4345	140.16
Sep	4607.76	153.59
Okt	4898.52	158.02
Nov	4785.31	159.51
Dez	5079.06	163.84
Total	**55349**	

Table 13: PV energy output for 29,5 kWp solar generator at 7° slope and 9° azimuth, using CSAF data

The difference between the two data sources is of roughly 2% and is negligible.

A steeper slope is also desirable to enhance the rain cleaning effect on the modules. Own empirical calculations based on data collection on site in Tema, Ghana show a positive effect due to cleaner solar modules at a slope of 15°. The effect of the slope deviation from the theoretical optimum remains in the low one digit percentage and can be neglected. The positive effect of rain cleaning the modules prevails over the theoretical loss.

The following table shows the theoretical loss of choosing a steeper slope than the optimal one of 8°:

Database	**PVGIS-SARAH**		**PVGIS-SARAH**	
Slope/Azimut	**8°/21°**		**15°/21°**	
Month	**kWh/Month**	**kWh/Day**	**kWh/Month**	**kWh/Day**
Jan	5202.01	167.81	5373.89	173.35
Feb	**4749.19**	**169.61**	**4823.97**	**172.28**
Mrz	5040.09	162.58	5017.06	161.84
Apr	4769.33	158.98	4637.78	154.59
Mai	4356.13	140.52	4155.53	134.05
Jun	3712.05	123.74	3523.61	117.45
Jul	**4155.31**	**134.04**	**3970.89**	**128.09**
Aug	4424.3	142.72	4297.42	138.63
Sep	4702.9	156.76	4703.1	156.77
Okt	5265.74	169.86	5327.29	171.85
Nov	5040.86	168.03	5196.08	173.20
Dez	5074.77	163.70	5272.17	170.07
	56492.68		**56298.79**	

Table 14: PVGIS-SARAH comparison of theoretical (yellow columns) and empirical (green columns) optimums for slope

When choosing a slope of 15° instead of the optimal 8°, the yearly production of the power system drops by less than 0.5%, from 56 492 kWh to 56 298 kWh.

In the months of higher irradiation, from October to February, the increased slope leads to an increased production. In the remaining months, a slight drop is expected. The above mentioned negligible difference in the total yearly production and the expected rise in production through cleaner solar modules due to the enhanced rain washing effect leads to the conclusion, that the increasing the slope from 8° to 15° has a positive influence on PV production.

Using CMSAF data, the effect is similar:

Database	CMSAF		CMSAF	
Slope/Azimut	7°/9°		15°/9°	
Month	kWh/Month	kWh/Day	kWh/Month	kWh/Day
Jan	5225.93	168.58	5452.46	175.89
Feb	4687.38	167.41	4786.05	170.93
Mrz	4953.05	159.78	4931.2	159.07
Apr	4748.1	158.27	4584.58	152.82
Mai	4290.24	138.39	4055.38	130.82
Jun	3629.17	120.97	3404.42	113.48
Jul	4099.48	132.24	3866.03	124.71
Aug	4345	140.16	4179.14	134.81
Sep	4607.76	153.59	4545.92	151.53
Okt	4898.52	158.02	4955.29	159.85
Nov	4785.31	159.51	4954.21	165.14
Dez	5079.06	163.84	5332.2	172.01
	55349		**55046.88**	

Table 15: CMSAF comparison of theoretical (yellow columns) and empirical (green columns) optimums for slope

Due to the limited influence of the slope and of the used radiation data on the calculation, further considerations in this study will be made using PVGIS-SARAH data with a solar generator slope of 15° and an azimuth of 21°.

Conclusion: slope variation

Changing the slope by increasing or reducing it by 5° does not perceivably affect the calculated results of the PV energy output in this study. The slope of the solar generator can be set to 15° if it is feasible, e.g. if the solar generator is free standing or installed on a flat roof. Should the installation occur on an inclined roof, if the roof angle is within 5° from the above mentioned 15° slope, the solar generator can be installed roof parallel, to ease installation. For larger deviations it is recommended to examine the effect by performing additional simulations.

Conclusion: Azimuth variation

Due to the location close to the equator, the effect of the azimuth angle of the solar generator on the PV energy output is limited. A PV generator facing South should deliver slightly more energy thorough the year than a PV generator facing North. Following own empirical data collection in the area, azimuths between -45° and 45° roughly deliver the same PV energy output.

5.2.4 Dimensioning of a PV power system for e-bus charging

Following the considerations made in the previous sections, a solar power system for e-bus charging should be able to provide the following energy:

No.	Battery status start	Event	Time period	h	Charging power	Consumption (-) /charging (+)	Battery status end
1	76 kWh	Evening run	5 – 7 pm	2		-33 kWh	43 kWh
2	43 kWh	Night charging	7 pm – 5 am	10	3.3 kW	+33 kWh	76 kWh
3	76 kWh	Morning run	5 – 8 am	3		-52.8 kWh	23.2 kWh
4	23.2 kWh	Morning charging	8 – 11 am	3	17.6 kW	+52.8 kWh	76 kWh
5	76 kWh	Midday run	11 am – 1 pm	2		44 kWh	32 kWh
6	32 kWh	Afternoon charging	1 – 5 pm	4	8 kW	+32 kWh	76 kWh

Table 16: E-bus discharging (yellow) and optimal charging times, energy and power (blue – night, green – day)

After the last evening run, the battery of the e-bus has to be recharged. The consumption figures in the table above are realistic. However, there are many influences on the consumption, that may increase the latter: e.g. transported weight, traffic situation, temperature, battery status, battery age, etc. To have a safety margin and thus to enable proper operation, it is recommended to start each run, morning, midday and evening, with a full e-bus battery.

Charging during night

Charging at night involves charging the PV power system battery first and then invert the battery energy to charge the e-bus.

The following figure shows the needed components and the effective PV power needed to charge the battery with 33 kWh:

Figure 7: Efficiency path for charging at night, using a solar power system

Charging during day

Charging during the day using an AC-coupled system architecture significantly increases the efficiency of the power generation to charging chain:

Figure 8: Efficiency path for charging during the day, using a solar power system

Both charging at night and during the day will be considered in the proposed power system architecture presented in section 5.2.8 Solar power system configuration.

5.2.5 Sizing of the battery

Line 1 and 2 in the table above determine the minimal PV power system battery size to ensure the e-bus starts the day with a full battery.

Assuming both batteries, the one of the e-bus and the one of the PV power system, to be lithium-ion batteries with an overall efficiency of 90%, the minimal battery size to ensure complete charging overnight is of 37 kWh (see Figure 7: Efficiency path for charging at night, using a solar power system).

5.2.6 Determining of the charging power

After the morning run, until the midday run, the battery needs to be charged with additional 52,8 kWh (line 4 in the table above). These can either be drawn out of the PV power system battery, or come directly from the PV generator.

In both cases, to ensure that the midday run is started with a full battery, 52,8 kWh need to be charged in a period of 3 hours, leading to a needed effective charging power of 17,6 kW.

Power reduction output of charging infrastructure due to high ambient and thus operational temperature must be considered when sizing the PV power system as well as the power factor if charging with alternating current.

It is therefore recommended to use a good safety margin when choosing the charging electronics and plan for at least 30% more than the needed effective 17,6 kW.

5.2.7 Determining the size of the solar generator

The size of the solar generator is given by the energy needed to recharge the battery between the morning and the midday run. In the period of time between 8 – 11 am, 44 kWh need to be charged into the e-bus.

The daily irradiance for a typical month July (month with lowest solar irradiation) is shown in the following graph:

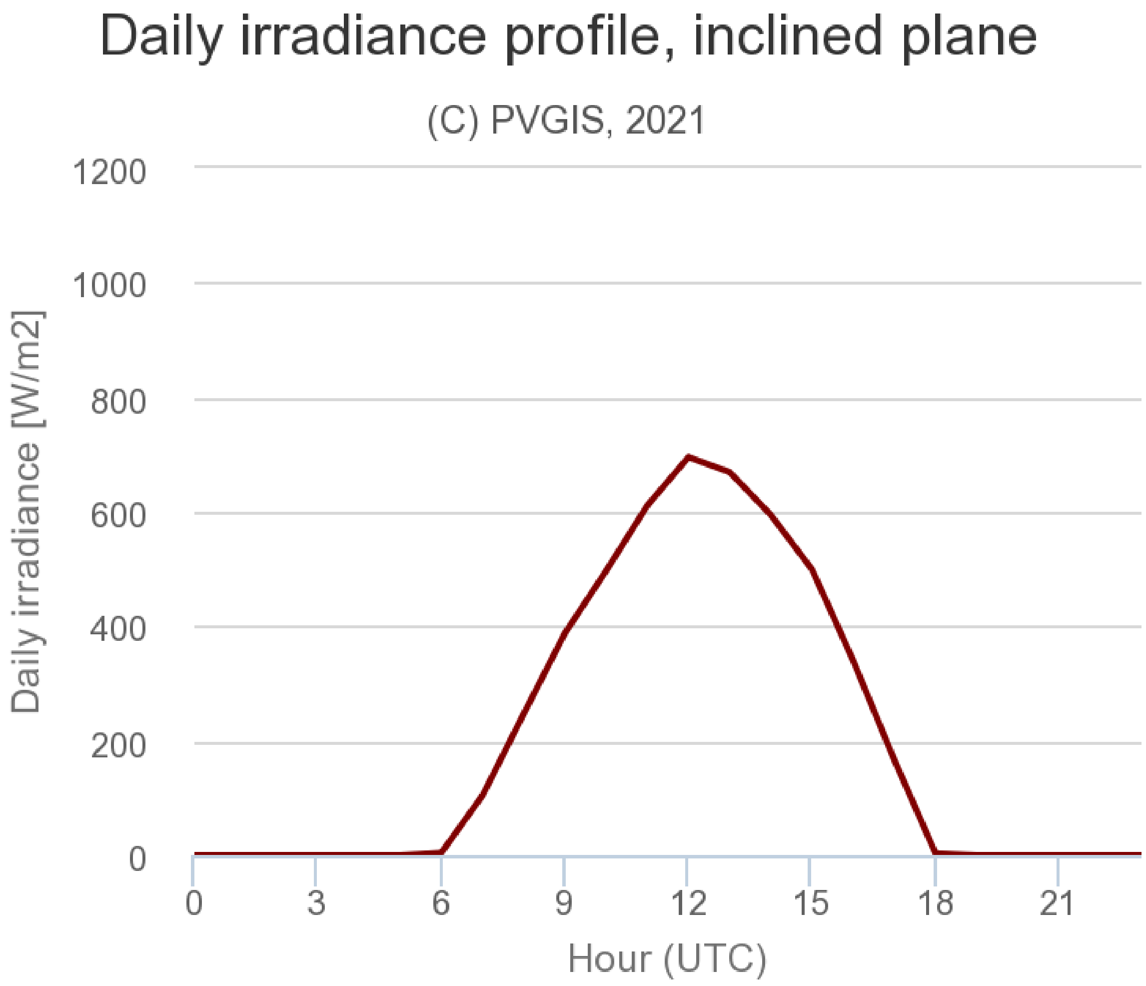

Figure 9: Daily irradiance in Tema on a 15° inclined plane (azimuth 21°)

The hourly values are:

Daily irradiance Tema	
Time	**Irradiance [W/m²]**
5	0
6	4.22
7	104.2
8	246.83
9	387.58
10	496.43
11	610.48
12	695.1
13	669.09
14	594.34
15	499.11
16	339.93
17	166.21
18	3.17
19	0

Table 17: Daily solar irradiance in Tema (morning charging time window in green)

Charging power between morning and midday runs

The raise of the solar irradiance between 8 and 11 am is nearly linear. Using an hourly average, gives the potentially available energy in the plane of the solar generator:

Time start	Time end	Irradiance start [W/m²]	Irradiance end [W/m²]	Irradiance average [W/m²]	Energy produced [kWh/m²]
8	9	246.83	387.58	317,21	0.3
9	10	387.58	496,43	442	0.4
10	11	496.43	610.48	553.46	0.5
Total					**1.2**

Table 18: PV energy output in the period 8 - 11 am

Using the total energy produced per square meter in the period of time 8 – 11 am from the table above, the resulting needed PV generator size equals:

$$Needed\ energy\ [kWh] = PV\ generator\ size\ [kWp] * Effective\ sunshine\ hours\ [h]$$

With the following:

- Needed energy = 44 kWh
- Effective sunshine hours = 1.2

The resulting PV generator size can be calculated as:

$$PV\ generator\ size = {Needed\ energy}/{Effective\ sunshine\ hours} = {44\ kWh}/{1.2\ h} = 36.7\ kWp$$

The needed PV generator is thus of 37 kWp.

Charging power for between midday and evening run

An analogous consideration to the needed charging power between the morning and midday run can be made for the afternoon charging, between the midday and the evening run. The goal is to have a fully charged e-bus battery at the beginning of the evening run.

The fall of the solar irradiance between 1 and 5 pm is also nearly linear. Using an hourly average, gives the potentially available energy in the plane of the solar generator:

Time start	Time end	Irradiance start [W/m²]	Irradiance end [W/m²]	Irradiance average [W/m²]	Energy produced [kWh/m²]
13	14	669.09	594.34	631.72	0.6
14	15	594.34	499.11	546.67	0.5
15	16	499.11	339.93	419.52	0.4
16	17	339.93	166.21	253.07	0.3
Total					**1.8**

Table 19: PV energy output in the period 1 - 5 pm

Using the total energy produced per square meter in the period of time 1 – 5 pm from the table above, the resulting needed PV generator size equals:

$$Needed\ energy\ [kWh] = PV\ generator\ size\ [kWp] * Effective\ sunshine\ hours\ [h]$$

With the following:

- Needed energy = 52.8 kWh
- Effective sunshine hours = 1.8

The resulting PV generator size can be calculated as:

$$PV\ generator\ size = {}^{Needed\ energy}/_{Effective\ sunshine\ hours} = {}^{52.8\ kWh}/_{1.8\ h} = 29.3\ kWp$$

The PV generator of 37 kWp needed for the charging between morning and midday run is enough also for the afternoon charging between 1 and 5 pm.

Final sizing of the PV generator

The considerations on the size of the PV generator in order to charge during the morning and during the afternoon lead to the necessary size of the solar generator. For an average day July, in the month with the lowest solar irradiation, the minimal size of the generator should be of 37 kWp, needed to charge the e-bus in the time between 8 and 11 a.m., the break between morning and midday run.

Being the power needed to charge in the afternoon less than 37 kWp, the sizing needed for the morning charging will be used for further considerations.

Empirical data and lessons learned from other installations in the area indicate that a higher PV generator power positively affect the autonomy of a power system. Obviously, a larger generator needs less time to output a certain amount of energy than a smaller one. In cases when the weather reduces PV output, due to clouds, rain or the harmattan wind, the number of days when the PV generator delivers enough energy to cover the needs raises, while investment for the other components as the storage and the battery inverters remains the same.

For that reason, a generator of 44 kWp is recommended for the solar power system charging the e-bus battery.

5.2.8 Solar power system configuration

With the above described sizing, the following power system represents a good starting point for further investigation and discussion:

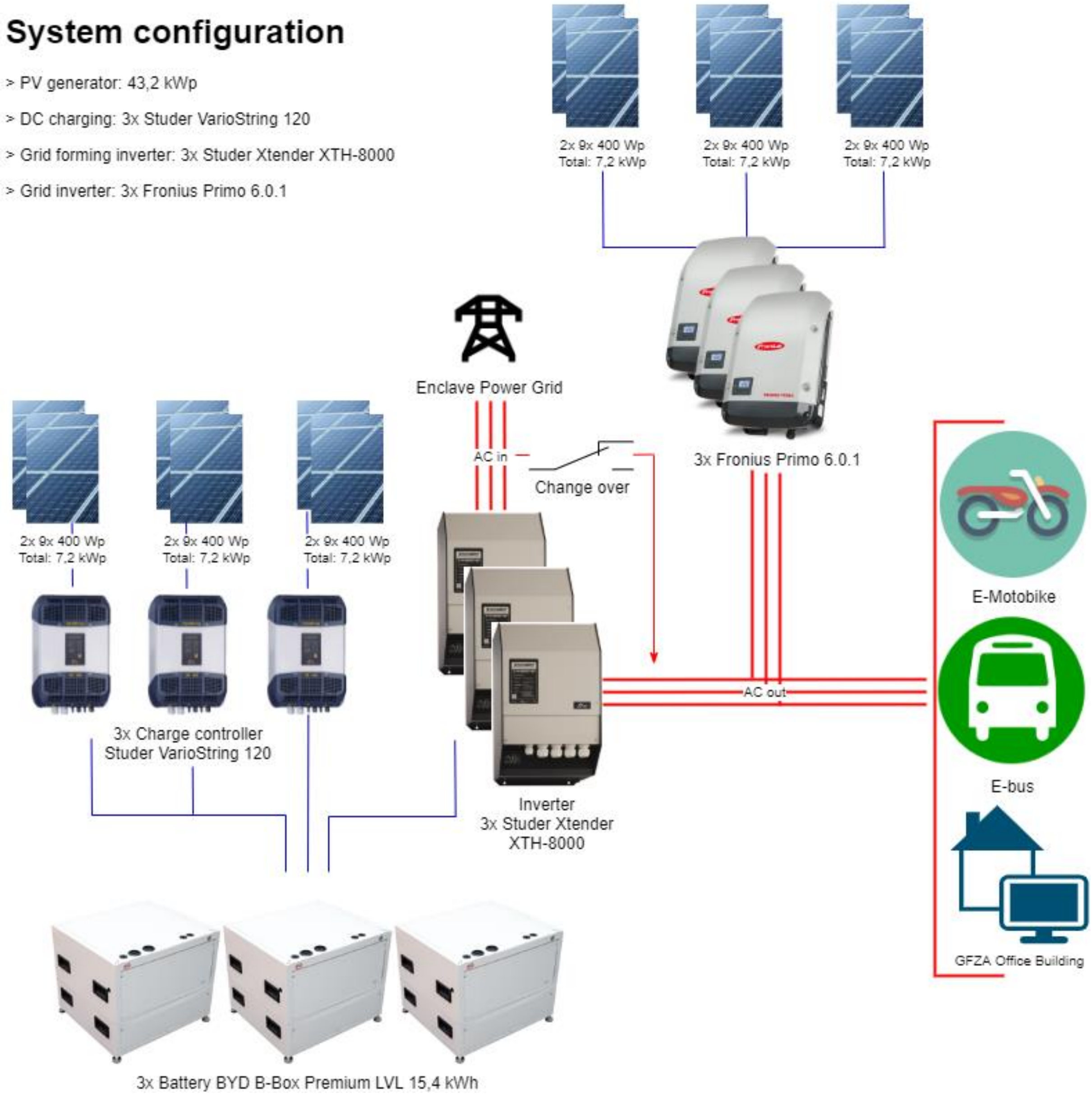

Figure 10: Power system for charging e-busses, e-motorbikes and power supply for GFZA office building

The area needed for the installation of the power system in the figure above is defined by the area of the PV generator consisting of 108 solar modules. With the area of one single module being 2 m², the total area needed is of 216 m². With a free standing, overhead installation, the area below the solar modules can be used as shaded parking lot. The space around the GFZA office building offers enough space for the installation. The connection point to the Enclave Power distribution point is in the area as well.

The above proposed power system can be adapted for longer autonomy time by extending the solar generator and the battery. Output power can be increased by adding battery inverters to be installed in parallel.

In case of prolonged bad weather or a reduction of the power system, the Enclave Power grid can be used as an additional power source for e-vehicles charging.

PV installation with larger autonomy

Larger PV installations that have several days of autonomy are possible, however they would produce excess energy for most of the year. From the financial point of view, such installations are only feasible if the excess energy can be used. In the case of the TEPZ, excess power could be used to serve office buildings or industrial production. Advantages of a larger power system would be the extended possibility of providing low carbon electricity at under grid level prices, as shown in the following section.

6 Comparison between utility grid charging and solar charging

The energy needed for the e-bus operation has been analyzed in the section 5 amounts to 129.8 kWh per day of operation (see Table 6: Energy demand for e-bus operation).

For a comparison of charging using the utility grid and using a solar power system it is important to understand that the benefits of a solar power system go beyond the energy needs of the operation of the e-bus. While a bus might not be operated every day, the solar system will still generate solar power that can be used for other purposes, e.g. for operating the GFZA office building or can be fed into the utility grid in the Enclave.

In this section, both the energy needed to operate an e-bus as well as the total energy produced by a solar power system will be considered.

6.1 Cost comparison

The approximate cost for the solar power system described in section 5.2.8 amounts to the following:

Component	Unit price [€]	Units	Total component price [€]
Solar module 400 W	120.00	108	12960.00
Support structure	2000.00	1	2000.00
Charge controller Studer VarioString 120	1734.02	3	5202.05
Battery inverter Studer Xtender XTH-8000	4432.19	3	13296.58
Grid Inverter Fronius Primo 5.0.1	1086.23	3	3258.68
Battery BYD B-Box LVL Premium 15,4 kWh	6269.33	3	18807.98
Cables, overvoltage protection, breakers	500.00	1	500.00
Installation	5000.00	1	5000.00
Total price			**61025.30**

Table 20: Cost of solar power system for e-bus charging

6.1.1 E-bus charging

If only e-bus charging is considered, the daily amount of electricity needed is of 129,8 kWh (see Table 6: Energy demand for e-bus operation).

The approximate cost of a solar power system that covers that need has been calculated in the previous section.

The cost comparison for charging the e-bus using the above mentioned solar power system and the utility grid is based on following data and assumptions:

Parameter	Value	Type (fact/assumption)
Utility grid electricity price	0.14 €/kWh[4]	Fact
Utility grid average price increase	3%/year	Assumption
Solar power system cost (capex)	61 025.30 €	Assumption
Solar power system operation and maintenance	2% of capex	Assumption

Table 21: Parameters for cost comparison between solar and grid charging, realistic scenario

While the assumptions in the table above might vary, they are based on empirical data and reflect the current prices, knowledge and expectations for both the utility grid power price as well as for solar power systems in Ghana.

Using the data from Table 21: Parameters for cost comparison between solar and grid charging, the yearly cost for electricity to charge the e-bus battery sums up to:

$$Cost\ of\ utility\ grid\ electricity\ for\ e_{bus} charging\ \left[\frac{€}{year}\right] = Needed\ electricity\ per\ day\ \left[\frac{kWh}{day}\right] * number\ of\ operationdays\ per\ year\ \left[\frac{day}{year}\right] * cost\ of\ electricity\ [\frac{€}{kWh}]$$

Following values have been used for determining the cost of utility grid electricity for e-bus charging:

- Needed electricity per day = 129.8 kWh
- Number of days per operation days per year = 365 days/year
- Cost of electricity = 0.14 €/kWh

Daily e-bus operation can be assumed due to the large number of employees in the TEPZ.

With these values, the yearly cost of utility grid electricity for e-bus charging sums up to:

$$Cost\ of\ utility\ grid\ electricity\ for\ e_{bus} charging\ = 129.8 \left[\frac{kWh}{day}\right] * 365\ \left[\frac{day}{year}\right] * 0.14\ \left[\frac{€}{kWh}\right] = 6\ 632.78 \frac{€}{year}$$

The following graph shows a cost comparison between charging through a solar power system and through the utility grid.

[4] Cost provided by Enclave Power Company (LMI Holdings Limited)

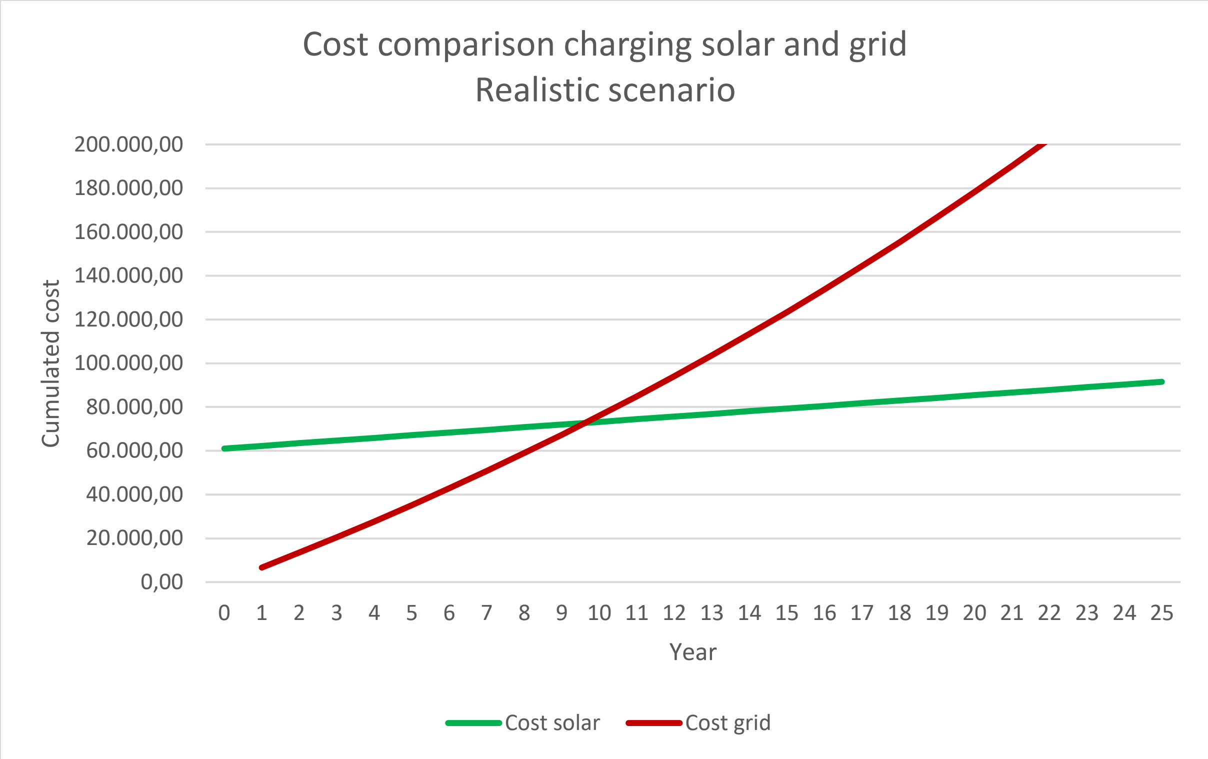

Figure 11: Cost comparison for charging through a solar power system and the utility grid, realistic scenario

The green line represents the cost for the solar power system, including the operation and maintenance cost. Both have been summed to 2% of the capital cost per year, constant over the lifetime of the power system. The 2% also include the replacement of components such as batteries and power electronics as the charge controllers and the inverters, if this will be necessary. By choosing appropriate high quality components, a manufacturer warranty of 10 years can be obtained. Looking at a power system lifetime of 25 years this leads to a realistic assumption that batteries and power electronics need to be replaced one time only. This is covered by the assumed operation and maintenance costs and included in the cost comparison above.

With the data, assumptions and considerations above, the break-even between solar and utility grid charging is reached after between 9 and 10 years. Provided that high quality components are chosen for the solar power system, financial break-even is reached while all the power system components are still covered by manufacturer warranty.

Solar power system financial advantage

The cost comparison emphasizes the financial advantage of a solar power system over the usage of utility grid power, especially in the case as the e-bus charging, when a large part of the produced solar energy is constantly and reliably used on a daily basis.

Conservative scenario for cost comparison

The cost comparison between solar and utility grid electricity for charging the e-bus can also be considered with a more conservative scenario, with a more moderate price increase for the utility grid power of 2% instead of 3% per year and a higher operation and maintenance cost for the solar power system of 4% per year, as summarized in the following table.

Parameter	Value	Type (fact/assumption)
Utility grid electricity price	0,14 €/kWh	Fact
Utility grid average price increase	2%/year	Assumption
Solar power system cost (capex)	61 025.30 €	Assumption
Solar power system operation and maintenance	4% of capex	Assumption

Figure 12: Parameters for cost comparison between solar and grid charging, conservative scenario

From the values from the table above, the following cost comparison between charging through a solar power system and the utility grid results:

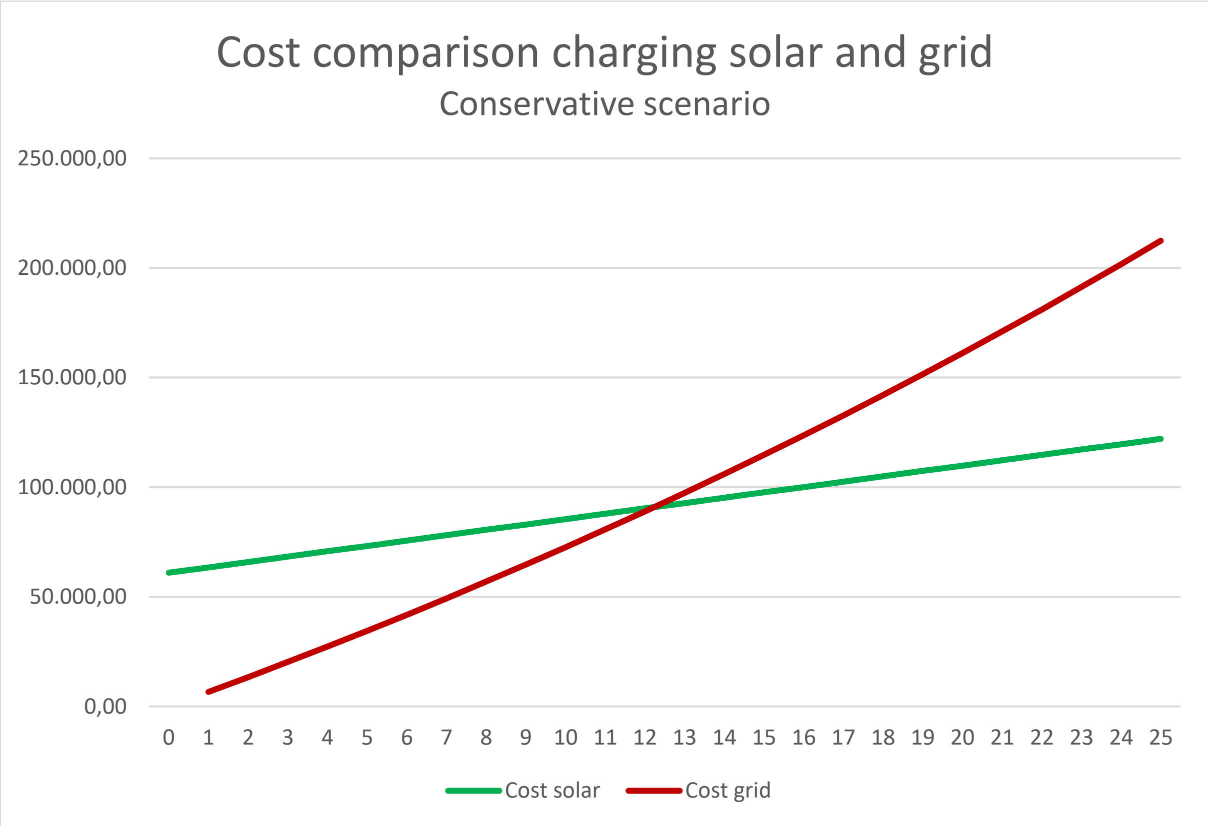

Figure 13: Cost comparison for charging through a solar power system and the utility grid, conservative scenario

Solar power system financial advantage in conservative price development scenario

Even when considering this more conservative price development scenario, break-even is reached in an acceptable time of less than 13 years, when the batteries and the power electronics are just out of warranty and are very likely to still be functioning correctly.

6.1.2 Further considerations for cost comparison

Two things are important to notice when considering the price comparisons in the previous section:

1. The solar power system has been sized to provide enough energy for the e-bus on an average day of the month with the lowest solar irradiation for the installation area.
2. The cost comparison only includes the costs per kilowatt-hour for the electricity from the utility grid. The environmental costs due to the negative impact of the high CO2 emissions for the utility grid power is not taken into account.

Excess power produced by the solar power system

The first consideration leads to an additional saving in respect to usage of utility grid power and can be quantified by subtracting the total energy needed for recharging the e-bus from the total energy that it expected to be produced by the proposed solar power system.

$$Excess\ power\ by\ solar\ power\ system\ \left[\frac{kWh}{year}\right]$$
$$= Total\ power\ by\ solar\ power\ system\ \left[\frac{kWh}{year}\right]$$
$$- Power\ for\ e\_bus\ recharching\ [\frac{kWh}{year}] =$$

In the following table the expected yield of the proposed solar power system is calculated.

Yield by solar power system

Month	**Equiv. Sunsh. Hours /day**	**hWh/day**	**Available surpluls energy/day [kWh/day]**	**Available surpluls energy/month [kWh/month]**
Jan	6.43	283.08	153.28	4751.56
Feb	**6.56**	288.44	158.64	4441.8
Mrz	5.67	249.42	119.62	3708.32
Apr	6.10	268.59	138.79	4163.72
Mai	5.59	246.07	116.27	3604.48
Jun	4.64	204.19	74.39	2231.68
Jul	**4.40**	193.70	63.90	1980.88
Aug	4.47	196.85	67.05	2078.56
Sep	4.64	204.15	74.35	2230.36
Okt	5.49	241.43	111.63	3460.6
Nov	5.81	255.77	125.97	3779.16
Dec	5.67	249.28	119.48	3703.92
Total surplus energy per year		**40135.04**		

Table 22: Available surplus energy from solar power system

By a utility grid electricity price of 0.14 €/kWh the additional saving amount to:

Month	**Available surpluls energy/month [kWh/month]**	**Additional savings/month [€/month]**
Jan	4751.56	665.22
Feb	4441.80	621.85
Mrz	3708.32	519.16
Apr	4163.72	582.92
Mai	3604.48	504.63
Jun	2231.68	312.44
Jul	1980.88	277.32
Aug	2078.56	291.00
Sep	2230.36	312.25
Okt	3460.60	484.48
Nov	3779.16	529.08
Dec	3703.92	518.55
Total additional savings [€/year]		**5618.91**

Table 23: Additional savings on electricity bill due to solar power system electricity usage

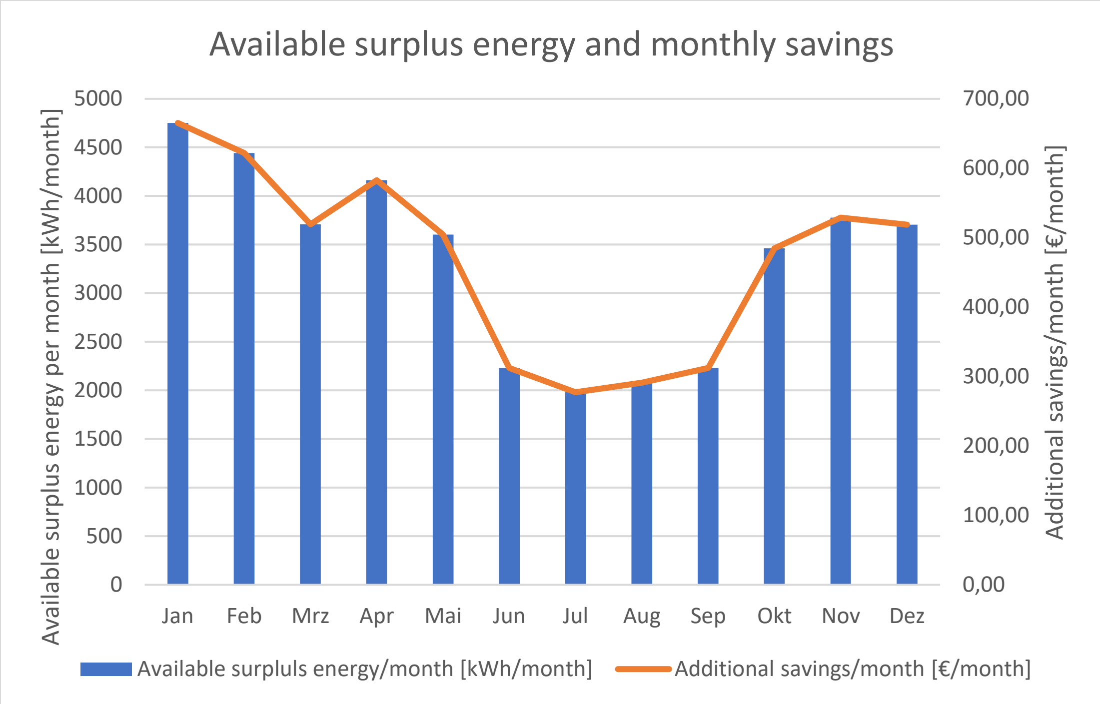

Figure 14: Available surplus energy and monthly savings

The monthly savings in the figure above are additional to the in Figure 11: Cost comparison for charging through a solar power system and the utility grid, realistic scenario and Figure 12: Parameters for cost comparison between solar and grid charging, conservative scenario.

The yield by the solar power system does not consider the efficiencies of the components used in the power system itself. Part of the production and thus part of the surplus will be lost due to the efficiencies of the components as described in section 5.2.4 Dimensioning of a PV power system for e-bus charging.

Even with the consideration of a significant loss due to the efficiencies of the components of the solar power system, the overall surplus remains well positive.

Consideration of the full cost of electricity production

The second consideration, the full costs for the utility grid electricity, including the environmental costs caused by the negative impact of the high CO2 emissions per kWh of generated power lead to a higher total cost for the utility grid electricity and a significantly earlier break-even point when comparing the solar power system cost versus using the utility grid.

6.2 Emissions comparison

The emission comparison between the solar power system and the electricity from the utility grid has been conducted using the specific CO2 emissions for the utility grid power mix at the TEPZ (see Table 8: Utility grid electricity cost and specific CO2 emissions) and two different values for the specific emissions of the electricity generated by the proposed solar power system.

Utility grid emissions

The utility mix emissions have been calculated to be 0.7 kgCO2/kWh. In CO2 emissions comparison below, this specific value has been calculated by the HSBO using the available utility grid energy mix of 31.5% hydro power and 68.8% thermal.

Solar system electricity emissions

A model developed by HSBO for the quantification of CO2 equivalent emissions for solar mini-grids has been used to quantify the emission of the hereby proposed solar power system.

The specific emissions amount to 0.054 kgCO2/kWh. The total emissions amount to 106 000 kgCO2 for the whole lifetime of the solar power system. This figure also includes one renewal of the batteries and the power electronics during the solar power system lifetime. The emissions for the renewal are accounted for from the beginning of the lifetime. The green line in the following figure, indicating the total CO2 emissions of the solar power system, does thus not show the typical increase in emissions around the half of the lifetime, when a renewal of components is expected to be necessary.

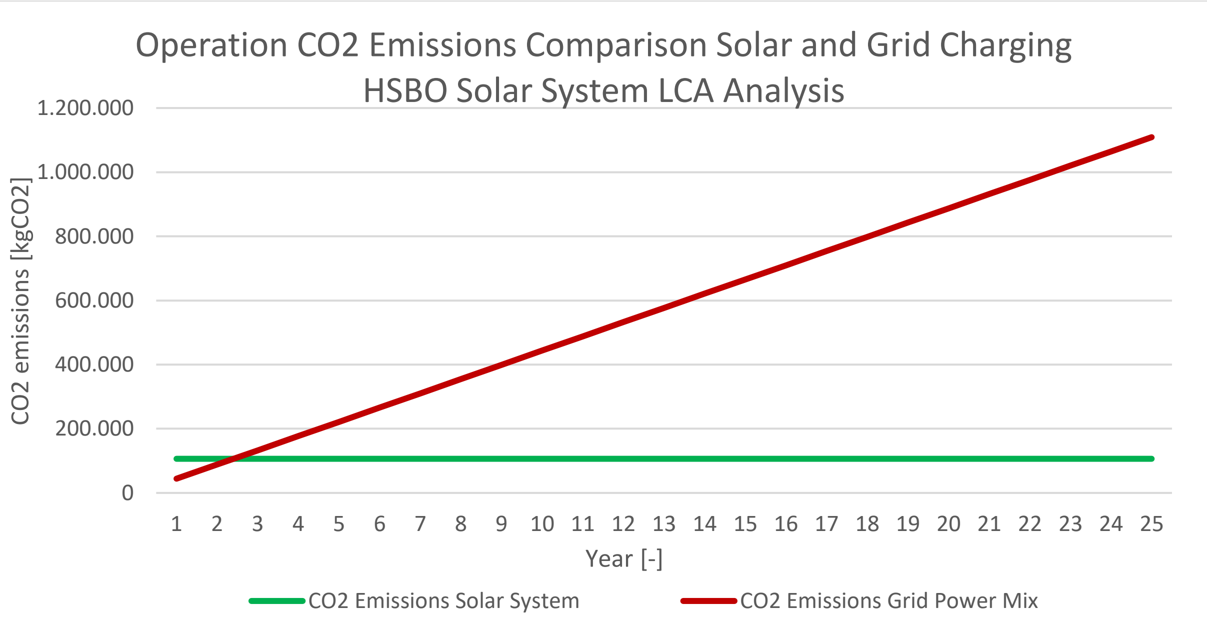

Figure 15: Operation CO2 Emissions Comparison Solar and Grid Charging, HSBO Solar System LCA Analysis

The figure above shows that the emissions break-even point between the proposed solar power system and charging from the utility grid is reached after less than three years of operation.

At the end of the solar power system lifetime the emissions from the utility grid result to be higher by more than a factor of 10, compared to the solar power system CO2 emissions.

7 Microgrid creation within the Tema Export Processing Zone, power trading and demand side management

The power system described in the section 5.2.8 Solar power system configuration generates a surplus energy, described in section 6.1.2 Further considerations for cost comparison.

This surplus, together with the economic and environmental advantages of solar power in the TEPZ described in the section 6 Comparison between utility grid charging and solar charging, leads to the advantages of creating a solar microgrid in the TEPZ, beginning by the solar power system for the e-bus charging and the office building of the GFZA.

8 Job creation

Within the topics described in this study, the best option for job creation lies in the installation, operation and maintenance of a solar power system to charge the e-bus, or to charge the e-busses in the future, and to serve the office buildings and industrial facilities in the TEPZ. The job creation and the solar installations go hand in hand with the financial and environmental benefits described in the this study.

Together with a platform for power trading the new microgrid has the potential to grow by adding installations on adjacent buildings by the companies using the buildings themselves. Using the platform for power trading, solar producers connected to the microgrid have the possibility to sell their surplus energy and make profit out of energy that would otherwise be wasted.

If done by local manpower, the installation of solar power in this industrial complex does have the potential for boosting local know-how and experience in the field. The advantage over large strictly grid tied installations are the lower capital cost of the single installations and the possibility of having different owners of power systems connected together into a power grid that enables power trading.

Different owners and a number of small installations mean that the capital costs are divided and held by many actors, thus making the installation of solar power system more feasible from the financial point of view and more realistic from the complexity side.

The existing power connection between the users in the TEPZ can be kept and used for the additional transmission of solar power within the TEPZ.

The larger the microgrid, the more jobs are created, within the TEPZ for the maintenance of the solar power systems and outside, within the companies installing the solar power systems in the TEPZ, therewith boosting the solar sector in the country.

From the e-mobility side, job creation involves the formation of mechanics to maintain the e-vehicles and the creation of local know-how for the installation and operation of charging stations.

Installation and operation of charging stations for e-mobility purposes have the potential to boost solar installation in general and jobs related to these: solar power system installers, charging stations operators as well as the solar market needed to support an increased number of solar installations.

9 Conclusions and recommendation for further steps

In this feasibility study routes and operation times for mobility service in the TEPZ have been identified and described.

Usage of an e-bus instead of a diesel powered vehicle brings the advantage of lower operational cost as well as a significantly lower CO_2 impact over the lifetime, assuming that the e-bus is powered by a low carbon electricity source.

A solar power system with battery storage bears both financial and environmental impact advantages compared to the current electricity mix in the utility grid in the TEPZ. With a financial break-even reached within 10 to 13 years, the warranty period of high quality solar power system components or slightly above, and a CO2 break-even reached in less than three years of operation, the advantages of a solar power system over the utility grid are very tangible.

Beyond charging of an e-bus, excess power from the solar power system can be used to serve office buildings, such as the GFZA office building. Usage of excess power to charge light electric vehicles to be used for personal mobility as a service or for food delivery is also possible, given the small size of the batteries and the low quantity of energy needed be light electric vehicles. Furthermore, a solar power system as described in this feasibility study is suitable to be extended by developing a solar microgrid which connects consumers in the TEPZ. The financial and environmental benefits described in this study apply also for further solar installation, especially in case they are connected together and the generated power is used in its entireness. The latter is a key factor for reaching financial and environmental benefits.

The implementation of a solar microgrid can be started with a first solar installation in the TEPZ. Potentially the one for charging of an e-bus. Installation of the proposed solar power system and inclusion of the GFZA office building as a consumer of excess power would mark a good starting point. An installation of a further power system on the GFZA office building, then connected with the e-bus charging solar power system to establish the base of a TEPZ microgrid, is a further step that can be taken. The current utility grid should be part of the local solar microgrid and provide energy when solar production is too low. Feeding in into the local utility grid also insures that the complete solar energy can be used, thus reducing both the cost per kilowatt-hour and the environmental impact.

From the technical Further investigation and load profile measurement in selected offices, starting from the GPZA office building is a step that should be taken.

Establishment of a platform for power trading within the TEPZ bears the potential to incentivize further solar installations by other companies in the TEPZ. To ensure a proof of operation for the power trading platform, power trading between the e-bus charging solar power system and the GFZA office building power system can be established.

Gaining new actors within the TEPZ interested to join the microgrid, incentivized by the expected savings by using solar generated power is a way to save financial resources, lower the environmental impact of the companies within the TEPZ and create local jobs for planning, installation, operation and maintenance of solar power systems and microgrids.

The operation of the e-bus together with the solar power system for charging and the microgrid with the GFZA office building must be empirically tested to validate the financial and environmental benefits predicted for the usage of the hereby proposed solar power systems.

Annex 4: Report SunCrafter

Feasibility Study

Solar-powered electric vehicle delivery service and sharing scheme at Tema Export Processing Zone

By SunCrafter GmbH

Berlin, 30.11.2021

List of Figures

Abbreviations

CO2 eq.	Carbon Equivalent
DoC	Depth of Charge
EPZ	Export Processing Zone
EV	Electric Vehicle
GHS	Ghanaian Cedi
GWP	Global Warming Potential
IoT	Internet of Things
Km	Kilometer
Kmh	Kilometer per hour
kW	Kilowatt
kWh	Kilowatt Hour
LEV	Light Electric Vehicle
MPPT	Maximum Power Point Tracker
SDG	Sustainable Development Goals
SSA	Sub-Sahara Africa
TUMI	Transformative Urban Mobility Initiative
UN	United Nations
Wp	Watt Peak
GIZ	Gesellschaft für Internationale Zusammenarbeit

Table of Content

Astract

Sustainable Transport Concepts are crucial for the sustainable economic development of Ghana and other African countries. The present study outlines and analyses the impacts of two micro e-mobility (sharing) schemes based on eMotorbikes as well as solar powered charging stations at the Tema Export Processing Zone. Both use cases are explored with regards to their technical feasibility, their economic viability as well as their environmental and social desirability. Based on literature and internet research and expert interviews, a model is set up. The assumptions regarding the first use case, a food delivery scheme, lead to a hypothetical system set up including 14 vehicles and 6 solar stations, delivering on average 1000 meals per day, covering the cost of the vehicles and infrastructure with an extra charge of 0.04 EUR or 0.27 GHS per meal. Both in terms of cost and CO2 eq. the electrified sharing scheme is superior to one that is based on combustion engine vehicles. The second use case, an employee transport sharing scheme which allows employees to travel across the zone to their respective work destinations flexibly, is analysed in three scenarios, assuming that either 10, 20 or 30% of employees use the sharing offer. Here the required fleet size ranges from 55 to 110 vehicles with 29 to 52 charging stations required for powering the service throughout the year. The cost per ride ranges from 0.16 EUR or 1.1 GHS in the moderate (10% usage rate) to 0.10 EUR or 0.68 GHS in the established (30% usage rate) scenario. Again, the electrified mobility scheme performs superior to a combustion engine based one, both in terms of economic viability and environmental impact.

The conclusions are summarized and connected to impacts on job creation and scalability of the use cases.

Lastly, a qualification concept regarding the usage and maintenance instructions of the solar stations and -in a limited way- the eMotorbikes is brought forward.

Intro

Project Scope

Sustainable Mobility is the way forward – not only in developed countries but especially so in developing countries, as it holds the potential for accelerated yet sustainable economic development.

The United Nations framework for Sustainable Transport spans across 6 indicators - safe, affordable, accessible, efficient, resilient, and minimizing carbon emissions and general negative environmental impact - and touches upon a vast variety of Sustainable Development Goals[1].

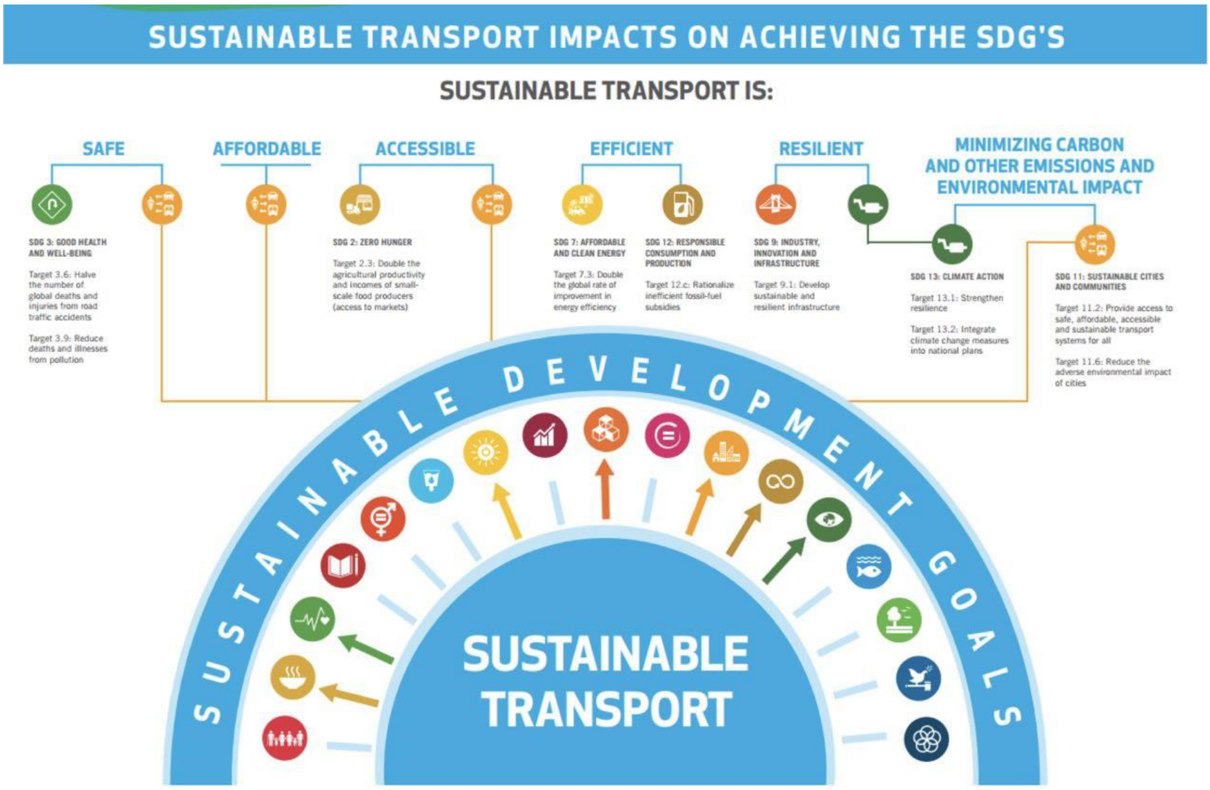

Figure 1 UN Sustainable Transport Framework (HLAG-St, 2016)

When exploring the feasibility of a sustainable mobility concept, the desirable outcome should show that all or at least the majority of the above parameters should be strengthened. In the conclusion of

[1] *HLAG-St, 2016*

the study we shall therefore assess the concepts impact within the UN framework of sustainable mobility.

The 'Transformative Urban Mobility Initiative' (TUMI), an alliance of the world's leading organizations in sustainable transport and part of the German 'Gesellschaft für Internationale Zusammenarbeit' (GIZ), focusses in two of their four Mobility Actions on the aspect of clean powering of mobility[2].

The main emphasis of the present paper lays on the clean powering of energy efficient transport solutions, therefore correlating largely with the focus of TUMI.

The solutions presented in the paper are energy efficient in up to four ways:

1. They are electrified,
2. solar powered,
3. shared,
4. and based on micro e-mobility.

We illustrate the fourth point with an example: A bus driving with two passengers in it is less efficient than an e-motorcycle with two passengers on it. Another driver for the choice of micro e-mobility is the purchasing power of the households in the region, which is oftentimes not sufficient to buy cars, yet the motivation to use motorized transport is high. Electrified micro mobility presents a cheap yet high convenience transport mode with positive status effects[3].

The rationale behind the electrified micro e-mobility being powered with off-grid solar systems rests on the fact that globally still about 800 million people are without access to electricity and - especially in SSA - a large percentage of households and firms are being connected to unreliable power supply[4]. This is also true for the country the study is set in and regular and sustained power outages across Ghana in 2021 showed that 'dumso' and its effects are still an obstacle in current times[5].

Therefore, not only in SSA rural regions but even in Ghana's urban centres, off-grid solar systems appear as crucial technology to enable micro e-mobility[6]. Based on the above-mentioned considerations, the

[2] Transformative Urban Mobility Initiative. Link: https://www.transformative-mobility.org/partners/giz

[3] Global Fleet, 2021, last accessed on 29.11.2021 via https://www.globalfleet.com/en/smart-mobility/africa-middle-east/features/micro-mobility-why-africa-leading-and-where-its-going?a=FJA05&t%5B0%5D=Africa&t%5B1%5D=Micro-mobility&curl=1

[4] last accessed on 29.11.2021 via https://www.sun-connect-news.org/articles/technology/details/a-new-horizon-for-solar-appliances/

[5] last accessed on 29.11.2021 via https://citinewsroom.com/2021/04/the-2021-dumsor-crisis-what-we-know-so-far/

[6] last accessed on 29.11.2021 via https://www.esi-africa.com/industry-sectors/future-energy/revolutionising-e-mobility-in-africa-one-bike-at-a-time/

scope of the study is the analysis of a set of indicators, decisive for the success of establishing a micro e-mobility (sharing) concept at the Tema EPZ.

The two use cases or concepts explored are 1) food delivery and 2) employee transport sharing system. The indicators which were explored cover three dimensions:

1. Technical feasibility i.e. matching power demand and supply.
2. Economic viability i.e. cost parity compared to Petrol fuelled systems.
3. Environmental and social desirability i.e. comparison of GWP of Petrol fuelled alternatives and general job creation potential.

Both concepts bring together vehicles provided by SolarTaxi (Ghana) and charging infrastructure provided by SunCrafter (Germany). The two presented concepts or use cases, serve to illustrate the potential of the solution. Some of the conclusions of the study are likely applicable to more use cases and indicate the level of replicability and scalability to comparable settings.

The study consists of four parts:

1. Introduction to project scope, context of the EPZ, vehicles and solar stations.
2. Outline of methodology.
3. Analysis of technical, economic, environmental and social indicators for concepts 1 and 2, including the conclusion on scalability, replicability and impact.
4. Qualification concept regarding usage and maintenance of both asset types, vehicles and charging stations.

Tema Export Processing Zone Enclave

Launched in 2000 and located east of the capital city Accra and 24km from the Accra International Airport, the Tema Export Processing Zone Enclave (from here on named Tema EPZ) hosts over 70 companies in which over 9000 People are employed. It covers a total of 4.8km2, which is divided into managerial zones, 4km2 managed by LMI Holdings and 0.8km2 managed by Ghana Free Zones Authority (GFZA). Currently, only 55% of the available land is used. The Tema EPZ hosts a range of on-site facilities including a dedicated electrical power grid, large water reservoir constructed to ensure the constant supply of water, a central sewerage system, telecommunication services and security enclosures. [7]

[7] Ghana Free Zones Authority, last accessed 29.11.2021 Link: https://gfzb.gov.gh/index.php/tema-export-processing-zones/

A first-class road network connects Tema EPZ to the Accra International Airport and Ghana's largest seaport, which is located in Tema. The enclave was created to be a multipurpose industrial park to enable non-free zone investors, corporate and start-ups to have access to an industrial site and superior services, to allow production within Ghana. [8]

Located in Tema, Ghana's major residential and industrial city. Tema is one of Ghana's fastest growing cities with well-developed infrastructure, including Ghana's largest seaport. There are many industries located in the Tema industrial area which is deemed a major hub of skilled labour.

Access to the Tema EPZ is possible by car or public transport. Arriving with a car, access to the premises is via the Accra-Aflao road which runs along the north side of the area, unfortunately there are no parking facility at the entrance of the enclave.
To arrive by public transport is possible, with the next official bus stop 2.5km from the entrance.

The Vehicles

The SolarTaxi Bike ST-02 is a 2kW electric motorbike, designed and built in Africa for Africa. The 72V 20Ah, 1.44kWh (DoC 50%) lead-acid battery provides a range of up to 50km and can be fully recharged within just over 3 hours (charging rate 72V 3A, 216W). The SolarTaxi Bike ST-02 can reach speeds of up to 65km/h with added safety features including hydraulic shock absorbers both front and rear, front disk brakes and rear drum brake.
The SolarTaxi Bike ST-02 offers a super-large steel framed tail box, ideal for mounting a delivery box or transporting an extra passenger.[9]

[8] idem

[9] Technical data sheet SolarTaxi Bike ST-02 November 2021

Figure 2 SolarTaxi Bike ST-02. Source: SolarTaxi

Electrical overview:[10]

Capacity: 1440Wh

Depth of Charge: 50%

Usable capacity: 720Wh

Charging rate: 216W (72V, 3A max)

Charge time: 200min

Motor size: 2kW

Range: 50km

Maximum speed: 65km

SolarTaxi is a Ghanaian owned manufacturer and operator of electric mobility vehicles, ranging from EVs to LEVs. SolarTaxi has an emphasis on the training and employment of local female engineers and mechanics.[11]

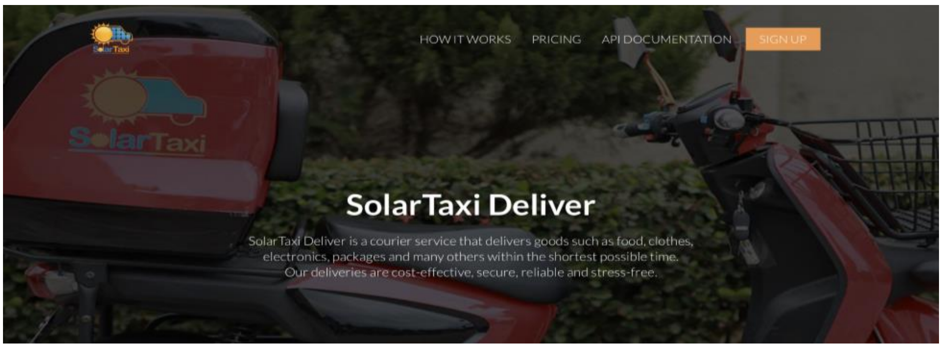

Figure 3 Solar Taxi Website Screenshot, 29.11.21

[10] idem
[11] Interview with Isaac Atia-Abugbilla, 23.11.2021

The Infrastructure

The SunCrafter SolarBay is a fully solar powered charging and docking station, custom designed to accommodate for local conditions in the Africa market.

The SunCrafter SolarBay is powered by locally sourced and certified 2nd-life solar panels, with all components able to be built or purchased locally. The integrated solar battery system (potentially locally sourced 2nd-life) ensures charging capacity at night. With a customisable power output, the SolarBay can be used to charge any type of light electric vehicle (LEV). Being completely solar powered, the SolarBay stations require no installation or grid connection, for agile adaptation of the charging network to accommodate the development of demand.

Each SolarBay incorporates LED lighting, phone charging facilities and can optionally support a public Wi-Fi hotspot and/or surveillance cameras.

Design Choice

The SolarBay was designed to balance the following features:

- maximum possible solar power generation (optimal solar tilt and maximum heat reduction)
- high visibility to increase user experience
- quick installation for rapid deployment
- agility for location optimisations
- maximum safety against theft and strong winds
- sustainable 2nd life or reusable components
- maximum local production potential

Component List

Each SunCrafter SolarBay comprises of:

2x Solar panels (min 315Wp each), locally sourced and tested

1x Solar panel mounting frame (steel), locally built

1x Base (concrete), locally constructed

1x Station mounting plate (steel), locally built

1x Solar mast (steel), locally built

1x IoT Battery Box, components designed in NL, made in China, locally bought and assembled

Custom-made 3 port dock, designed in Germany, built in China

Figure 4 Rendering of proposed solar station with eMotorbikes at EPZ Canteen

Electrical overview:

Solar capacity: min 630Wp (2x 315Wp)

Tilt of solar panels: 25º

Battery capacity: 2.4kWh

Output power: 500W max

Output voltage: 1-60VDC / 220VAC

SunCrafter is a German, female-led manufacturer and operator of off-grid solar powered charging infrastructure for LEV in Europe and Africa. The last projects took place in Kumasi and Accra, where 3 SolarBay stations (model 1) were installed to power shared cargo e-bikes and e-mopeds.

Figure 6 SolarBay at KNUST Campus, Kumasi, Nov. 2021

Figure 5 SolarDock at EUREF Campus, Berlin, Okt. 2021

Docking and Charging SolarTaxi Bikes St 02 at SunCrafter SolarBay stations

Dock-based sharing systems in comparison to free-floating systems, have the advantages of added security for the vehicles and reduced operational costs.

Security/reliability:

Once a vehicle is docked and locked at a solar station, the vehicle can only be removed for a rental/delivery or service staff. Vehicles parked at solar stations are under surveillance 24/7, reducing risk of vandalism and theft. If a vehicle is stolen or damaged during a rental or delivery, the user/staff member is able to be held reliable. Upon returning of the vehicle, the user takes a photo of the via within the sharing app. This photo will be reviewed in the case of a damage report by a following user.

Reduced Operational Costs:

Unlike free-floating systems, dock-based sharing systems require minimal relocating/rebalancing and charging operations. The majority of relocating/rebalancing of vehicles can be done by incentivising with rental discount rates via the sharing app to dock vehicles at certain solar stations. In this particular case the docking is accompanied by the charging of the vehicles, which reduces the operational effort even further.

Methodology

The goal of the study is to analyse the feasibility of solar powered e-motorbike sharing concepts on the Tema EPZ, with the perspective to scale and replicate such concepts in comparable conditions. Therefore, the study is to fulfil two conditions:

- Customized to the Tema EPZ.
- Replicable to other sites.

In the 2nd use case „employee transport sharing concept', the model was built to account for a vertical upscaling of the system instead of a horizontal one, meaning instead of broadening the geographical scope, the density of the nodes was increased.

A literature and internet research was the basis to outline the pillars of Sustainable Mobility and gather information about the Tema EPZ. The findings resulted in the formulation of the introduction.

Then, expert interviews were conducted with representatives of the Tema EPZ, namely Mr. Boli, campus director, and Frederick Adjei, project coordinator. The following learnings came from these interviews:

- A food delivery system would improve coordination and management, while reducing operational stress on the canteen.
- Electric mobility is highly desired but always deemed unimaginable due to the grid power instability.
- By providing a large scale and centralised on-site food production facility, the campus can provide cheaper meals, therefore incentivising workers to buy meals on the campus.

With the help of the freeware 'Solar Atlas' by SolarGIS[12], the solar irradiation of the location was determined. On this basis, and with the technical data about the vehicles and the solar stations, we were then able to build a technical model resting on the main assumptions.

In the next step, the technical model was complemented with an economic model as well as a section concerning the Global Warming Potential. Both were used to compare the solar powered electrical sharing system to a fossil fuelled alternative.

[12] SolarGIS, 07.2021, last accessed: 01.12.2021. https://globalsolaratlas.info

Global Warming Potential is measured in kilograms of CO2 equivalent (kg CO2 eg.). It was chosen as the environmental impact indicator as it is easy to interpret and can even be translated into cost, through a (hypothetical) carbon price.

Subsequently, based on an input-output[13] analysis, the potential influence on job creation was assessed. Lastly, a site visit offered an opportunity to validate some of the technical and other assumptions underlying the model.

[13] ILO 2013: Methodologies for assessing green jobs. Last accessed on 29.11.2021 via https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_176462.pdf

Electrical Sharing Concept for delivery and commute

Intro to Sharing Concept: Electric vehicles powered by solar charging stations

Ownership and operational model

Instead of every individual buying an individual vehicle, with each vehicle requiring initial capital and ongoing maintenance, sharing vehicles are owned and operated by a central company, allowing users and delivery drivers access to vehicles via an app. For the use of private transport, a usage fee is calculated. This usage fee covers all costs of the vehicle, including fuel, maintenance, insurance and initial purchase price. The sharing model is considered to optimize the user benefit and the cost and resources required. The benefit of this digitalised vehicle sharing concept for food delivery, is the ability to hold individual drivers responsible for the vehicle during usage.

User Journey

Users and drivers must first register and validate their identification and connect a payment method to the sharing app. Vehicles are parked, locked and charged at the solar stations between rentals. If a vehicle is parked at a solar station, it is free to be taken or rented. The user must be within a 5-meter radius of the solar station to be able to unlock a vehicle via the app. As soon as the vehicle is removed from the dock, the rental begins. The rental ends automatically once the vehicle is docked again at a solar station. An in-app photo is required at the end of the trip. This is used in the case of a dispute over vehicle damages.

Concept 1: Food delivery from canteen to businesses in the EPZ

Figure 7 Canteen Tema EPZ. Source: SunCrafter

Figure 8 Location of canteen. Source: Google Maps

Assumptions about the delivery service and number of vehicles

On site there is a canteen building, which is currently not operational. The canteen has a maximum meal capacity of 1000 meals per day according to Mr. Boil.

We assume that from the up to 9000 employees on campus, an average of 10% order food on a daily basis. We are assuming further that there is a variability of employees on site, with a peak of 5000 employees during middays, stemming from an overlap of early and late shifts.

We assume that the canteen serves breakfast, lunch and dinner. The total amount of meals per meal time ranges between 200 and 500 during the midday peak.

With an estimated 10 meals which can be transported per delivery trip we arrive at a maximum of 50 trips at lunchtime and a total of 100 trips per day.

With the meal time peaks being approximately 2 hours long, and each average trip of 5km taking about 30 minutes, we derive that at the busiest time 14 vehicles are required to conduct all the trips.

Food Delivery Service - Assumptions	
Employees on site	9000
Number of employee's on-site morning	3000
Number of employee's on-site midday	5000
Number of employees on-site evening	2000
Percentage of employees ordering food on-site	10%
Number of meals ordered morning	300
Number of meals ordered midday	500
Number of meals ordered evening	200
Total number of meals delivered per day	1000
Number of meals delivered per trip	10
Number of trips morning	30
Number of trips midday	50
Number of trips evening	20
Number of trips per day total	100
Average trip length (km)	5
Average time per trip (minutes)	30
Peak time duration (minutes)	120
Number of trips per vehicle per peak time	4
Number of vehicles required morning	7.5
Number of vehicles required midday	12.5

Number of vehicles required evening	5
Maximum number of vehicles at peak time	12.5
Redundancy rate of vehicles	1.1
Number of vehicles required	13.75
Total required fleet size (rounded)	**14**

Electrical capacity and number of stations

From the calculated vehicle demand (14), the required electricity and hence solar charging stations can be derived.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6												
6 - 7	2	1	8	17	19	16	14	17	22	34	26	12
7 - 8	66	64	79	95	93	76	71	78	107	152	153	107
8 - 9	168	168	170	184	172	141	132	142	180	239	250	210
9 - 10	259	255	249	256	234	189	182	191	227	299	319	291
10 - 11	325	322	315	315	280	227	222	235	275	351	376	348
11 - 12	365	370	359	349	306	255	258	277	328	394	412	378
12 - 13	374	387	374	350	308	263	279	295	346	408	416	384
13 - 14	349	364	346	322	282	245	261	280	329	378	378	353
14 - 15	287	303	288	265	232	205	225	239	278	305	301	285
15 - 16	197	212	203	186	161	145	167	180	203	209	201	191
16 - 17	97	111	106	96	81	77	92	101	106	96	82	87
17 - 18	11	16	19	17	15	19	28	24	17	7	2	8
18 - 19							0					
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	2,500	2,573	2,515	2,451	2,182	1,859	1,930	2,060	2,417	2,872	2,917	2,654

Figure 9 Total photovoltaic power output [Wh] per month for SunCrafter solar stations in Tema, Ghana[14]

Each station generates on average 2,4 kWh[15] daily throughout the year. We opt for 100% security of supply and therefore have defined June, the month with the lowest solar irradiation in Ghana

[14] Global Solar Atlas, last accessed on 29.11.21
[15] Based on parameters listed under section: The Infrastructure - Electrical Overview, calculated 12.2021 by globalsolaratlas.info

(1,86kWh), as the baseline for all following calculations. To account for seasonal variability and self-consumption, we arrive at 1,61 kWh.

From the assumed 100 trips per day, each with an average length of 5km and electrical parameters of the eMotorbikes (0.7kWh battery capacity and 45km range), we derive that 6 stations, with 0.6kWp installed capacity, would service this demand. For both, the vehicles and the charging stations, we have factored in a redundancy rate of 10% and then rounded up to derive the number of units required.

Electricity required for vehicles (daily) total distance of entire fleet / distance per battery x battery capacity

500km / 45km per battery x 0.7kWh per battery = 7.78kWh

Number of stations required Electricity required (daily) / electricity produced baseline month (per day)

7.78kWh / 1.61kWh = 4.83 Stations + redundancy of 10% = 6 stations (rounded up)

Matching electricity demand and supply

Fleet	
Total fleet distance per day (km)	500
Average distance per vehicle daily (km)	36
Battery pack capacity per vehicle (kWh)	0.7
Range per battery (km)	45
Required charges per day	0.79
Required electricity per day per vehicle (kWh)	0.56
Required electricity per day for entire fleet (kWh)	7.78
Station Daily Average	
Generated electricity (kWh)	2.4
Self-consumption of station daily (kWh)	0.25
Usable electricity (kWh)	2.15
Station Monthly Minimum (June)	
Generated electricity (kWh)	1.86
Usable electricity (kWh)	1.61
Station Monthly Maximum (November)	
Generated electricity (kWh)	2.92
Usable electricity (kWh)	2.67
Stations	
Installed solar capacity per station (kWp)	0.6
Number of stations required in June	4.83

Redundancy rate charging stations	1.1
Total number of stations required (rounded)	6
Number of parking docks required per station (rounded)	3

Cost of sharing service

The vehicles are leased on a monthly basis for a rate of 130 EUR per month for the first two years. As of the 25th month, the leasing rate reduces to 30 EUR per month[16]. The total cost of vehicle leasing and maintenance for the entire fleet of 14 vehicles over a 5-year period equals 34,729 EUR or 236,905 GHS.

The solar station leasing costs are distributed in the same structure as the vehicle leasing rates, with a higher initial monthly rate and a reduced rate after the first two years of operation. A total cost for leasing 6 stations including maintenance over a 5-year period is 17,864 EUR or 121,891 GHS.

Additional costs of the sharing operation are made up by the cost of the sharing app, the surveillance system, the registration back end, the service hotline and the insurance. A cost of 1800 EUR annually, plus an additional 0.02 EUR per trip is estimated[17].

To be able to break down the cost to the delivery trips equally, we then derive an average annual cost from all three categories, vehicle, solar station and general operational cost. To pay the cost in equal rates however an interest free loan would be required. The total annual cost for the solar powered electrical delivery service amounts to 12,316.8 EUR or 84,041 GHS. Per trip this equals 0,37 EUR or 2.5 GHS adding an extra of 0,04 EUR or 0.27 GHS to each delivered meal.

Cost components of food delivery system

Vehicle Cost		Solar Station Cost	
Cost of vehicle per annum (year 1-2)	1920€	Cost of solar station per annum (y 1-2)	2400€
Cost of vehicle per annum (year 3-5)	360€	Cost of solar station per an. (Y3-5)	480€
Total cost fleet over 5 years	34,720€	Total cost solar stations over 5 years	17864€
Av. Annual cost	6944€	Av. Annual cost	3572€
Operational & Administrative Cost			
Operational cost of sharing system fix/annually		1800€	
Variable cost per vehicle trip		0.02€	

[16] Calculated on the SolarTaxi website 28.11.2021 Link: https://solartaxi.co/solar-bikes/
[17] Based on German service provider offer, converted to local purchasing power parity

Cost per trip	
Total cost of sharing system annually	12316€
Number of workdays per year	355€
Cost per trip (incl. variable cost)	**0.37€**
Cost per meal (€)	**0.04€**

Comparison to fossil fuel powered delivery service: cost and global warming potential (GWP)

Based on the current average price/ litre of Petrol in Ghana (0.97€/l or 6.61 GHS/l[18]) a total fuel cost per annum of 5.853,95 EUR is derived for the 177.500km total length of all trips. We assume a fuel consumption of 3,4 litres per 100kWh[19], which is a good but not excellent performance among small motorbikes.

Cost for combustion engine system

Cost for petrol (EUR)	0.97
Fuel consumption per 100km (l)	3.4
Cost per 100km (EUR)	3.298
Total distance per annum, food delivery (km)	177500
Petrol cost per annum (EUR)	**5853.95**

Powering the vehicles with the solar stations costs 3572.8 EUR in comparison, thereby proving to be 39% cheaper in cost.

[18] As viewed on 25.11.2021 on globalpetrolprices.com. Link: https://www.globalpetrolprices.com/Ghana/gasoline_prices/
[19] Based on spritmonitor ranking as viewed on 25.11.2021 https://www.spritmonitor.de/en/evaluation/economic_motorcycles.html

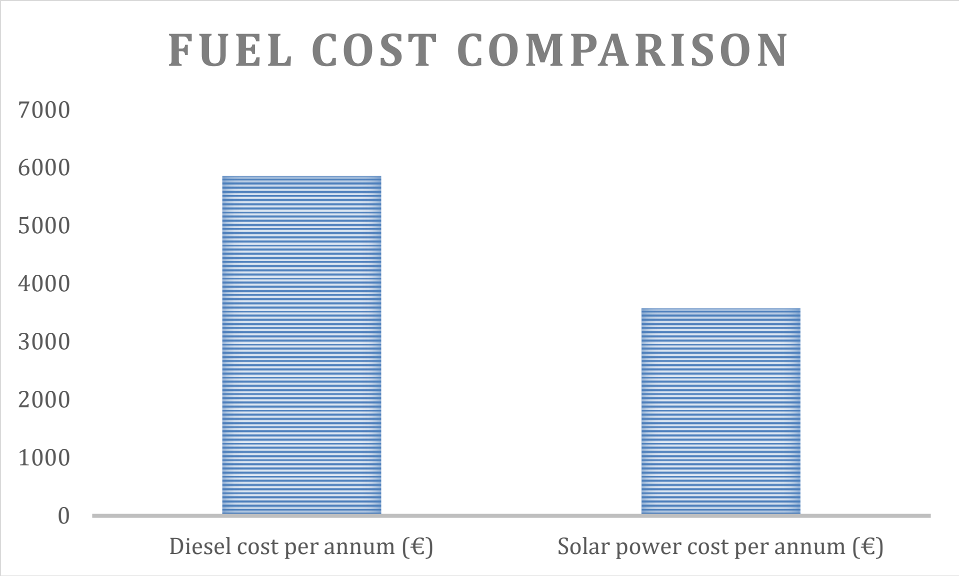

Figure 10 Fuel Cost Comparison delivery service

We measure the GWP by calculating the CO2 equivalent (CO2 eq.) per kilometre travelled. Based on a prior study of Schelte et. al.[20] we determine the CO2 eq. per kWh of generated electricity from the solar stations to be below 50g, translating to 0,78g of CO2 per km.

GWP comparison petrol vs. solar fuel

CO2 eq per kWh (solar station) in kg	0.05
km per kWh solar station	64.29
CO2 eq per km (electric vehicle powered at solar station)	0.0008
CO2 eq/annum solar stations (kg)	138.06
C02 eq per liter of petrol	2.39
km per 1 liter of petrol	29.41
CO2 eq per km in kg (petrol powered motorbike)	0.08
CO2 eq/annum petrol fuel (kg)	14435.72

The petrol fuelled kilometre in contrast accounts for 81,33 g of CO2 eq[21].

[20] Schelte et al., 2021: Environmental Impact of Off-grid Solar Charging Stations for Urban Micromobility Services
[21] Calculation based on petrol statistics as viewed on 26.11.2021. Link: https://ecoscore.be/en/info/ecoscore/co2

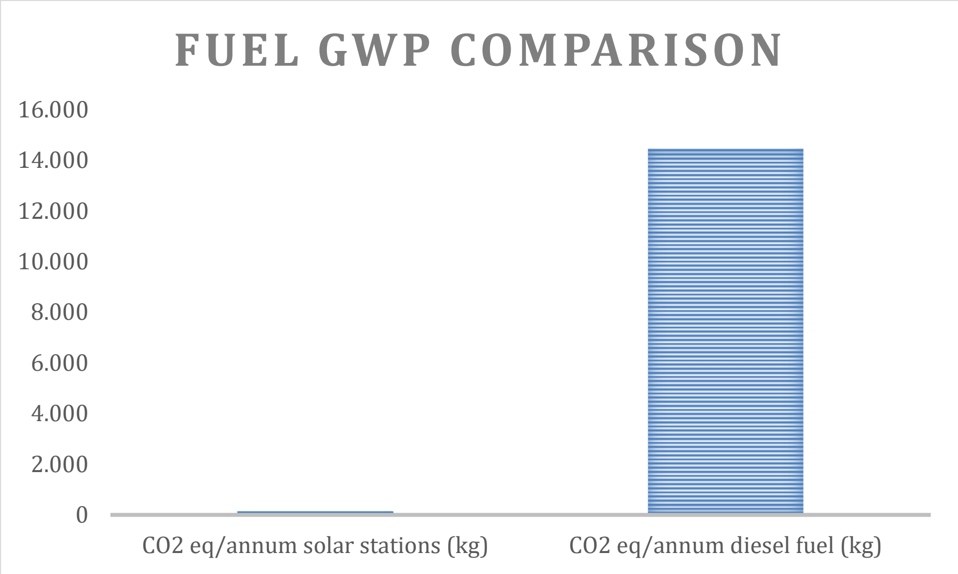

Figure 11 Fuel CO2 eq. comparison food delivery

Job Creation Potential

The opportunity of job creation in this pilot project lays less in the total number of jobs created, yet rather in the quality of the skilled jobs as well as the scalability of the concepts leading to potentially many more positions. The skilled opportunities require electrical and mechanical training towards future technologies, thereby guaranteeing young people positive long term and local career perspectives.

The employment effects are derived from the total number of trips, the meals prepared, the vehicles and charging stations built and maintained in the scope of the use case. Only direct jobs are considered, indirect or induced jobs are not.

We also do not compare to the potential employment effects a combustion engine vehicle delivery system would potentially create.

For meal preparation and packaging we calculate the creation of 22 unskilled jobs, while the delivery of meals would create another 7 driver positions.

The building, maintenance and administration of the vehicles would create 2 skilled jobs. The building and maintenance of the solar stations another 1 skilled position. Altogether the solar-powered eMotorbike food delivery concept leads to 29 unskilled and 3 skilled jobs being created.

Number and location of "nodes"

A node is defined as the location of one or more charging stations in close proximity including available vehicles. In the "food delivery" use case all stations and vehicles are located directly at the canteen, drivers begin and end their trips there.

Map

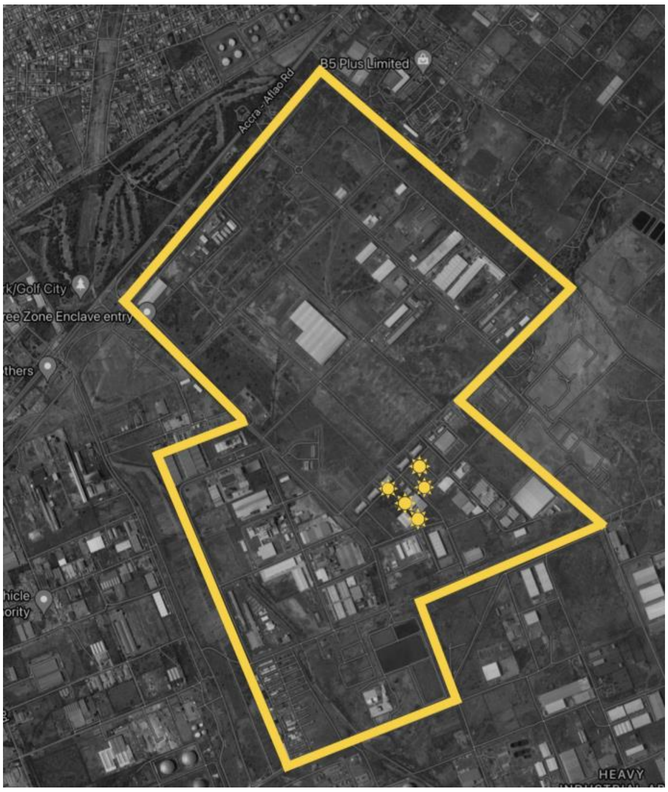

Figure 12 Map with nodes 'food delivery' concept

Conclusion of feasibility and outlook

The concept is technically feasible with 6 solar stations covering the electricity demand of a minimum 14 vehicles at one node, which is located right at the canteen.

It is economically viable as it undercuts the cost of a combustion powered delivery vehicles-based system by 39% in fuel cost.

In environmental terms it is desirable, as it reduces the GWP by 99% compared to a combustion engine vehicle delivery system. From a social impact perspective, it holds the potential to create and sustain 29 unskilled and 3 skilled employment opportunities.

The concept lends itself to be rapidly replicated to other campus settings across Ghana and the rest of Africa. The benefits of implementing this system will lead to an increase of future-secure local jobs and a large reduction in CO_2 emissions.

Concept 2: employee sharing scheme with nodes at key points

To extend the benefit of the shared electric motor bikes beyond the canteen delivery service, a second concept was prepared. This concept targets at facilitating travel to and from the workplace of employees in the Tema EPZ, assuming a drop off at one of the official entries.

Assumptions about employee-based sharing scheme

Three scenarios were mapped, accounting for different utilization rates on the sharing system and accordingly increasing densities of nodes across the zone. The higher the usage rate, the more nodes can be served and the denser and more convenient the sharing system in the zone. This is a circular relationship as a more convenient system also motivates a higher share of employees to rely on the sharing system to travel the last kilometres to their workplace. Nodes are positioned at the zone entrances as well as at company entrances or intersections between companies.

Moderate scenario

Assumptions

In the lightest scenario it was assumed that 10% of the employees traveling from the entrance to their early, day or night shift and back would use the provided sharing vehicles.
The assumed peak travel times, so the time where the majority of employees arrive e.g. for a night Shift, spans no more than 2 hours. Average trip length was estimated to be 3km and trip duration to be 15 minutes. An important parameter is the number of people traveling at one time with one vehicle. As we are looking at standard motorbikes, we set two as the maximum and average number. However, we believe that in case of large amounts of employees and factory workers traveling to one premise in one given time, it would be beneficial to increase the maximum and average number of people traveling per trip to 4 or more, e.g. by adding a side-cart to the motorbike or changing to a different vehicle type such as an electrified golf cart. The impact on other variables such as electricity consumption and cost should be modelled, but we predict it to be rather moderate.

Employee transport sharing concept - assumptions

Number of employees total	9000
Number of employees morning	3000
Number of employees midday	5000

Number of employees evening	2000
Percentage of employees using sharing vehicles for commute	0.1
Number of journeys per person per day	2
Number of people traveling per trip/vehicle	2
Number of person journeys total per day	2000
Number of vehicle trips per day	1000
Average trip length in km	3
Average time per trip in minutes	15
Peak time duration in minutes	120
Number of trips per vehicle per peak time	8
Number of vehicles required morning	18.75
Number of vehicles required midday	50
Number of vehicles required evening	43.75

Fleet size, electricity demand and number of solar stations

From this we can deduct the necessary fleet size at the busiest time, change from morning to day shift, to be 50 vehicles. Including a redundancy rate of 10%, the fleet size in this scenario is 55 vehicles.

To power the 2700km per day of travel, 49 km per vehicle on average daily, 29 solar charging stations are required to produce the necessary 42 kWh daily in the month of lowest solar irradiation, which again here serves as the base line. This means of course that in all other month's surplus energy is being generated which can flexibly be used for other applications as needed.

Fleet	
Required vehicles to meet peak demand incl. 10% redundancy	**55**
Total fleet distance per day (km)	2700
Average distance per vehicle daily (km)	49
Battery pack capacity per vehicle (kWh)	0.7
Range per battery (km)	45
Required charges per day	1.09
Required electricity per day per vehicle (kWh)	0.76
Required electricity per day for entire fleet (kWh)	42
Station Daily Average	
Generated electricity (kWh)	2.4
Self-consumption of station daily (kWh)	0.25
Usable electricity (kWh)	2.15
Station Monthly Minimum (June)	

Generated electricity (kWh)	1.86
Usable electricity (kWh)	1.61
Station Monthly Maximum (November)	
Generated electricity (kWh)	2.92
Usable electricity (kWh)	2.67
Stations	
Installed solar capacity per station (kWp)	0.6
Number of stations required in June	26.09
Redundancy rate charging stations	1.1
Total number of stations required (rounded)	**29**
Number of parking docks required per station (rounded)	3

Cost of sharing

The leasing rate and conditions for the vehicles remain the same as in scenario 1. The annualized cost for the vehicle fleet amounts to 27,280 EUR or 186,132 GHS including maintenance.

The cost of docking and charging with the solar stations at the nodes amounts to 17,865 EUR or 121,893 GHS.

We estimate double the operational cost as for that of the food delivery service operations. This amounts to 3,600.00 EUR annual fixed costs for the maintenance and operation of the sharing app plus a service fee of 0.02 EUR per ride, the cost per trip in this scenario amounts to 0.16 EUR or 1.1 GHS.

Cost components for employee transport sharing system

Vehicle Cost		**Solar Station Cost**	
Cost of vehicle per annum (year 1-2)	1920	Cost of solar station per annum (year 1-2)	2400
Cost of vehicle per annum (year 3-5)	360	Cost of solar station per an. (Year 3-5)	480
Total cost fleet over 5 years	136400	Total cost solar stations over 5 years	89320
Av. Annual cost	27280	Av. Annual cost	17864
Operational & Administrative Cost			
Operational cost of sharing system fix/annually		3600	
Variable cost per vehicle trip		0.02	
Cost per trip			
Total cost of sharing system annually		48744	
Number of workdays per year		355	
Cost per trip (incl. variable cost)		**0.16**	

Comparison to fossil fuelled system alternative

Keeping all parameters as described in the “delivery service concept” a total cost of petrol per year of 31,611.30 EUR or 215,685 GHS is calculated, exceeding the cost of the solar charging by over 66% while offering less convenience and safety as the docking is not included when accounting just for the fuel price.

In terms of CO2 eq. per kilometre, the solar station performs better with 0.78g than petrol with 29.41g.

Cost Comparison Petrol vs. Solar Fuel			
Cost for Petrol in EUR	0.97	0.97	0.97
Liter per 100 km	3.40	3.40	3.40
Cost per 100km	3.30	3.30	3.30
Total km per annum	958500.00	1278000.00	1917000.00
Petrol cost per annum	31611.33	42148.44	63222.66
Saving solar vs petrol	-43.49	-43.00	-49.33
GWP Comparison Petrol vs Solar Fuel			
CO2 eq per kWh (solar station) in kg	0.05	0.05	0.05
Km per kWh solar station	64.29	64.29	71.43
CO2 eq per km (electric vehicle powered at solar station)	0.00	0.00	0.00
C02eq (kg) per an for solar station	745.50	994.00	1341.90
C02 eq per liter of Petrol (kg)	2.39	2.39	2.39
Km per 1 liter of Petrol	29.41	29.41	29.41
CO2 eq per km (Petrol powered motorbike)	0.08	0.08	0.08

Job Creation

The employment effects are derived from the total number of trips and therefore vehicles and solar stations required in the sharing system. Again, only direct jobs are considered.

The administration of the sharing system would lead to up to 2 skilled jobs, the building and maintenance of the vehicle could lead to another 6 skilled jobs being created. The building and maintenance of the solar stations to another 3 skilled jobs. Altogether the solar-powered shared e-motorbike system in the moderate usage scenario can lead to up to 11 skilled jobs being created.

Number and distribution of nodes

These 29 solar stations can be spread across up to 20 nodes. The aim here is to place at least a third of the stations at EPZ entrances, so that the vehicles can be securely parked there between the last and first shift of the successive day. It might be necessary to install extra (non-electrified) docking at the entrances, so that excess vehicles can be stored there safely overnight. Additional relocation activities between shifts might be necessary, which are not modelled in this study but could potentially lead to additional cost and employment opportunity.

Apart from at the entrances, stations are spread as decentralized as possible so that there are nodes in proximity to every business premise. Thanks to user data collection and the agility of the solar stations after initial trials, movements of the employees across the campus can be analysed to then optimize the allocation of the stations.

Map

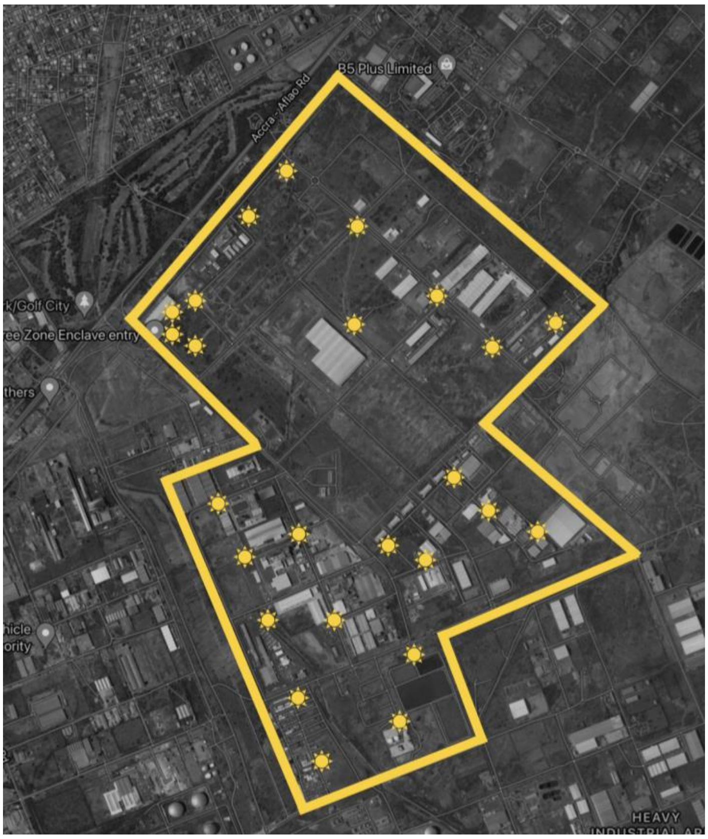

Figure 13 Map with nodes, moderate scenario, 'employee transport' concept

Intermediate and Established Scenarios

Assumptions

The next two scenarios are based on the usage rates of 20 and 30% respectively. Again, a circular relationship can be assumed here, with more users leading to more nodes, therefore reducing the operational costs per trip, making the service cheaper and more convenient for more employees.

Employee transport sharing concept -assumptions

Percentage of employees using sharing vehicles for commute	**0.2**	**0.3**
Number of journeys per person per day	2	2
Number of people traveling per trip/vehicle	2	2
Number of person journeys total per day	4000	6000
Number of vehicle trips per day	2000	3000
Average trip length in km	2	2
Average time per trip in minutes	12	10
Peak time duration in minutes	120	120
Number of trips per vehicle per peak time	10	12
Number of vehicles required morning	30	37.5
Number of vehicles required midday	80	100
Number of vehicles required evening	70	87.5

Fleet size, electricity demand and number of solar stations

To cover the busiest time, keeping all parameters equal to the "moderate scenario", we derive a required fleet size of 88 and 110 vehicles respectively. It is in these more extensive scenarios that other vehicle types with a higher number of people traveling per trip, can decrease the demand for electricity and charging stations significantly, without decreasing the decentrality and number of nodes. When only two people travel per trip, the electricity demand will need to be satisfied by 39 or respectively 52 stations.

Fleet		
Required vehicles to meet peak demand incl. 10% redundancy	**88**	**110**
Total fleet distance per day (km)	3600	5400
Average distance per vehicle daily (km)	41	49
Battery pack capacity per vehicle (kWh)	0.7	0.7
Range per battery (km)	45	50

Required charges per day	0.91	0.98
Required electricity per day per vehicle (kWh)	0.64	0.69
Required electricity per day for entire fleet (kWh)	56	75.6
Station Daily Average		
Generated electricity (kWh)	2.4	2.4
Self-consumption of station daily (kWh)	0.25	0.25
Usable electricity (kWh)	2.15	2.15
Station Monthly Minimum (June)		
Generated electricity (kWh)	1.86	1.86
Usable electricity (kWh)	1.61	1.61
Station Monthly Maximum (November)		
Generated electricity (kWh)	2.92	2.92
Usable electricity (kWh)	2.67	2.67
Stations		
Installed solar capacity per station (kWp)	0.6	0.6
Number of stations required in June	26.09	34.78
Redundancy rate charging stations	1.1	1.1
Total number of stations required (rounded)	**39**	**52**

Cost of Sharing

Keeping all parameters as described in the ‚moderate scenario', annualized cost for the sharing system amounts to 71,272 EUR or 4,859,869.95 GHS in the ‚intermediate scenario' and 90,192 EUR or 615,384.84 GHS in the ‚established scenario' respectively. This translates to 0.12 EUR or 0.82 GHS and 0.10 EUR or 0.68 GHS per ride respectively. This illustrates the price output elasticity stemming from the vertical scaling of the sharing system.

Cost Components Employee Transport Sharing System – intermediary scenario

Vehicle Cost		**Solar Station Cost**	
Cost of vehicle per annum (year 1-2)	1920	Cost of solar station per annum (year 1-2)	2400
Cost of vehicle per annum (year 3-5)	360	Cost of solar station per an. (Year 3-5)	480
Total cost fleet over 5 years	218240	Total cost solar stations over 5 years	120120
Av. Annual cost	43648	Av. Annual cost	24024
Operational & Administrative Cost			
Operational cost of sharing system fix/annually		3600	
Variable cost per vehicle trip		0.02	
Cost per trip			
Total cost of sharing system annually		71272	
Number of workdays per year		355	

Cost per trip (incl. variable cost)	**0.12**

Cost Components Employee Transport Sharing System – established scenario

Vehicle Cost		**Solar Station Cost**	
Cost of vehicle per annum (year 1-2)	1920	Cost of solar station per annum (year 1-2)	2400
Cost of vehicle per annum (year 3-5)	360	Cost of solar station per an. (Year 3-5)	480
Total cost fleet over 5 years	272800	Total cost solar stations over 5 years	160160
Av. Annual cost	54560	Av. Annual cost	32032
Operational & Administrative Cost			
Operational cost of sharing system fix/annually		3600	
Variable cost per vehicle trip		0.02	
Cost per trip			
Total cost of sharing system annually		90192	
Number of workdays per year		355	
Cost per trip (incl. variable cost)		**0.10**	

Comparison to a petrol powered sharing system

The comparison between petrol cost and the price for solar charging, shows that petrol costs amounts to almost double with 42,148.11 EUR instead of 24024 EUR and 63,222.66 EUR instead of 32032 EUR annually respectively.

The comparison of Co2eq per kilometre remains the same as in the ‚moderate scenario' with 0.78g to 29.41g.

Cost Comparison Petrol vs. Solar Fuel		
Cost for Petrol in EUR	0.97	0.97
Liter per 100 km	3.40	3.40
Cost per 100km	3.30	3.30
Total km per annum	1278000.00	1917000.00
Petrol cost per annum	42148.44	63222.66
Saving solar vs petrol	-43.00	-49.33
GWP Comparison Petrol vs Solar Fuel		
CO2 eq per kWh (solar station) in kg	0.05	0.05
Km per kWh solar station	64.29	71.43
CO2 eq per km (electric vehicle powered at solar station)	0.00	0.00
C02eq (kg) per an for solar station	994.00	1341.90
C02 eq per liter of Petrol (kg)	2.39	2.39
Km per 1 liter of Petrol	29.41	29.41
CO2 eq per km (Petrol powered motorbike)	0.08	0.08

Job Creation

The employment effects are derived from the total number of trips and therefore vehicles and solar stations required in the sharing system. Again, only direct jobs are considered.
The administration of the sharing system would lead to up to 2 respectively 3 skilled jobs, the building and maintenance of the vehicle could lead to another 9 respectively 10 skilled jobs being created. The building and maintenance of the solar stations to another 4 respectively 5 skilled jobs. Altogether the solar-powered shared e-motorbike system in the intermediate and established usage scenario can lead to up to 15 respectively 18 skilled jobs being created.

Number and distribution of nodes

The increase in stations required is used to spread the nodes even more densely across the zone, aiming to position nodes with one or more stations at every business premise. Still, about a third of the stations will remain located at the entry points to the zones. The distribution across the zone into 31 and respectively 40 nodes is a suggestion, which needs to be adapted as soon as detailed information about the movement of the employee across the zone is available.

Map

The distribution of nodes between the two more advanced scenarios differs mainly in density of the network.

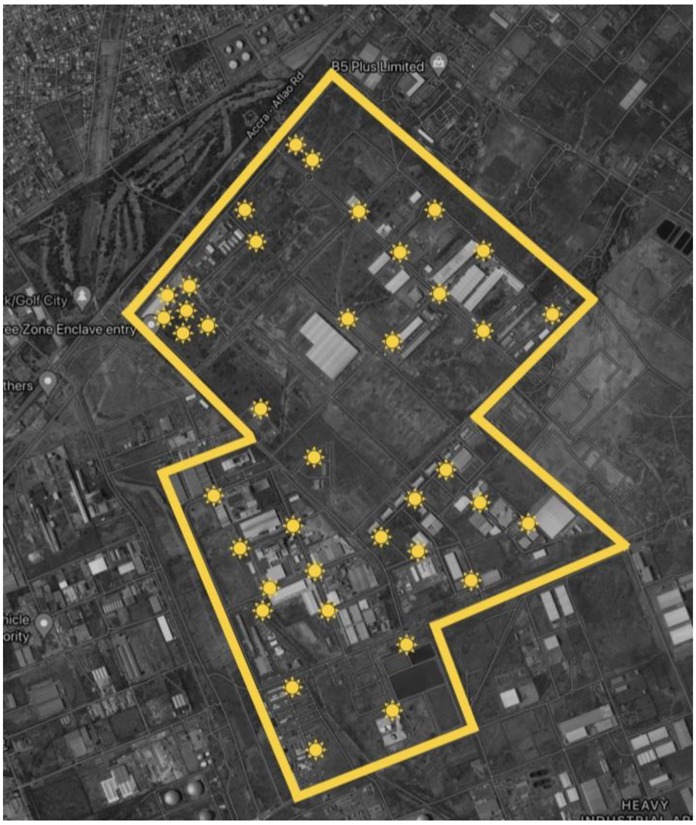

Figure 15 Map with nodes, intermediate scenario, 'employee transport' concept

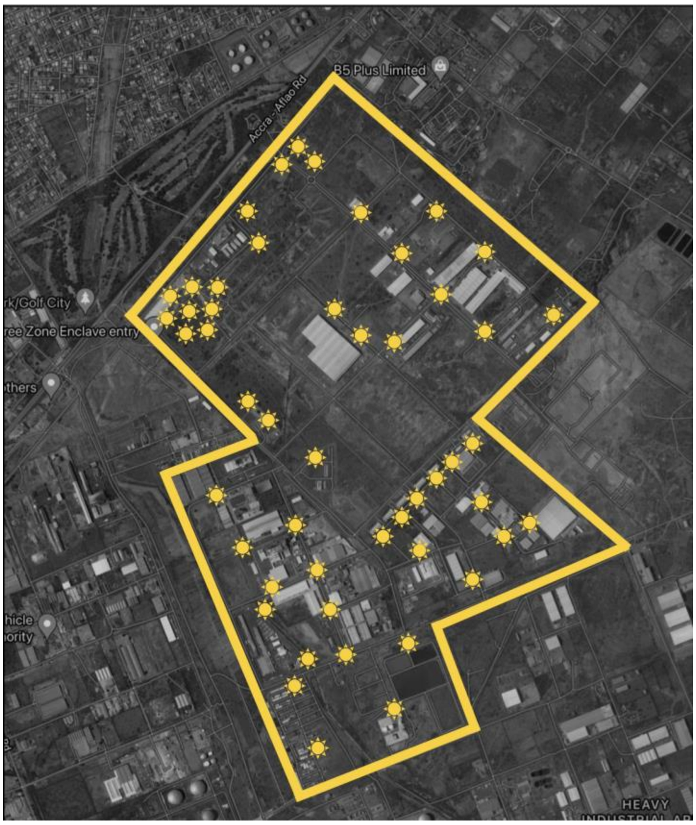

Figure 14 Map with nodes, established scenario, 'employee transport' concept

Conclusion of feasibility and outlook

The use case is split into three scenarios assuming an increasing utilization rate of the employee transport sharing system. Therefore, the indicators on feasibility, viability and desirability come with three figures each.

To ensure the technical feasibility of the use case 29/39/52 solar stations cover the electricity demand of 55/88/110 vehicles at 5/17/29 nodes across the zone and at its entrances.

It is economically viable as it undercuts the cost of a petrol-powered sharing system by 43.5/43/49.3% in fuel cost respectively. However, when considering the local purchasing power, it needs to be evaluated if the concept is viable in absolute terms, that means if offer is affordable enough to attract a large share of employees to use it.

From an environmental perspective it is desirable as it reduces the GWP by up to 99% or 154.6 t of CO_2 eq. annually as seen in the most established scenario, compared to a sharing system in which regular motorbikes with combustion engines are deployed. In terms of social impact, it holds the potential to create up to 18 skilled jobs for young people in the future oriented employment sectors of renewable energy and e-mobility.

The concept lends itself to be replicated in campus settings of all kinds, but also beyond because the positive effects in terms of job creation and pollution and noise reduction can contribute to improved quality of life in many African cities. According to this study, a shared micro e-mobility service for employee transport satisfies all the regarded criteria of Sustainable Mobility as defined by the UN, namely affordability, efficiency, resilience, and minimization of carbon emissions and general negative environmental impact. While the paper does not explore the dimensions of safety and accessibility, it can generally be stated that the accessibility to micro mobility is higher for less affluent households. In terms of safety, the general road and traffic conditions need to be considered, as well as the available alternatives such as public transport, traditional motor bikes, walking, ride hailing etc.

How to for vehicles and infrastructure

Solar Taxi ST/02

Figure 16 Solar Taxi Bike ST 02

Maintenance of vehicles

Included in the monthly fee of 130 EUR, SolarTaxi provides a full vehicle and service package. This includes a monthly inspection of the vehicles on-site and on demand maintenance and servicing. This does not cover theft or damage to the vehicles.

In the case of repair needed, users and campus staff can contact SolarTaxi directly to register the service request. A team from Accra will inspect the vehicle on-site and either repair or replace the vehicle.

SunCrafter SolarBay

Visual

Figure 17 Solar Taxi and Charging Station Rendering

Transport and Handling

The SolarBay can be transported locally with the aid of a forklift or pallet jack. Prior to relocating a station, the electrical system must be switched off and all vehicles removed from the docks. Please note that stations should not be relocated during heavy winds.

Health and Safety

Installation:

The station should not be installed in a location prone to flooding

Using:

- The station should not be used during heavy rain and lightning storms
- Ensure the charging adapter is not wet or corroded prior to charging vehicle

Set Up

Location: Stations must be installed on level, dry and solid ground in an unshaded location. The station must not obstruct emergency exits, private and public access ways. Permission must be granted by the authorities prior to installation.

Electrical setup: Each solar station is checked and set into operation by a trained and qualified solar technician.

Construction steps:

1) Mounting Plate: position of solid, level ground
2) Base: carry onto Mounting Plate, fixed into position with securing brackets
3) Solar Mast: placed into Base hole and fixed with safety bolts
4) Solar Mounting Frame: with aid of a ladder, fix mounting frame onto the Solar Mast
5) Solar panels: with aid of ladder, position solar panels in Mounting Frame and secure
6) Battery Box: secure onto base in allocated brackets
7) Dock: fix the docks into the allocated space on the Base Plate
8) Electrical: The electrical connection is to be done by a SunCrafter train technician

Usage Instruction

Users unlock vehicles and begin a rental via the app. The rental is automatically ended as soon as the vehicle is docked at a station.

Maintenance

Stations are connected to the cloud, allowing performance to be remotely monitored. Any electrical errors are automatically notified to SunCrafter maintenance teams.

Recommended is:

A monthly visual inspection:

- damage to vehicles and stations
- dust collection on the solar panels
- Bluetooth inspection of the system

A half yearly service of the station:

- battery quality testing
- solar panel output testing
- Power output testing

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