

RESEARCH ARTICLE

REVISED Analysis and study of the potential increase in energy output generated by prototype solar tracking, roof mounted solar panels [version 2; peer review: 1 approved, 1 approved with reservations]

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Abstract

Roof mounted solar panels come in form of fixed panels, unable to adjust to sun's position during day and throughout the year. As an effect, the efficiency of such solution is usually dependent on the roof slope and position of the building in relation to sun's day arc during seasons. These problems can be bypassed in free standing solar installations by equipping solar panels with solar tracker installations. Thanks to solar tracking, solar panels can be dynamically positioned perpendicular to the sun position and gather energy more efficiently throughout the day. This article presents a possibility of creating a roof mounted solar tracking panel to increase irradiance efficiency. A prototype of solar tracking panel with two axes of movement was designed with an intention of an easy adaptation to being mounted on sloped surfaces of building roofs. A reference stationary panel was used to compare the efficiency of both solutions. A 5-day study was carried out to determine if the proposed solution could provide any benefits. Based on the study, the authors made an attempt to draw a conclusion whether the design could considerably increase the solar energy output to be worth the extra spending associated with solar tracker installation.

Keywords

solar tracker, household solar energy, roof solar panels

Open Peer Review

Approval Status

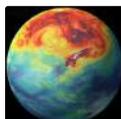
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Any reports and responses or comments on the article can be found at the end of the article.



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REVISED Amendments from Version 1

This new version of the article has mainly addressed issues pointed out by Dr Zeundjua Tjiparuro. A small change has been introduced to the abstract of the article. A lot of structural changes and changes in the vocabulary have been introduced throughout the entire contents of this article. Mainly, two paragraphs have been moved to the "Testing procedure" section and one paragraph was removed entirely from the "Introduction". In connection to that, two references [Mehleri *et al.*, 2010 and Rowlands *et al.*, 2011] were removed from the text. Additionally, two new figures have been added (Figure 5 and Figure 6; the old Figure 5 have been re-labelled to Figure 7).

Any further responses from the reviewers can be found at the end of the article

Introduction

Renewable energy sources are increasingly perceived by the public as a beneficial alternative to fossil fuels in context of preservation of the environment by limiting the carbon emissions. Recent decades show a steady increase of public interest in percentage of renewable energy sources in the overall energy production¹⁻⁷. More people are also choosing to supply their homes with renewable energy, mainly through the installation of household solar panel systems in the form of free-standing solar installations and roof mounted panels. Even the citizens of countries located in higher latitudes (such as Poland, England or Sweden, and other countries in Europe located on similar latitudes) with less annual access to solar energy due to weather and seasons have showed an increase of interest in household solar panel installations. The increase of awareness and willingness to focus on renewable energy sources can partly be attributed to numerous government programs that promote the transition with numerous discounts and advertise positive results of such transition. The EU is putting large emphasis on promoting renewable energy sources in recent years by dedicating numerous grants for co-financing own solar installations and introducing regulations that favor renewable energy. Thanks to the financial support, it is possible to fund a household solar installation with relatively small financial outlay which attracts many household owners previously discounting such solution due to large entry costs. Another factor that contributes to this situation is the advancement in solar cell efficiency and energy storage technologies. This further decreases the payback time for investment costs which attracts more people.

The advantage of free-standing solar installations over the roof mounted ones can become apparent at the point of determining the optimal tilt angles. Free-standing solar panels can be easily equipped with solar tracking devices, coupled with one or two motors that rotate the panel in one or two axes of movement. This method eliminates the need for determining a fixed tilt angle and allows for dynamic adjustment of solar panel tilt angle depending on the season and time of day. As a result, solar panels equipped with solar tracking capabilities can output between 10% and 60% more energy depending on the tracking technology used and considered time of the day for peak efficiency calculations⁷⁻¹⁷. In addition, countries that

are located on higher geographic latitudes can get more benefit from tracker installations because of the higher volatility of sun position during different seasons.

The disadvantage of free-standing solar installations is the lower return of investment because of additional costs associated with solar tracker and motors required for the system. The cost efficiency of different solutions may vary greatly, depending on whether there are policies in effect, that allow for either storing excess energy in the communal grid or selling it back to the grid⁷. If there are no such policies in effect, the use of two axis solar trackers may be the only option worth considering due to high amount of budget that has to be allocated for batteries that store the excess energy. If such policies exist, then solar trackers appear more cost effective, especially on areas with lower solar potential.

This project aims to create a prototype solution that would enable solar tracking on panels usually mounted on household roofs in urbanized areas. Such a solution could potentially increase the daily energy output of solar panels, giving better energy yields from a relatively small space of a household roof. Such a solution could also make roof solar installations more viable in areas of the globe, where daily sun coverage is mediocre or poor. This article is focused on the testing of the first few iterations of the prototype to verify the authors' prediction that such a project could bring benefit.

Methods**Object under examination**

This article concentrates on exploring possibilities of combining the flexibility of free-standing solar panels, equipped with solar trackers and the relatively compact nature of roof mounted solar panels (Figure 1). The idea is motivated by the search for a middle ground solution that would provide at least a portion of benefits carried from the use of solar tracking panels without the large space requirement. Building owners in heavily urbanized areas and household owners in tightly packed residential districts do not possess enough space to fit a cost-effective, ground-mounted solar installation, large enough to justify being fully equipped with solar trackers. The design of the test stand featuring a solar tracker, will be oriented towards the ability to be mounted on a sloped roof. A study will involve an analysis of the solar tracking panel efficiency versus a fixed solar panel in a configuration resembling a mounting on a sloped roof. The obtained results will serve in further research to determine if the potential gain is enough to justify expenses that relate to solar tracking installations.

Measuring equipment and appearance of the laboratory stand

The plan for the study included construction of two test benches after conceptual design phase in SIEMENS NX 12. The first test bench was meant for creating a reference data set for the standard mounted roof solar panel. It was designed with the slope angle of 45° (a set of adjustable feet to give some room for adjustment of the slope on site was added to the stand in later stages of the project). The model and its individual spatial projections was shown in Figure 2.



Figure 1. Examples of different types of solar installations. (a) Free standing solar panel, equipped with a solar tracker and actuators, enabling the tracking of sun position throughout the days and seasons¹⁷. (b) Roof-mounted solar panel with a fixed mount and no ability to track the sun.

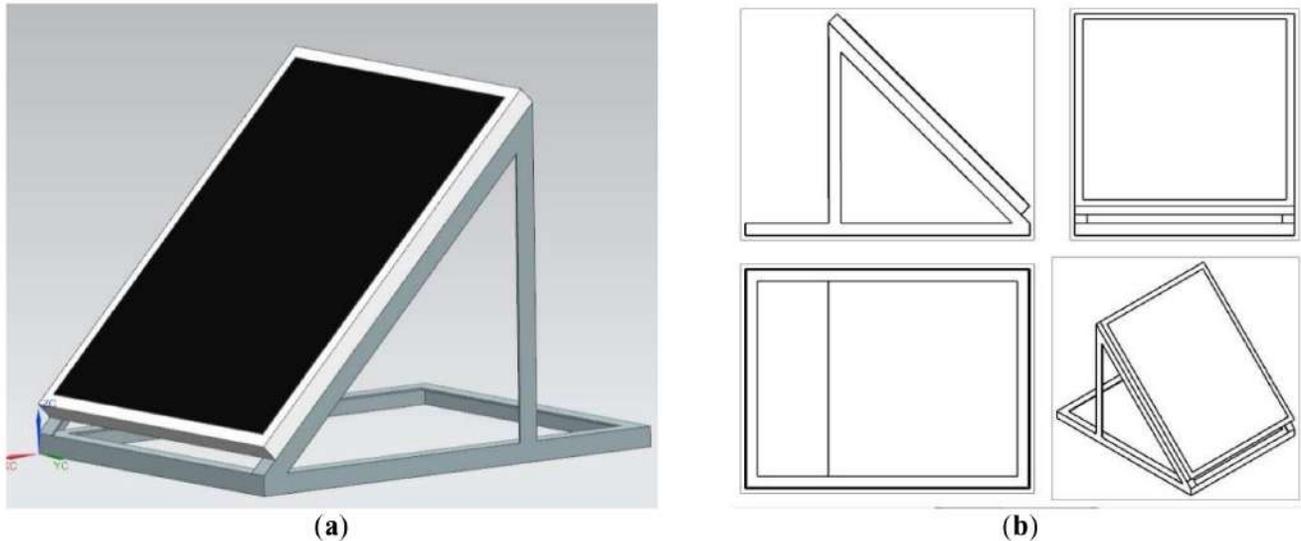


Figure 2. CAD model of a test bench for a reference solar panel mounting. (a) Isometric view. (b) Spatial projections.

The second test bench was capable of rotating in two axes. In order to enable the following of the sun trajectory during the day, a GPS-based solar tracker was added. The assumption was to enable vertical tilt of around 90 degrees and horizontal tilt of roughly 45° in each direction. To realize the movement, bench was equipped with two self-locking linear actuators, with substantial force of 4000 N to provide control even in windy weather. In order to make the construction more compact and suited for roof applications, the decision was made to use the vertical axis as primary axis. The horizontal axis of movement was a secondary axis. This approach unfortunately restricted the freedom of movement, of the solar panel and complicated the solar tracking algorithm because of the necessity to convert spherical coordinate system to a cylindrical one, in case of the azimuth angle and panel horizontal tilt. The solar tracker was created using an Arduino Uno programmable circuit, coupled

with a GPS module, with a solar tracking algorithm that uses GPS as input data. After a search for appropriate solar tracking algorithm in literature sources, a decision was made to use the derivative of a PSA (Plataforma Solar de Almeria) algorithm to calculate sun position out of the data provided by the GPS module^{8-12,15,18-21}. The model of a solar tracking panel and its individual spatial projections were shown on [Figure 3](#).

To accommodate the aforementioned system of axis movement with the applied algorithm, a series of angular conversions was prepared, that converted outputted azimuth and zenith angles into angles that were to be achieved by the stand, to properly track the sun position. Solar tracker was set to adjust panel position every 90 seconds. In terms of a proper comparison between results obtained from the reference test bench and the solar tracking test bench, both of them were equipped with

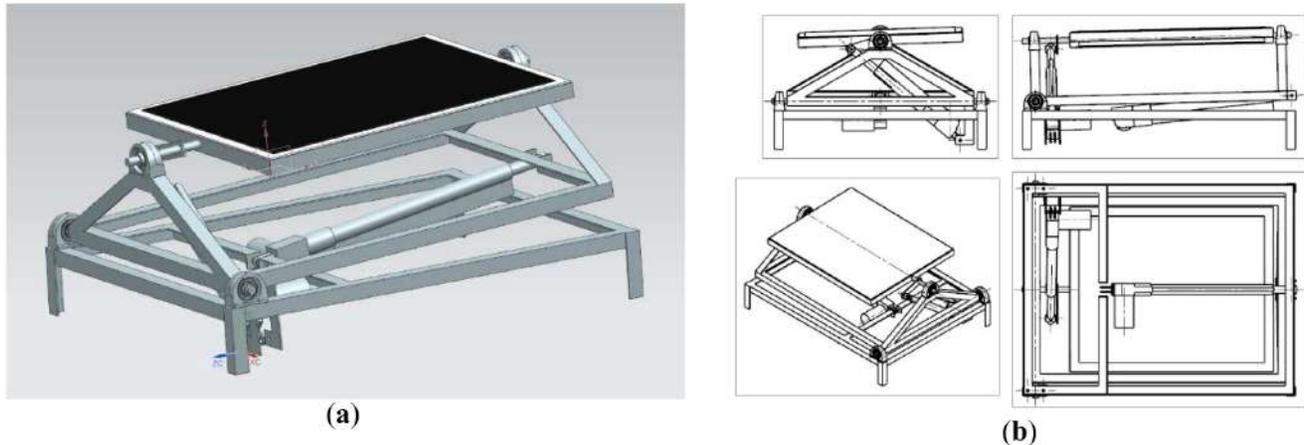


Figure 3. CAD model of a test bench for a prototype roof mounted solar panel equipped with a solar tracker. (a) Isometric view. (b) Spatial projections.

identical 50 W monocrystalline solar panels, with a work surface of 540×670 mm, capable of outputting 2.78 A of current at 18 V. The same Arduino Uno controller used for the implementation of the solar tracker algorithm was also responsible for registering power outputs of both solar panels at 30 second intervals due to lack of a proper MPPT controller. The power readings were saved on the SD Card memory in form of files that contained consecutive power readings in beforementioned 30 second intervals recorded throughout the day. The outputted power was being drained by two 100 W power resistors, converting all the electrical energy into heat. Each panel had its own power registering loop, coupled with own power resistor. The circuitry involved in the study is completely separated from the measurement loop to avoid any interference from the actuators or the controller. To avoid overflow of memory on the Arduino Uno controller it was unfortunately decided to omit the measurement of power draw from the whole solar tracker circuit during its operation. It is a consideration to upgrade the measuring system in the future experiments, to also include this power draw in the equation. Although the panels are planned to be implemented as a new roof mounted solution, it was very hard to find building owners willing to spare their roof for testing purposes. To mitigate this obstacle, a decision was made to try and consider the possible range of movement, a panel could have, when mounted on a roof. The possible application of the current construction to a building roof would involve rotating the panel by 180° along its base and adjusting the calculation of zenith angle, to include roof inclination in the equation. For the purposes of this experiment, both panels were placed on the ground with adjustable feet as supports. The mechanical part of both test stands was completed around June. The electrical wiring and programming of the Arduino controller was completed in August, just before the tests began. A complete setup placed in its final study destination can be seen on [Figure 4](#) and [Figure 5](#).

Test procedure

The research was conducted right after the completion of test benches which took place in August 2020. It took a total of

5 days between 14.08.2020 and 18.08.2020 (including that day). The research was conducted in Poland, Upper Silesia, with geographic coordinates of $50^\circ 22' N$ and $19^\circ 15' E$. The sunrise, at the time of the experiment, on average, took place at 5:33 CEST (3:33 GMT). The sunset, at the time of the experiment, on average, took place at 19:58 CEST (17:58 GMT). The average length of the day was around 14 hours and 35 minutes. The area at which the experiment was conducted, was a rectangular plot with width of around 15 meters (in W-E direction) and length of around 100 meters (in S-N direction). Test benches were placed on the furthest side towards the west of the plot and around the middle in the N-S direction. The positioning was dictated by the trees that were growing in the near vicinity of the plot, from the east side. A bird's eye view sketch was provided in [Figure 6](#) to better illustrate the area where solar panels were placed. Because of the aforementioned trees, the sun was accessible from around 7:30 CEST (5:30 GMT) in terms of mornings. The view was almost unobstructed from the west side, however, which allowed for tracking the sun almost up to the time of sunset. Both test stands were placed on adjustable feet to keep them in level. According to the information provided, the procedure of daily measurement was as follows:

1. taking off the covers that secure the stands from the morning dew and rain
2. activation of test stands around 7:00 CEST (5:00 GMT) and their calibration (the microcontroller which was operating both motors was turned on and set to calibrate the motor positions with GPS data)
3. visual verification of the correct solar panel alignment and a check of the state of hardware and software in the case of spotted misalignment
4. in case of any errors or damage spotted, necessary debugging or repairs
5. continuation of the experiment throughout the day, up until around 20:30 CEST (18:30 GMT) when the sun is below the horizon already



Figure 4. Completed setup placed at its final study destination. The stationary solar panel was raised to adjust its angle to around 30° which is an optimal angle for the latitude of Poland, Upper Silesia, based on the information provided by local solar panel mounting companies.

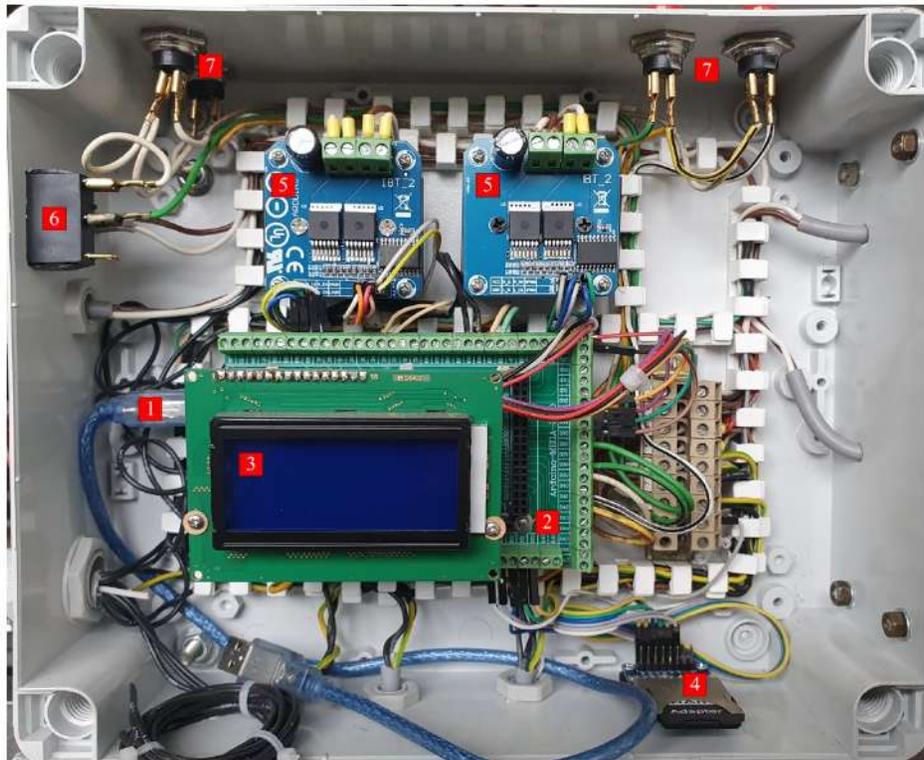


Figure 5. An image of the electronic circuit made for the solar tracker. 1 – visible USB connection to the Arduino Uno main board, 2 – Arduino MEGA, 3 – display panel, 4 – SD Card memory slot, 5 – motor controllers, 6 – main power switch, 7 – calibration and manual control buttons.

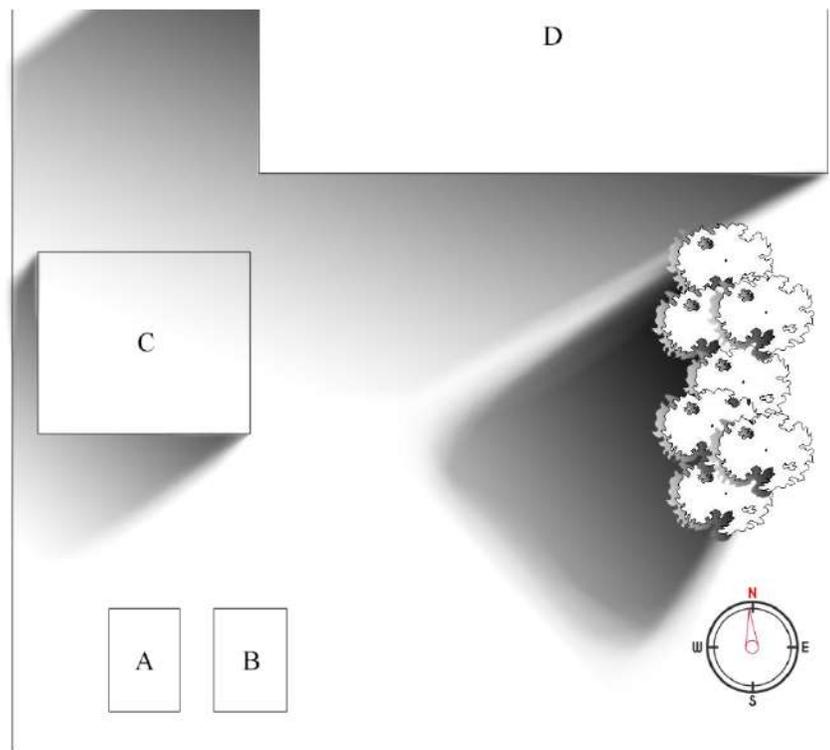


Figure 6. A rough sketch of the plot where solar panels (**A** and **B**) were placed. Rectangles named **C** and **D** represent a shed and a household in the vicinity. A tree line was also marked on the right side. Gradient areas are a rough representation of cast shadows around the early morning, when they were the biggest concern.

6. stopping the arduino microcontroller by cutting the circuitry from external power supply
7. extraction of the gathered data by pulling the SD card with the data from the SD card slot (Figure 5) and copying the files to the laptop and USB stick for redundancy
8. securing the stand with covers for the night

The raw data consisted of the datemarking each day of the ongoing experiment, time at which each sample (a power output reading received from the controller with a 30 second interval) was taken and power output values from the fixed, reference solar panel and the tracking panel. The data from each day was processed in Microsoft Excel. All measurements taken throughout the period of the study were placed on a uniform timescale (to achieve that, some samples had to be moved in time by 1–10 seconds). The timescale ranged from 7:00 CEST (5:00 GMT) to 20:00 CEST (18:00 GMT) reflecting the daily study schedule. The time interval between each sample taken was 30 seconds.

The data were grouped by readings taken from each day of the study period. The day was also divided into three periods: morning (from 7:00 to 10:00), midday (from 10:00 to 15:00) and evening (from 15:00 to 20:00). Throughout the study period,

the measurements were taken during different weather conditions. The weather was mostly sunny from 14th to 17th with occasional cloud patches covering the sky from few minutes to about an hour and a short rainfall occurring during the evening of 16th. There was a substantial cloud coverage throughout the evening of 17th.

Table 4 was divided into two separate percentages called raw measurement inputs (RMI) and calculated interval gains (CIG) of energy between measurements. Because the circuit was only taking single measurements of power output each 30 seconds (RMI), to calculate an estimate of energy produced between each measurement, a mean value between 2 subsequent measurements was taken and multiplied by the time between each measurement (CIG). This was a simple attempt at calculating the rough energy output which unfortunately is prone to rounding errors and that is why the calculation of efficiency was done through the comparison of both RMI and CIG. Deviations between those two percentages are especially apparent in mornings of 14th and 15th when there were troubles with the operation of solar tracker.

Results

Table 1 and Table 2 show the aggregated data from gathered samples, showing the total energy gathered on each day by stationary and tracking solar panel. See *Underlying data* for the full combined and ordered data collected from each sample²².

Table 3 shows a difference in energy gathered between tracking panel and a stationary panel. Table 4 shows the calculated efficiency of tracking solar panel in reference to stationary solar panel.

Due to a storm occurring after the morning of 18th the test, that day, had to be stopped. Additionally, in the morning of 14th and 15th there was a necessity to do some maintenance of the

Table 1. Energy collected by stationary solar panel.

Date	Energy collected in Joules (J)			
	MORNING	MIDDAY	EVENING	TOTAL
14.08.2020	47491.50	559920.30	165526.80	772938.60
15.08.2020	66753.30	418826.40	141862.50	627442.20
16.08.2020	119195.40	772084.80	99255.90	990536.10
17.08.2020	134105.40	638697.60	50764.80	823567.80
18.08.2020	61661.10	3594.30	-----	65255.40
TOTAL	429206.70	2393123.40	457410.00	3279740.10
AVERAGE	85841.34	478624.68	91482.00	655948.02

Table 2. Energy collected by tracking solar panel.

Date	Energy collected in Joules (J)			
	MORNING	MIDDAY	EVENING	TOTAL
14.08.2020	11335.20	564304.50	311209.80	886849.50
15.08.2020	54188.10	453057.00	404502.60	911747.70
16.08.2020	194316.60	802172.40	149549.10	1146038.10
17.08.2020	204126.00	662093.70	109598.70	975818.40
18.08.2020	106896.30	4080.90	-----	110977.20
TOTAL	570862.20	2485708.50	974860.20	4031430.90
AVERAGE	114172.44	497141.70	194972.04	806286.18

Table 3. Difference in energy collected between stationary and solar tracking panels.

Date	Difference in energy collected in Joules (J)			
	MORNING	MIDDAY	EVENING	TOTAL
14.08.2020	-36156.30	4384.20	145683.00	113910.90
15.08.2020	-12565.20	34230.60	262640.10	284305.50
16.08.2020	75121.20	30087.60	50293.20	155502.00
17.08.2020	70020.60	23396.10	58833.90	152250.60
18.08.2020	45235.20	486.60	-----	45721.80
TOTAL	141655.50	92585.10	517450.20	751690.80
AVERAGE	28331.10	18517.02	103490.04	150338.16

solar tracker which involved debugging the software and resulted in a loss of potential power gains during this time period. It can be seen in the negative values, presented on Table 3 and Table 4. This big difference was caused by the tracking panel being greatly misaligned to the position of the sun.

The total averaged results showed a rough increase in tracking panel power generation of about 22–23% in relation to the stationary panel throughout the study period. In terms of mornings, the data was heavily disturbed by the problems that occurred during the test. Nonetheless, the data shows an increase in power income by 29–33% during morning periods throughout the entire study. Evening periods showed over a double amount of

energy produced whereas middays showed about 4% increase due to both panels working at full capacity. A graph, presenting an average difference in power gains between stationary and tracking solar panel, throughout the day, is shown on Figure 7.

Figure 7 represents an average daily difference in consecutive power output readings between stationary and solar tracking panels based directly on gathered samples from both solar panels throughout the study period. The red line represents an average of measurements taken from the same time of day throughout the study period. Again, due to problems in the first two days of the study, the graph is heavily disturbed in the

Table 4. Efficiency gain of tracking panel in reference to stationary panel.

Date	MORNING		MIDDAY		EVENING		TOTAL	
	RMI	CIG	RMI	CIG	RMI	CIG	RMI	CIG
14.08.2020	-83.57%	-76.13%	0.82%	0.78%	87.77%	88.01%	12.64%	14.74%
15.08.2020	-16.27%	-18.82%	8.2%	8.17%	184.77%	185.14%	44.62%	45.31%
16.08.2020	62.74%	63.02%	3.91%	3.9%	50.45%	50.67%	15.7%	15.7%
17.08.2020	52.1%	52.21%	3.68%	3.66%	115.78%	115.9%	18.49%	18.49%
18.08.2020	73.19%	73.36%	13.94%	13.54%	-----	-----	69.89%	70.07%
TOTAL	28.68%	33%	3.87%	3.87%	112.8%	113.13%	22.26%	22.92%
AVERAGE	31.57%	33%	4.01%	3.87%	113.17%	113.13%	21.94%	22.92%

RMI, raw measurement inputs; CIG, calculated interval gains.

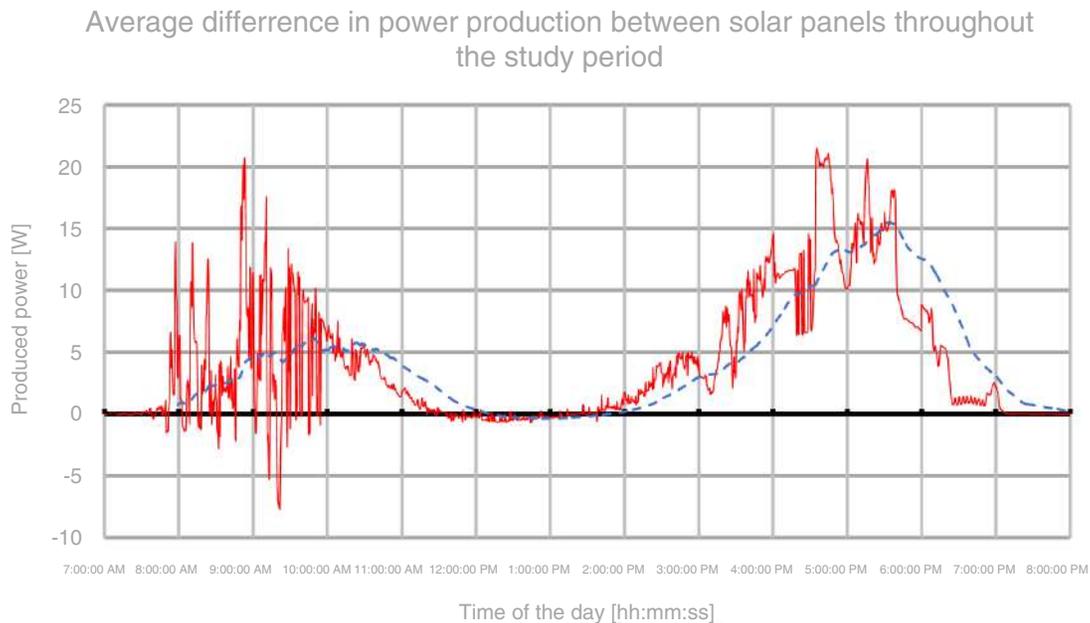


Figure 7. Graph representing the daily difference in power gains between panels during the study.

morning period. The blue dashed line represents a moving average with a window of 120 samples (equal to one hour). Judging by the moving average, it can be noticed that the peak gain of around 5 W/s was achieved between 9 and 10:30. The efficiency gains are diminishing past 11 and there are no visible gains between 12 and 14. Again, past 14, the solar tracking panel starts to gather more energy with a peak gain of around 15 W/s around 17:30. After that, the gains start to quickly diminish again to 0 towards the evening hours.

Discussion

The average daily energy outputs from [Table 1](#) and [Table 2](#) were converted to kW-h. Based on this calculation, a stationary solar panel was outputting energy at a level of 0.182 kW-h per day and an average power output of solar tracking panel at a level of 0.224 kW-h per day. The difference in outputted power between stationary and solar tracking panel was 0.042 kW-h which amounts to a 22–23% gain in panel efficiency due to solar tracking ability. The overall mediocre performance of both solar panels over the entire span of the study can be attributed partly to some cloud coverage in the 3rd and 4th day of the study, and a thunderstorm in the 5th day, which forced the authors to terminate the study as early as 10 am. Gains in tracking solar panel performance of this design are lower than those presented in [7,10](#) and comparable to results presented in [14](#). The short study period of just 5 days in this setting is highly prone to statistical errors due to the small amount of data collected. Technical difficulties with solar panels in the beginning of the study and bad weather towards last days could have also contributed to this poor performance result over other studies.

There is a noticeable gain in power output efficiency of solar tracking panel during the morning (29–33%) and especially evening hours (113%). It is most probably due to stationary solar panels positioning and tilt being optimized for maximum efficiency during hours with best solar irradiance. Because of that, there are almost no gains of power over stationary solar panel during midday hours. The daily average collective gain in power from morning and evening hours with a solar tracking panel amounted to around 0.037 kW-h, which contributes around 88.1% of total power gains of solar tracking panel over the stationary solar panel. The results could've probably been even higher in favor of mornings and evenings if the test period took longer. This means that tracking solar panels take most of their benefit from solar energy collection during mornings and evenings. Given that the sun elevation decreases significantly towards the winter season, it is possible that more gains are to be had.

It is very hard to determine the economic cost efficiency based on the information gathered so far. Solar panels bought for the study cost around 393 PLN (101.91 USD) each and the spending associated with construction of both stands reached around 1700 PLN (440.73 USD), with about 2/3 of this cost being spent on the tracking solar panel because of its increased complexity. Another 1030 PLN (267.02 USD) was associated directly with solar tracking panel and that was a spending on actuators. Around 3250 PLN (842.53 USD) was spent in total on the construction of both test stands from which around 2556 PLN

(662.61 USD) was associated with the construction of solar tracking panel. The solar tracking panel took around 78% of the budget and 22% were associated with the stationary panel. This means that solar tracking panel project cost around 3.7 times more than the stationary solar panel which indicates a fairly high cost compared to gains in efficiency. However, these costs are uncertain due to few factors. It has to be noted that this project was done by the researchers themselves omitting any costs associated with professional assembly and installation which influence the cost of solar panel installation significantly as pointed out in [5](#). Also, due to small factor of the study, there were no batteries or inverters involved which also contribute greatly to the costs of overall installation^{5,7}. Broader research should be conducted to determine the effects of abovementioned factors on the overall economical profitability of such installation, including any grants and discounts or national policies regarding renewable energy.

Conclusions

Despite the big number of obstacles and troubles during the study period, the obtained results show some correlation with results presented in other papers. This signifies that such adaptation of roof mounted solar panels may become a valid solution. The obvious conclusions from this study involve the need for longer testing periods to increase the data pool and reduce the effect of errors and anomalies on the aggregated data. The 50 W power generation limit of used solar panels should also be increased in the future by upscaling the test stands, to investigate power increase with more photovoltaic surface area and decrease the margin of error associated with small scale experiments being more prone to fluctuations caused by small objects obstructing the sunlight as an example. Future studies should also involve studying periods in other seasons, to investigate potential power gains that come with different sun elevations during different seasons. The tracking algorithm used for this study was very basic and lacked many utility functions that a fully-fledged solar tracker has. This is an issue that should also be addressed by future studies on more advanced tracking algorithms. For longer study periods, the tracker must be upgraded with a wind measuring probe that is able to determine bad conditions for solar panel work and be able to fold the panel, to prevent any damage. Also, a data registering system must be upgraded with additional memory banks, to be able to collect more data during long periods and provide the data on the power draw, generated by the circuitry and the actuators. Alternatively, a proper MPPT power draw registering system must be added to the testing stand to properly measure the power draw of all elements. It is also very important to investigate the economical profitability of the proposed solution by investigating economical landscape in search of additional costs and benefits associated with solar panel installation.

Given the infancy of this project, this study was able to provide the data needed for its continuation. In further studies, it is imperative to thoroughly analyze all the potential scenarios that this system would be able to work with, such as different weather conditions and different seasons. Furthermore, a problem of power draw, by the included circuitry, and its effect on the

resulting efficiency should be investigated. Lastly, it is also important to conduct a study referring to the advantages of using solar trackers on roof mounted solar panels versus the additional costs that they can generate and potential decrease of roof space that is connected with the problem of panels covering each other.

Data availability

Mendeley Data: Research data on prototype solar panel power output. <http://doi.org/10.17632/2bgvhmtrpx.2>²².

This project contains the following underlying data:

- Samples. (A collection of data recordings in the .txt format from the days of the study.)

- Research_data.xlsx. (Spreadsheet with combined and ordered data collected from each sample.)

Data are available under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/) (CC-BY 4.0).

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Wan Zuha Wan Hasan 

Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia

The prototype solar tracking was well working based on the proposed solution. It was a very practical solution to provide a solar tracker in order to increase power energy from solar. The outputs have shown very significantly. Since the solar tracker is a quite well-known solution, the author should discuss more on installation and costing issues against the total collected energy for both ground and roof top installation.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Robotic and Automation, Solar Energy

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 11 March 2021

<https://doi.org/10.5256/f1000research.30552.r79908>

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Zeundjua Tjiparuro

Department of Mechanical, Energy & Industrial Engineering, Botswana International University of Science and Technology, Palapye, Botswana

1. In the abstract please edit the line: *This article presents a possibility of creating a roof mounted solar tracking panel to **increase its efficiency**.* (Change bold words to...to increase irradiance efficiency).
2. In the Introduction please edit this line: *The increase of awareness and willingness to focus on renewable energy sources can partly be **contributed**...*(change bold word to: attributed).
3. Still in the Introduction, please edit this line: *Thanks to the financial support it is possible* (..punctuate with a coma after the word support).
4. In paragraph 2 of the Introduction in the sentence [*big or small factor....* (delete the word factor)].
5. Sentence 2, in paragraph 2, of the Introduction: is either misplaced, or incomplete and will need editing to make it fit where it has been placed. The main problem is that it combines several factors which are diametrically opposite. For instance, space availability is certainly a limitation, but then combining this with household power consumption, which is certainly a motivation for installing solar, makes the write up sound ungrounded. Then another deterrent follows in: costs of installation and maintenance. This how your write up looks starting with the sentence: *Apart from the space availability, authors in 5-7 also mention financial factors such as estimated monthly and yearly household power consumption or costs related to solar panel installation and maintenance....*[the question is, the factors are mentioned as what? Problems to the installation or factors influencing installation?] But the sentence that follows is one for motivating for installation, but the next two on albedo and snow are a mix of opposites again, leaving the reader confused as to whether the author is motivating or discouraging. In fact, most of the things that the author wants to write about here have been covered in the preceding paragraph, and he is better off deleting the whole of this paragraph.
6. The reader will be lost as to which of these installations are better in this sentence: [*The difference in energy production efficiency between stationary mounted solar panels and solar*

panels equipped with solar tracking capabilities can vary from 10% to 60% depending on the tracking technology used and considered time of the day].

7. This sentence is not fitting well where it has been placed [*In addition, countries that are located on higher geographic latitudes can get more benefit from tracker installations because of the higher volatility of sun position during different seasons*] since the preceding sentence is on the advantage of free standing installations being amenable to fitting trackers, the above sentence comes in to disrupt the flow which should continue to point out some limitations of trackers as the author does in the next sentence.
8. What is the meaning of the bold part in the first sentence on page 4, column 1: [The article has a **preliminary character** in terms].
9. What or which test stand is being referenced in second paragraph on page 4, column 1, the sentence goes like: [The design of the **test stand**....]
10. This sentence, in column 2, page 4, first paragraph has typos highlighted bold. It also makes a claim of adjustable feet which are not there in the model in the figure number referenced: [...and a set of adjustable feet to give it some room for adjustment of the slope on site. The model and its individual spatial projections **were** shown **of** Figure 2...]
11. The following description, under Test Procedure, must be supported by a bird's eye view sketch of the site complete with geographical coordinates, otherwise it is unnecessarily complicated [*Test benches were placed on the furthest side towards the west of the plot and around the middle in the N-S direction. The positioning was dictated by the trees that were growing in the near vicinity of the plot, from the east side. Because of the aforementioned trees, the sun was accessible from around 7:30 CEST (5:30 GMT) in terms of mornings. The view was almost unobstructed from the west side, however, which allowed for tracking the sun almost...*]
12. In the list of steps on page 6, the sentence: [*activation of test stands around 7:00 CEST (5:00 GMT) and their calibration*] is not clear what was done.
13. The next step too is not clear as to what was exactly done [*verification of correct solar panel alignment after the calibration and routine check of the state of hardware and software*].
14. What is a research aperture in step 6...[*stopping the research aperture...*] please show it.
15. Show a diagrammatic illustration or labelled images of your experimental set up so that all the modules mentioned in you procedure such as the one below are clear to the reader...[*extraction of the gathered data by pulling the SD card with the data from the SD card module and copying the files to the laptop and USB stick for redundancy*].
16. The listed steps will be much better if numbered than just using bullets.
17. The sentence below, immediately after the list of steps, will need editing as the reader will not know what measurement series is, and what samples are.[*The raw data consisted of the date, at which each measurement series was done, time at which each sample was taken and power readings from the fixed, reference solar panel and the tracking panel...*].

18. First paragraph under results....please attend to the matter of SAMPLES as highlighted in my foregoing comment.
19. Delete the bold part of the sentence below [*Table 3 shows a difference in energy gathered between tracking panel and a stationary panel, **derived from the data***]
20. With respect to the Tables, I think the [J] in the subtitles is the unit of energy [Joules], if so, the small subtitles for your tables must read like this: [Energy collected in Joules (J)].
21. Results should not include the methodology, please find where to fit the methodology below in the appropriate place under **Test Procedure**. [*The data were grouped by readings taken from each day of the study period. The day was also divided into three periods: morning (from 7:00 to 10:00), midday (from 10:00 to 15:00) and evening (from 15:00 to 20:00). Throughout the study period, the measurements were taken during different weather conditions. The weather was mostly sunny from 14th to 17th with occasional cloud patches covering the sky from few minutes to about an hour and a short rainfall occurring during the evening of 16th. There was a substantial cloud coverage throughout the evening of 17th.*]
22. Firstly, the author must show, even with simple equations, how the raw measurement inputs (RMI) and calculated interval gains (CIG) percentages were calculated. Secondly, the author must know that the percentages he is proposing lack persuasion as he does not point out to their use by previous researchers, or if they are novel approached, and explain why was a novel approach chosen over existing one. Additionally, my previous comment on unacceptability of putting procedure under results is valid for this sentence/paragraph. The author must find an appropriate place for it under **Test Procedure**.
23. Not clear from the Tables and Figures presented by the author how he comes by this observation [The aggregated data showed a rough increase in tracking panel power generation of about 22–23% in relation to the stationary panel throughout the study period.]
24. How was the Total column in Table 4 calculated?
25. [...**was shown on Figure 5**] change to [...is shown in Figure 5].
26. The following claim is not in the paper nor is it part of the data recorded or calculated from recorded data: [*Results of the study have shown an average daily power output of a stationary solar panel at a level of 0.182 kW-h per day and an average power output of solar tracking panel at a level of 0.224 kW-h per day. y. The difference in outputted power between stationary and solar tracking panel was 0.042 kW-h...*].
27. Look at this sentence in your conclusions, the part I show in bold is not clear [decrease the margin of error that **is contributed to small scale experiments**].
28. Look into the following sentence too and replace with bold work with [by]....[This is an issue that should also be addressed **before** future studies.]

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 12 Jul 2022

Jacek Harazin, Politechnika Śląska, Gliwice, Poland

Dear Doctor Tjiparuro,

First and foremost, I'd like to thank you for a very detailed breakdown of your review. It has shed a lot of light on many issues with my article writing. I value that while still being a young researcher, trying to obtain my own title. I hope that my new revision of the article will do justice to your comments. I will try to address your comments in a similar manner.

Ad1. to Ad4. Necessary corrections were made

Ad5. After reading the paragraph and after some consideration, given that I can now look back at my own work with a dose of criticism, I came to a similar conclusion that there was no more value added in this section and decided to remove it as suggested.

Ad6. I have slightly changed the wording of this sentence to point more clearly on panels with solar trackers.

Ad7. I have split this section in two and tried to use better wording to present advantages and disadvantages more clearly and avoid contradictions.

Ad8. I believe that this sentence was just a product of me being personally a bit too shy and insecure about this area of research. This article was a journey onto new waters for me personally. I have decided to remove this bit of unnecessary digression to avoid confusion.

Ad9. This was a reference to the test stand with a solar tracker. I have slightly modified the sentence to make it clearer.

Ad10. Yes, that was a mistake of trying to refer to later stages of the project. A set of “screw-on” feet was later added to both test stands to give it more adjustability on the grassy dirt. Unfortunately, I do not have any technical images for the later stages because the project was being developed and readjusted “on the go”. I have tried to describe it in the article itself to correct this mistake.

Ad11. I have prepared a sketch, which will be placed as the new “Figure 6”. It is not very technical, but I hope it will be clear enough to give a picture of the testing environment that I have tried to describe previously. A rough geographical position was initially mentioned at the first paragraph under the “Test procedure”. I unfortunately can’t narrow it down any more due to the plot being part of someone’s private property which was graciously lent for our testing purposes.

Ad12. I have tried to expand this description and make it more precise.

Ad13. This issue has also been addressed similarly.

Ad14. I have changed the wording of this point to be more precise of what I operated in that stage. The actual circuit was also added as the new “Figure 5”.

Ad15. I have also tried to address this comment with the new figure I’ve placed.

Ad16. Numbering has been added.

Ad17. I have tried to word this sentence more clearly so it should cause less confusion.

Ad18. Same as above.

Ad19. The mentioned part was deleted.

Ad20. I also changed the naming like you suggested.

Ad21. The addressed paragraph was moved to the “Test procedure” section.

Ad22. I have also moved this paragraph to the correct section, and I have tried to explain the equations more clearly. I’ve decided to not insert any specific equations because the formula was very basic and simple. I may have not said that in clear enough manner previously. Basically, because my aperture was taking power output measurements only once each 30 seconds (RMI), I figured that CIG may be a helpful datapoint. I have calculated an average amount of energy produced between each consecutive pair of measurements.

The average was taken from each two neighbouring power output measurements and then multiplied by the interval of 30 seconds.

Ad23. This result was obtained by averaging the registered power output differences and average gathered energy difference between stationary panel and a panel with a solar tracker on the span of the entire experiment (5 days). I have tried to reword this sentence to better explain how these results were obtained.

Ad24. The total column in table 4 was calculated in the same way as I have mentioned above, just that the result was based on a daily measurement.

Ad25. Correction has been made.

Ad26. This claim was a result of a quick conversion of energy gathered by solar panels, mentioned in tables, from Joules into kilo-Watt-hours. I did forget to actually explain where these values came from all of a sudden. I changed the description to make this conclusion less accidental.

Ad27. I have tried to rephrase this sentence and make my thoughts more clear.

Ad28. The sentence has been corrected.

Again, thank you very much for your attention to detail. I hope that this set of corrections will be acceptable at the very least. I have tried to improve the clarity of my procedures as much as I could. Unfortunately, I have lost memory of some of my decisions made during this research because of the time it took me to finally address these issues, for which I apologise.

Best Regards,

Competing Interests: No competing interests were disclosed.

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