GOSTEAM Hands-on Activity Template *(Inquiry-based)*

Title:

Solar panel placement on Earth, the Moon and Mars!

Short Description (Max 500 words):

During this activity students learn how the innovative engineering of photovoltaics enables us to transform the sun's energy into electricity using photovoltaic panels. At first, in this activity we will explain how people use the sun as a renewable energy source for power on Earth as also, how the sun is used as a renewable energy source for power in space missions.

Moreover, students will learn about some major criteria and conditions to be addressed in order to select optimal areas for PV solar panels placement on Earth, Moon and Mars.

Keywords (Up to 5):

Spatial Modelling, Surface Analysis, Solar PVs

Information about the Implementation

Age and language of the students:

Language: Greek

Age:	9-12	12-15	15-18	18+
	[ ]	[x]	[ ]	[ ]

Number of Lessons – Duration (per lesson):

Number of Lessons: 1

Duration per Lesson: 45'

Subjects:

For which subject(s) the activity is usable, is it an interdisciplinary activity?

Science [x]

Physics [x] Chemistry [ ] Biology [ ] Geosciences [x] Environmental [x] Other [ ]

Technology [x]

Engineering [x]

Arts [ ]

Mathematics [x]

Information about the Scenario

Curriculum and country:

Link of the current activity to the curriculum:

Country:	Greece	Class:	Secondary	Grade:	9 - 12

Topic: Geography, Physics, 2D – 3D Surfaces, Spatial Analysis, Surface characteristics

Objectives (Max 100 words):

Description of the learning objectives

Some of the key objectives to be addressed through this activity include:

1) Given solar PVs, students list the spatial variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels,
2) To understand some crucial aspects and spatial characteristics for solar PVs placement.
3) Analyze and compare the power requirements at different places and their school.

Materials (Max 100 words):

Which resources and materials (software, hardware) are needed?

Material: Search Engines

Software: Global Solar Atlas

Spatial concepts, skills, and abilities:

Which spatial concepts and skills are covered by the activity?

Spatial concepts:

Primitives: Identity/Name ☐ Location ☑ Space/Time ☐

Simple: Distance ☐ Direction ☐ Connectivity ☐ Movement ☐ Boundary ☐ Shape/Area ☐ Adjacency ☐

Difficult: Overlay ☐ Buffer ☑ Topology ☐ Coordinate ☑ Map ☐ Scale ☐ Shortest Path ☐ Navigation ☐ Surface ☑ Slope/Gradient ☐ Aspect ☑ Contour ☐

Complex: Interpolation ☐ Map Projection ☐ Spatial Dependency ☐

Other:

Spatial skills:

- [ ] Map literacy
- [ ] Navigation/orientation
- [ ] Estimating distances and directions
- [x] Recognizing and understanding patterns/Understand and identify models of spatial organization
- [x] Select an ideal location based on the given spatial features
- [ ] Visualization
- [ ] Understand and identify spatial correlations/ dependencies
- [ ] Categorize spatial entities/ geographic features and identify hierarchies
- [ ] Compare spatial entities and draw analogies among them
- [x] Identify/determine connections/relations
- [ ] Understanding scale in space and time
- [x] Delineation of spatial regions/ zones based on given features/ properties

Short Description

Navigation/orientation: Finding one's way in unfamiliar environments, interpreting and giving walking and driving directions.
Estimating distances and directions: Measure paths, weighted distances, angles.
Map literacy: Using, interpreting/understanding, learning from, and communicating acquired spatial knowledge from maps, comprehension of geographic features represented as points, lines, or polygons.
Recognizing and understanding patterns/Understand and identify models of spatial organization. Delineation of spatial regions/zones based on given features/properties: Regionalization processes, pattern recognition and clustering identification in the 2d and/or the 3d world.
Select an ideal location based on the given spatial features: Single or multi-criteria siting and optimal areas identification.
Visualization: Visualizing spatial entities from written/oral verbal descriptions, from their 2d or graphical representations or through mental transformations; such as axis rotation or perspective taking.
Understand and identify spatial correlations/ dependencies: The ability to realize, identify and explain patterns, clusters and relevant spatial dependencies.
Categorize spatial entities/geographic features and identify hierarchies: Identify the hierarchical form of data and gradients between spatial entities.
Compare spatial entities and draw analogies among them: Calculate and compare different geometric objects' shapes, area and boundaries.
Identify/determine connections/relations: The ability to identify links and common characteristics among spatial entities and between humans and spatial entities.
Understanding scale in space and time: The understanding of changes/transitions through space and time for different spatio-temporal scales.

Geospatial concepts and spatial abilities documentation (see Section 3.2):
http://www.gosteam.eu/wp-content/uploads/2021/05/GOSTEAM_IO1_A1_final.pdf

Description of the activity in detail

Question Eliciting Activities

Provoke curiosity

Usually, the most effective way to provoke students' curiosity is by presenting an exciting video or a series of photos

You can start the Activity by introducing to students the following videos:

Generating Power on Mars (Solar Panels on Mars)

What If the Sahara Desert Was Covered With Solar Panels? (Solar Panels on Earth)

What If We Covered the Moon With Solar Panels? (Solar Panels on the Moon)

Propose preliminary explanations or hypotheses

Formulate the scientifically oriented questions that teachers will present to the students to trigger their engagement in thinking about the topic investigated based on their existing knowledge. Make these questions digitally available and easily usable, e.g., by integrating them in the materials described in the previous step.

It is best to ask these questions in the context of a relative discussion.

- Which spatial characteristics must converge?
- All cities worldwide can produce enough energy from solar panels to cover their energy needs?
- What if we cover the entire Lunar surface with PVs?

Active Investigation

Plan and conduct simple investigation

Provide the teachers with a specific plan of the investigation that will take place. Offer instructions about the activities they students will need to perform and what kind of materials they may need. Describe ways that the teachers can use to facilitate the students to focus on evidence.

This is the phase in which students are being prepared for the subsequent phase of evidence gathering during observation.

Ask students to prepare a short presentation to respond to the following questions. They can be encouraged to include technical reports, articles or similar to illustrate some of the information they find. Students may choose one or more question to research and work in small groups.

What criteria are considered as the most important?

What type of data are needed? How can we analyze these data?

What tools are used?

Can we estimate the produced energy?

Keywords and definitions:

- Latitude: a measure that identifies the north-south location of a point on the Earth. It is the angle between the line connecting a point on the Earth and the Earth's center, and the equatorial plane of the Earth. There are three ways to express latitude. The most familiar shows 0-90 degrees north latitude and 0-90 degrees south latitude. In the computer era, this became -90 to +90, where -45 is equivalent to 45 degrees south latitude. The third method is less familiar and is called the colatitude. Colatitude is 0 degrees at the north pole, 90 degrees at the equator, and 180 degrees at the south pole. So, 45 degrees south latitude is equivalent to a colatitude of 135 degrees.
- Longitude: a measure that identifies the east-west location of a point on the Earth. It is the angular distance along a line of latitude from the Greenwich Meridian (located outside of London) – a reference longitude set at 0 degrees. There are three equivalent ways to express longitude, and scientists tend to use them interchangeably. The most familiar for longitude is 0-180 degrees east longitude and 0-180 degrees west longitude. It can also be expressed as 0-360 degrees east longitude, or just 0-360 degrees longitude. In that case, 270 degrees east longitude is equivalent to 90 degrees west longitude. The third system arose in the computer era when carrying both a number (0-180) and a character (east or west) was inconvenient. The new convention of -180 to +180 was then developed. In this case, -90 is equivalent to 90 degrees west longitude.
- Renewable energy: energy that can be replenished in a short period of time, such as energy from solar, wind, water or geothermal sources. Typically, there is little concern that these sources of energy will become scarce or used up, unlike fossil fuels. Fossil fuels include coal, oil and gas.
- Solar collector: a device that captures the sun's energy and focuses it in a small area as a more usable or storable form. These devices can be simple, such as a greenhouse, or complex like solar panels or solar concentrators.

- **Solar radiation:** the electromagnetic radiation or energy emitted by the sun. The energy coming from the sun peaks in visible wavelengths, but also includes ultraviolet and infrared wavelengths.

  Source: https://www.jpl.nasa.gov/edu/teach/activity/think-green-utilizing-renewable-solar-energy/

<u>How solar panels work:</u>

What is Earth's Solar Energy Budget?

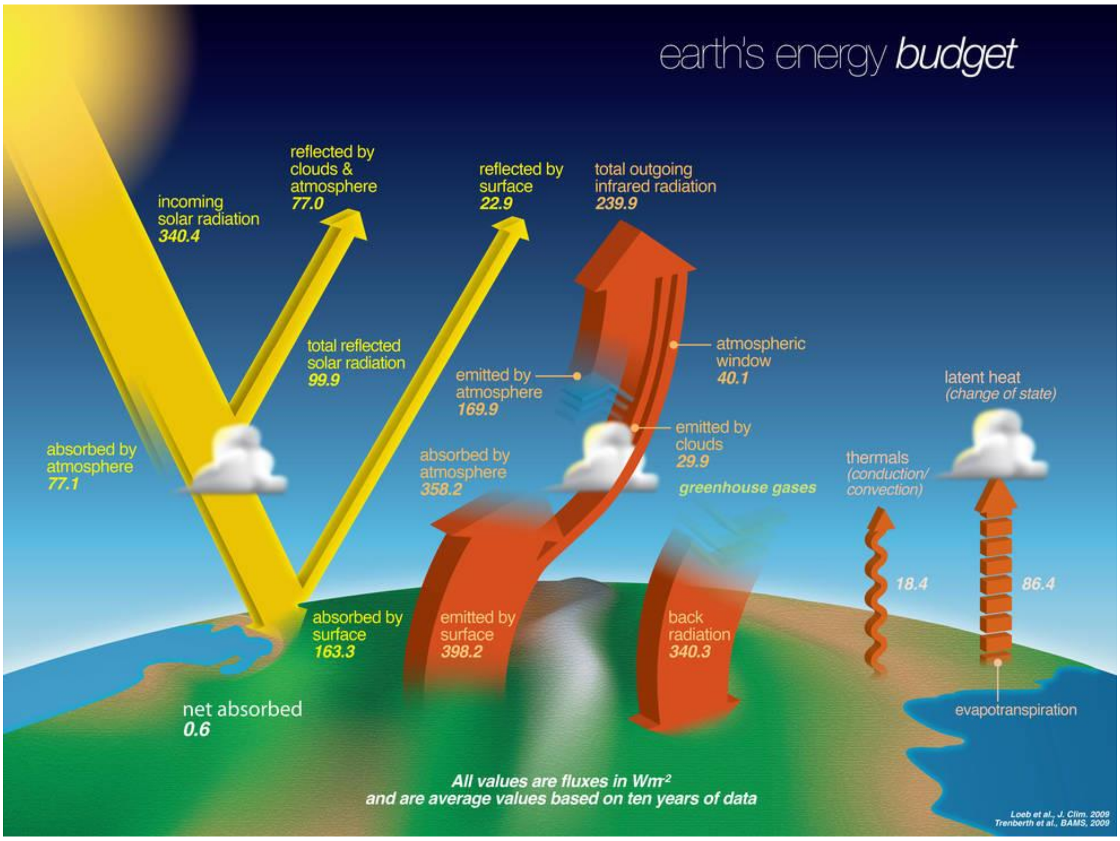


Figure 1: Earth's Solar Energy budget

Earth's energy budget describes the balance between the radiant energy that reaches Earth from the sun and the energy that flows from Earth back out to space (see Figure 1).

About 30 percent of the sun's incoming energy is reflected back to space by clouds, atmospheric molecules, tiny suspended particles called aerosols, and the Earth's land, snow and ice surfaces (see Figure 1).

The Earth system also emits thermal radiant energy to space mainly in the infrared part of the electromagnetic spectrum. The intensity of thermal emission from a surface depends upon its temperature (see Figure 1).

Source: https://www.nasa.gov/feature/langley/what-is-earth-s-energy-budget-five-questions-with-a-guy-who-knows

How can we capture the Sun's energy?

Passive | Solar Concentrators | Photovoltaic Panels

Figure 2: How can we capture the Sun's energy

How do we measure electricity usage?

- Watts - A watt is a unit of power. It is a Newton meter per second, or can be given as a joule per second.
- Kilowatts – 1000 watts equals one kilowatt (kW)
- Kilowatt-hours (kWh) – A device such as a plasma TV, which uses 1,000 watts for one hour consumes one kWh of power.

How do solar panels work?

So the sun emits heat and light – this much we all know. And light, you may also know, is made up of tiny particles called photons. Meanwhile, every solar panel is essentially a magnetized sandwich, with each slice of "bread" being a sheet of densely packed atoms. When photons from the sun hit a solar panel, the design of the panel causes the photons to knock electrons off of these atoms. This generates an electric current, which then powers your house or gets stored in a battery (see Figure 3).

Solar PV panels work by absorbing the light – not the heat – from the sun, and turning it into usable electricity.

There are, however, solar water heating systems that use solar thermal panels. These panels do collect heat from the sun, and use it to heat up water that is stored in a hot water cylinder. A boiler or immersion heater can be used as a backup to heat the water further to reach the temperature you want.

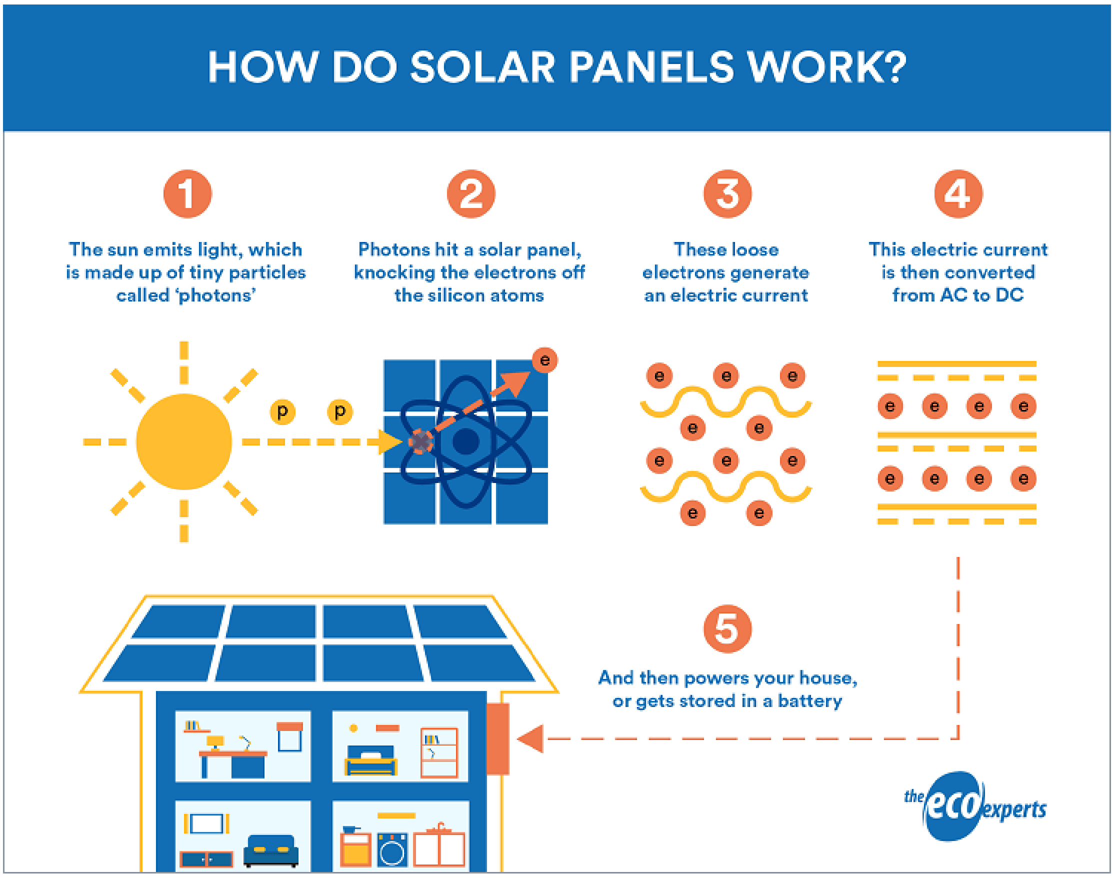


Figure 3: How solar panels work steps

A typical solar module usually sits snug in a glass casing, which offers a much-needed layer of protection for the silicon PV cells. Under this glass exterior is a layer of insulation, as well as a protective back sheet – this makes sure no heat is lost, and prevents humidity building up inside the panel.

Solar panels also have an anti-reflective coating that increases sunlight absorption, allowing the cells to soak up more sunlight.

What are solar panels made of?

Each solar panel is made up of approximately 32-48 solar cells, which are in turn made from a semiconducting material called silicon. Most panels either use monocrystalline or polycrystalline silicon, "mono" offering a higher level of performance than "poly".

The solar cells are then connected together using soldered metal, creating an impressive matrix-style structure. If that's the sandwich filling, all you need now is the bread. A layer of glass (approx. 7mm thick) goes on top, and a polymer-based backsheet goes on the back. Stick on a strong aluminium frame with EVA glue, and you've got yourself a solar panel.

Do solar panels need direct sunlight?

That's where it gets a little tricky. No one could blame you for thinking that a solar panel does its best work on a hot summer's day. However, seeing how complicated these devices are, you can assume they're pretty capable of functioning in different types of weather.

Part of this is true. Solar panels (obviously) need the sun to operate; the more sun that shines down onto the panel, the more efficient it will be at producing energy. That much is easy to figure out.

The surprising part is that solar panels are actually less efficient in intense heat. Yes, we know – a device that operates best in direct sunlight is impeded by high temperatures. It's certainly a bit of a design flaw – perhaps an obstacle for **future solar panel generations.**

Do solar panels work in cloudy weather?

The idea that "solar panels stop working on cloudy days" is a common misconception. Remember that light is a spectrum, and solar panels want all of it. While clouds can obstruct *visible* light, there are still multiple different wavelengths of light that can penetrate through even the thickest of cloud. After all, when clouds coat the sky, it's not like we're all stumbling around in darkness – it's very much still bright.

Since clouds have the potential to stunt your panels' efficiency, you want to make sure you invest in a solar panel system that will be able to absorb as much sunlight as possible. That's why we've compiled a list of the most efficient solar panels in 2020 with the maximum efficiency lay within 19.8 – 22%.

The best conditions for solar panels

You can't control the weather, but there are four key things you can do to ensure you get the best out of your solar panels.

1. **Point them south:** The direction that your solar panels are facing is the number one most important factor when setting up a solar PV system.
2. **Angle them at 30°:** Solar panels always operate at maximum performance when the sun is directly perpendicular to them. You want the sunlight to be hitting your panels as directly as possible. For example, in the winter they should be positioned at a steep 60°, while in the height of summer a low 20° is best.
3. **Remove the shade:** There's no point in getting the perfect direction and angle for your solar PV system if it's just going to sit in shade. Be sure to clear away anything that might cast a shadow on your panels, particularly any big trees.
4. **Keep them clean:** As dust and dirt build up on your panels, this will gradually make them less effective. The sunlight will find it harder to reach the solar cells beneath the grime, and consequently you'll have less electricity to use at home.

Life expectancy of solar panels

The vast majority of residential solar panels typically come with a **25-year warranty**, although they are built to last around **40-50 years**.

Source: https://www.theecoexperts.co.uk/solar-panels/how-it-works

Determining the Best Location for a PV System

Solar panel orientation

Creation

Gather evidence from observation

The selected resource (e.g., a simulation, an experiment, an animation, a graph, or other exhibit of similar nature) must provide students with an opportunity to collect evidence addressing the scientific questions presented in previous stages through direct or indirect observation. Provide guidance to the teacher organize and manage the activity most effectively and efficiently.

It is recommended to introduce group work at this stage. Guide the teachers to divide students in groups, each of which will be facilitated by the teacher to formulate and to evaluate explanations to the scientific questions based on the collected evidence.

Step 1: Open the Global Solar Atlas Platform

Global Solar Atlas Platform: https://globalsolaratlas.info/map

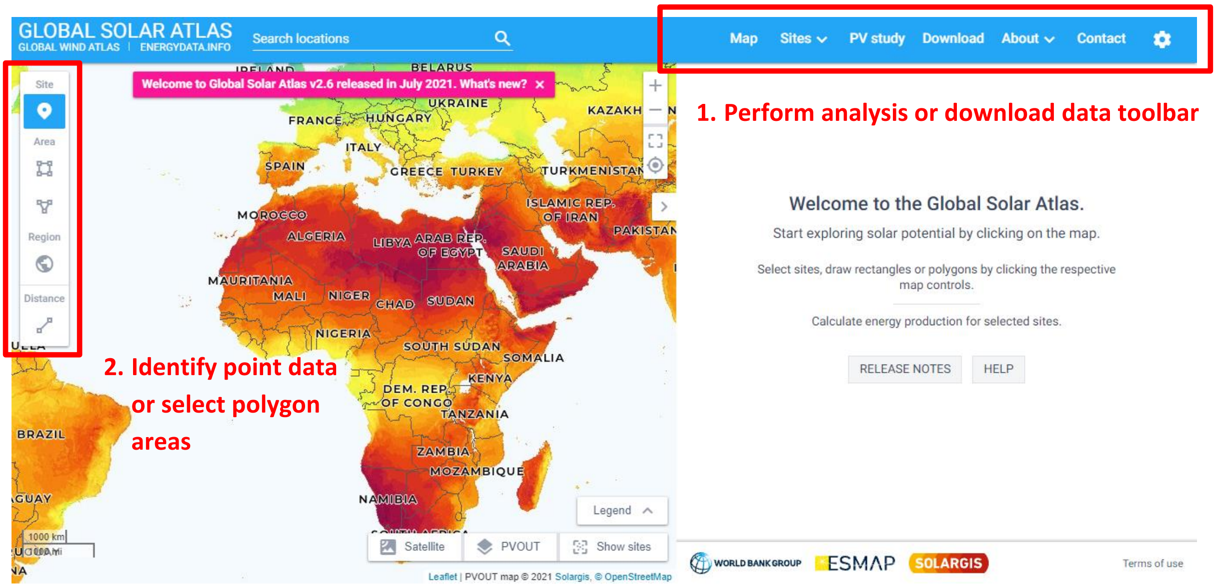


Figure 4: Global Solar Atlas interface – Global Solar

Navigate and explore the platform options in order to familiarize yourself with the tools and the options provided.

On the top right of your screen you can find the global in-situ solar radiation network where you can also download data (Sites tab).

You can also download reports on per country basis with detailed information, graphs and maps of the annual solar irradiation (PV Study).

Finally, you can download maps, poster and spatial data (Download tab) which you can load, edit and visualize on a GIS platform (i.e. QGIS).

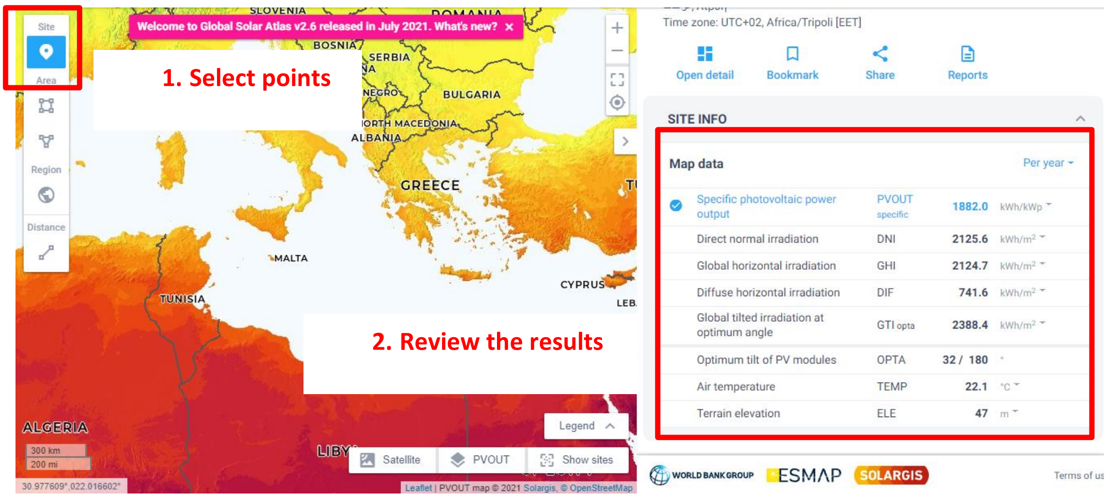


Figure 5: Identify Solar Irradiation at different areas

At the first part of the Activity you can ask from students to navigate to the map, to select three different areas (by clicking with their mouse on the map) and keep notes on the results extracted on the right of their screen (see Figure 5).

A first cycle of discussion begins by asking students to explain the differences of the solar irradiation values at different locations!

Which are the differences of the Direct, Horizontal and Diffused solar irradiation?

Try to identify areas on both the Northern and the Southern hemisphere, how do you explain the differentiations on the Optimum tilt values (considering the slope and the orientation)?

Can you identify in some areas any correlation between the terrain elevation and the Global Solar Irradiation values? (you can change the map layout by clicking on the variables on the right panel, see Figure 6. Also, expand the Legend).

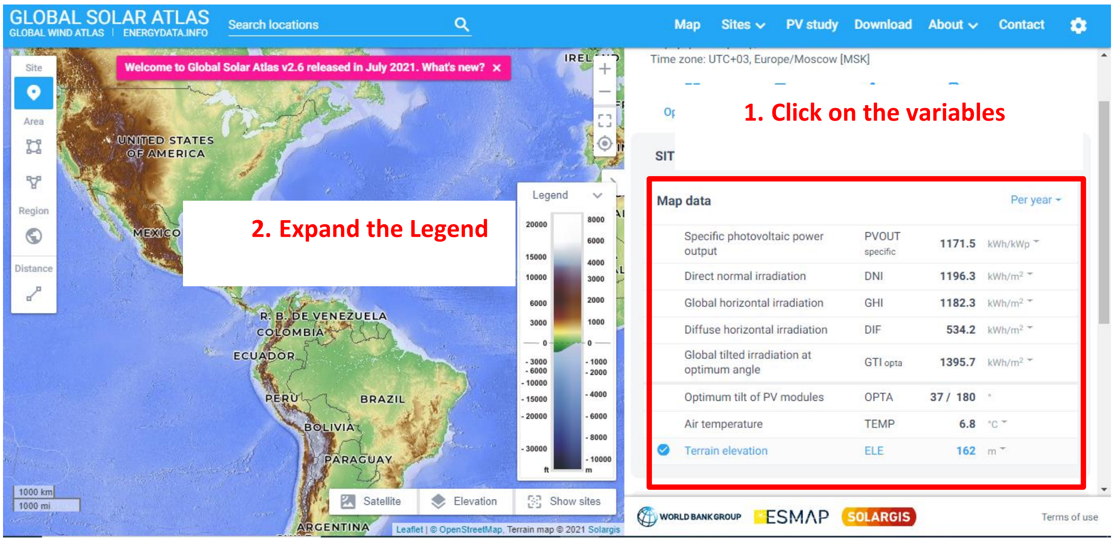
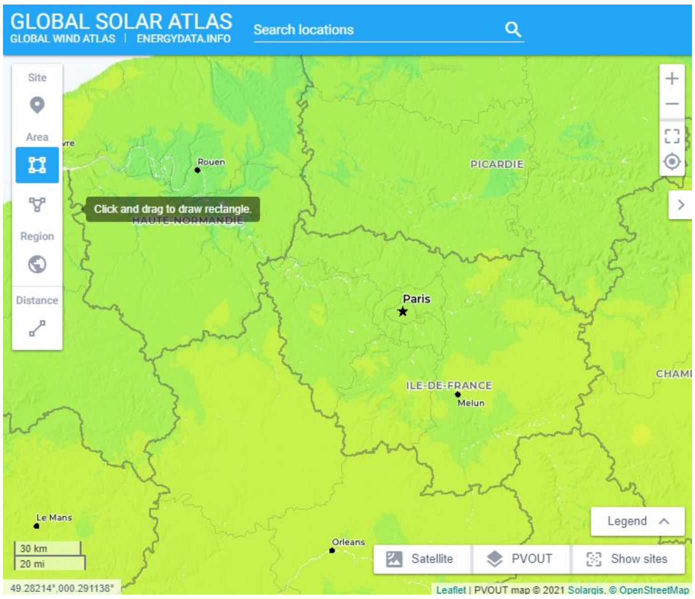


Figure 6: Visualize air temperature, terrain elevation and other spatial variables

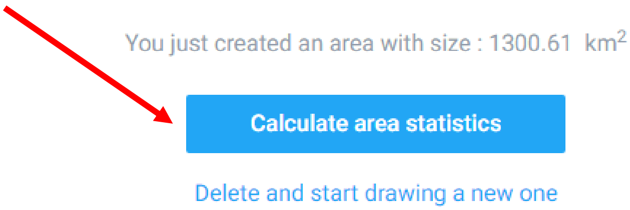
Step 2: Global Solar Atlas – 1st area, France:

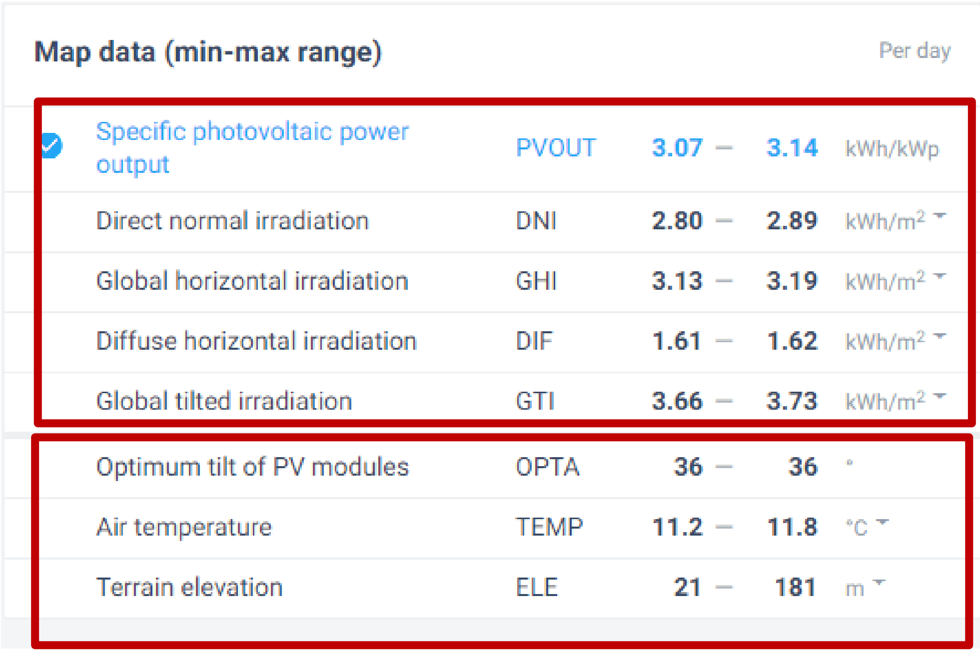
Let's start from Paris!

1. Draw a rectangle to select an area of interest.
2. Try this area (rectangle) to be larger than 100 km^2!



3. Then we select calculate area statistics! A brief description of the solar irradiance characteristics will appear!





Map data (min-max range) Per day

Specific photovoltaic power output	PVOUT	3.07	—	3.14	kWh/kWp
Direct normal irradiation	DNI	2.80	—	2.89	kWh/m^2
Global horizontal irradiation	GHI	3.13	—	3.19	kWh/m^2
Diffuse horizontal irradiation	DIF	1.61	—	1.62	kWh/m^2
Global tilted irradiation	GTI	3.66	—	3.73	kWh/m^2
Optimum tilt of PV modules	OPTA	36	—	36	°
Air temperature	TEMP	11.2	—	11.8	°C
Terrain elevation	ELE	21	—	181	m

Figure 7: France case study (broader area of Paris)

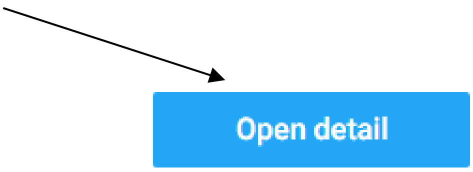
Analyse the results! For example, what's the difference between direct and diffuse irradiation? The total extracted power by a Solar PV system?

Why these values are so low? (these are the daily values)

Why the variability of the areal solar radiation is low?

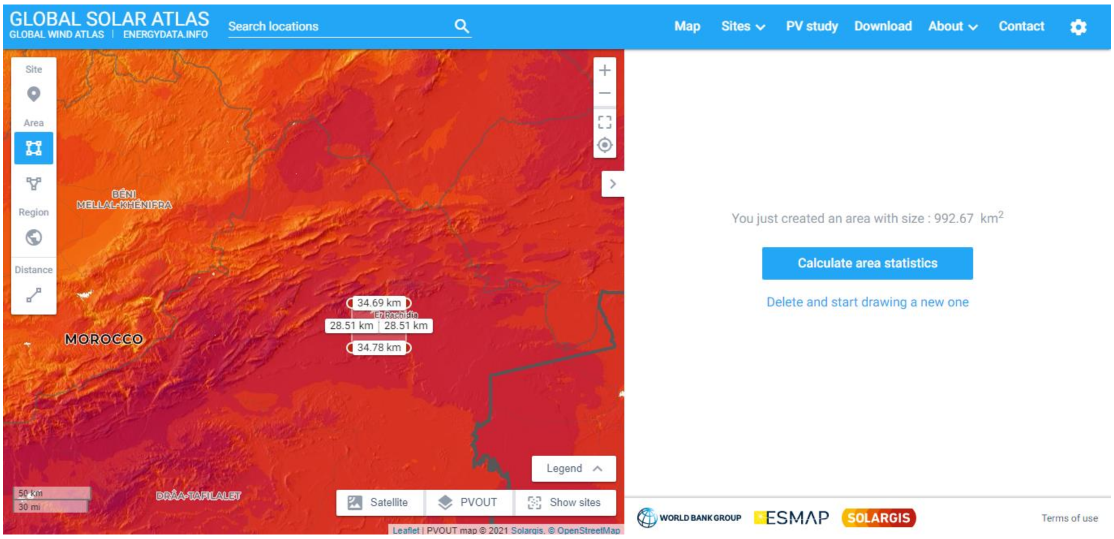
Click on "Open detail" to open the full documentation of the results!

Keep notes on the results!



Step 3: Global Solar Atlas – 2st area, Marocco:

Navigate to the broader Morocco area and identify "El Rachidia".



Similarly to Paris, draw a polygon and estimate the area statistics!

During this step we can start with a few comparisons between the two areas:

Differences on the PV power output?

Differences on the diffuse irradiation? (short differences)

The optimum tilt range decreases! Why?

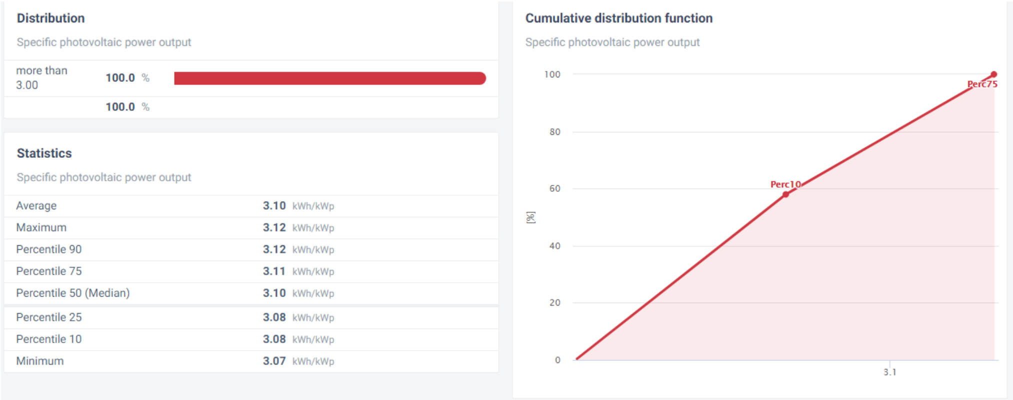
Map data (min-max range) — Per day

Specific photovoltaic power output	PVOUT	5.17	–	5.31	kWh/kWp
Direct normal irradiation	DNI	6.12	–	6.37	kWh/m^2
Global horizontal irradiation	GHI	5.74	–	5.82	kWh/m^2
Diffuse horizontal irradiation	DIF	1.79	–	1.93	kWh/m^2
Global tilted irradiation	GTI	6.59	–	6.74	kWh/m^2
Optimum tilt of PV modules	OPTA	31	–	34	°
Air temperature	TEMP	17.0	–	20.8	°C
Terrain elevation	ELE	937	–	2012	m

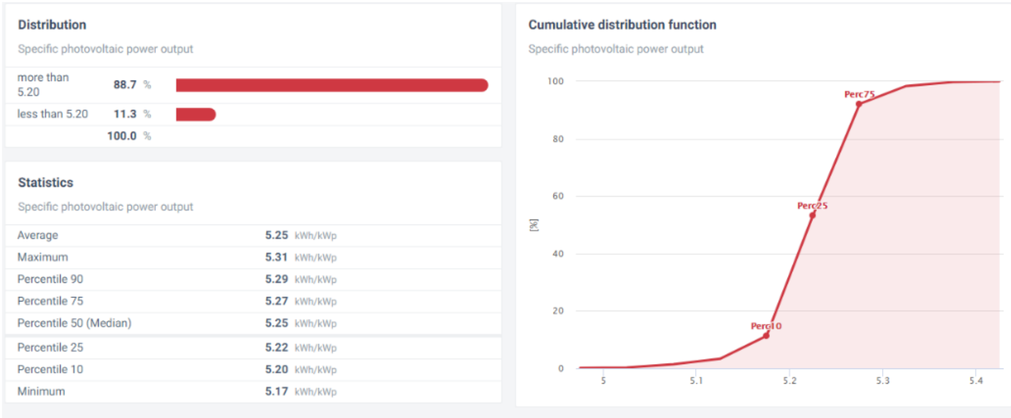
Figure 8: Morocco case study (broader area of El Rachidia)

Compare the statistical results!

Paris



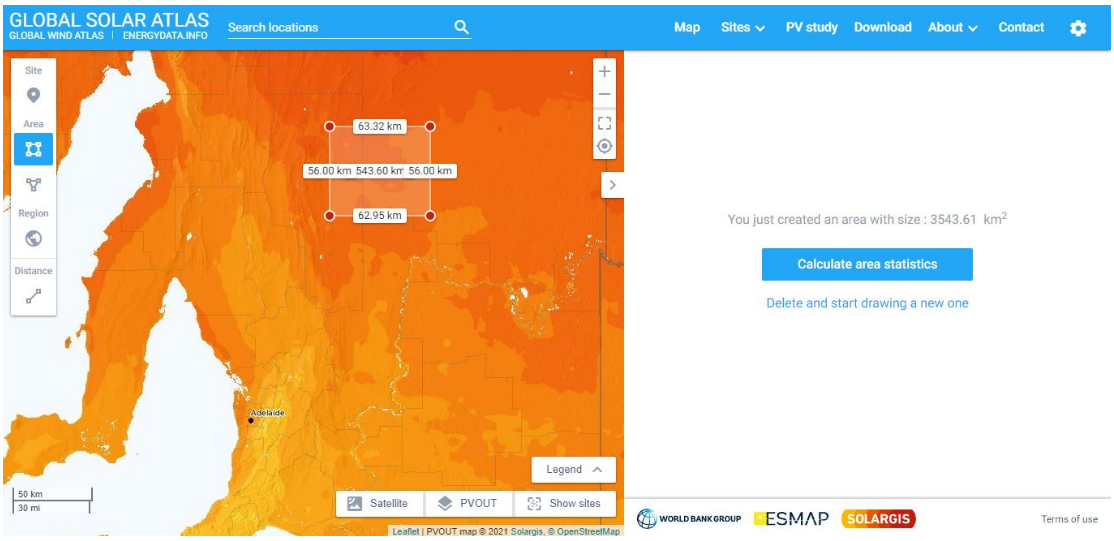
Er Rachidia



Which Cumulative distribution function is better? What the slope of the CDF may reveal?

Step 4: **Global Solar Atlas – 3rd area, Adelaide:**

Navigate to the Australia and identify the broader "Adelaide".



For the broader Adelaide area, results seem to be better than Paris and inferior to El Racidia.

Also, the optimum tilt is the same as El Racidia! Can you explain this?

But for which orientation?? South, North??

A second cycle of discussion begins for explaining the importance of the surface aspect/orientation for PV site-prospecting worldwide.

Map data (min-max range) Per day

Specific photovoltaic power output	PVOUT	4.73	4.84	kWh/kWp
Direct normal irradiation	DNI	6.35	6.56	kWh/m²
Global horizontal irradiation	GHI	5.22	5.30	kWh/m²
Diffuse horizontal irradiation	DIF	1.41	1.44	kWh/m²
Global tilted irradiation	GTI	5.90	6.04	kWh/m²
Optimum tilt of PV modules	OPTA	30	31	°
Air temperature	TEMP	15.8	17.3	°C
Terrain elevation	ELE	49	420	m

Figure 9: Australia case study (broader Adelaide area)

Before we move on to the aspect explanation, let's try to guess which is the optimum tilt for the higher latitude areas, i.e. North Canada? Or even for the North Pole or Antarctica?

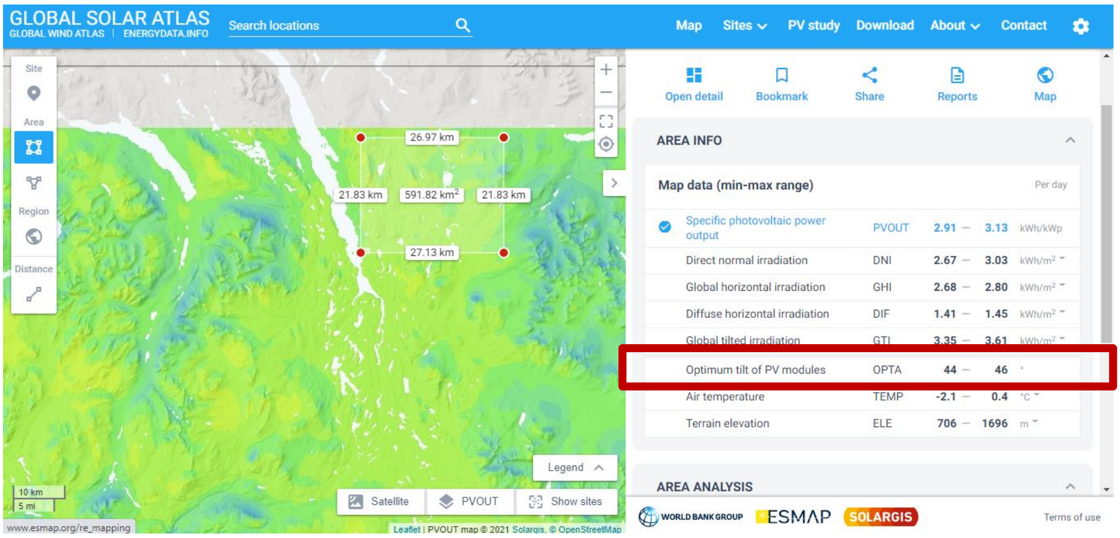


Figure 10: Optimum tilt for Canada

In the following map you can see the solar PVs orientation differences according to the distance from the Equator and whether an area is located in either the Northern or the Southern hemisphere!

A common procedure we can follow using GIS (QGIS platform) is to estimate the aspects of an area using the digital elevation model (DEM).

You can see the following tutorial in order to better understand the Aspect calculation scheme!

https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-aspect-works.htm

Global Solar Irradiation, Orientation:

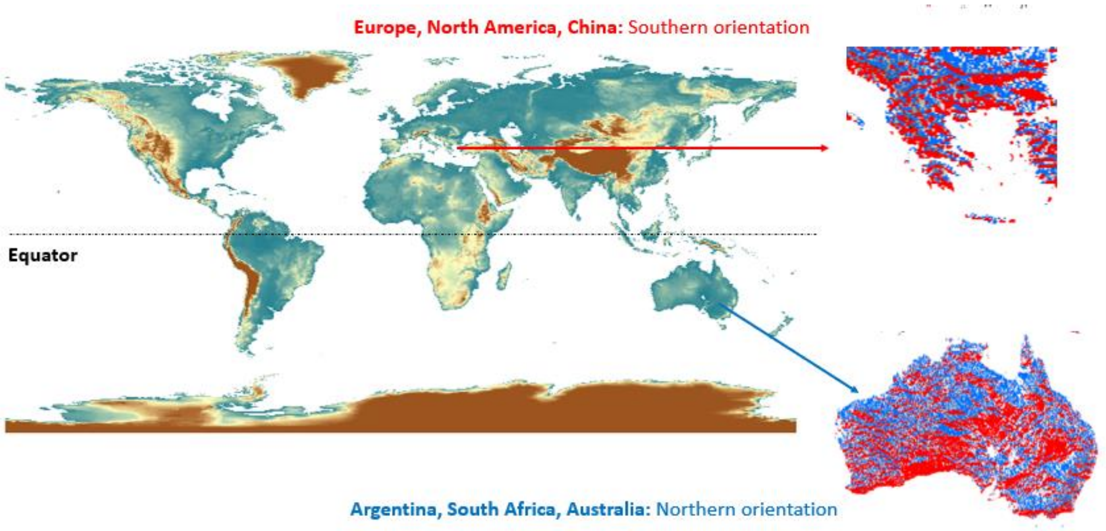


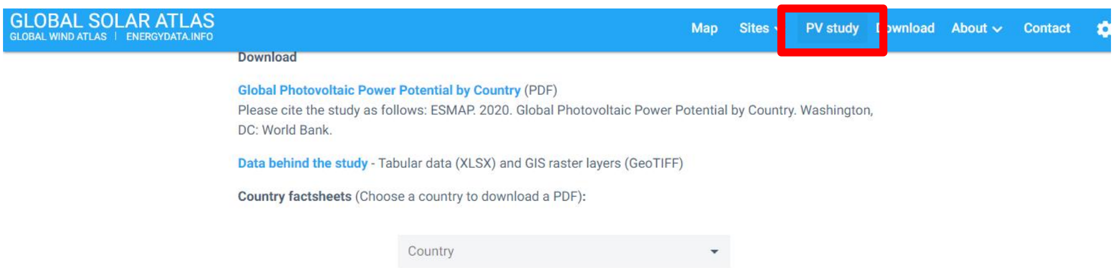
Figure 11: Solar PVs orientation at different places worldwide

Step 5: PV Study – Analytical report:

Now that we explained many different spatial aspects of the produced energy by solar PVs, we can move on to the analytical reporting of a PV study among different countries.

- Different graphs and diagrams will be analyzed, explained and discussed! How Lat-Lon coordinates affects the energy variability?
- Can you estimate how many solar panels must be placed in order to cover the national energy demands in each selected country?

- There is enough space? Can you estimate the available space per country? What data are needed? (i.e., Landcover, surface constraints)



Step 6: PV Study – Find your school!:

First you have to identify your school coordinates!

For this task, we will need the Google Maps web viewer. Follow the instructions presented in Figure 12.

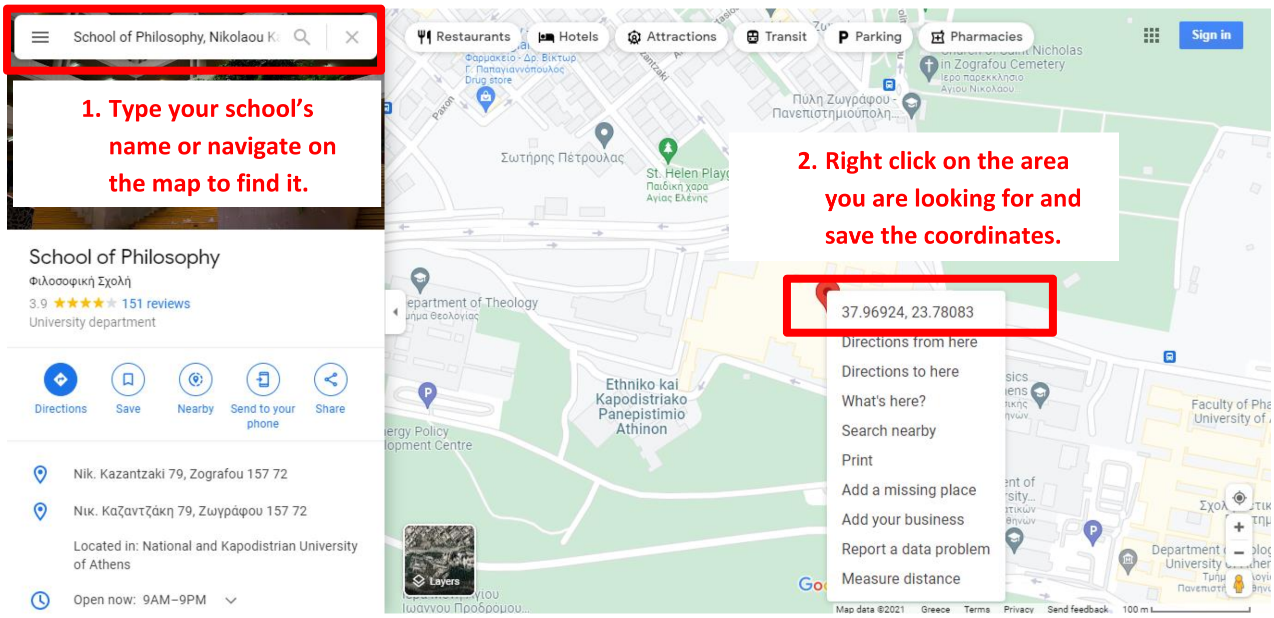


Figure 12: Google Maps Lat-Lon coordinates extraction

After you find the coordinates of your school, return to the Global Solar Atlas platform and paste the coordinates on the “Search for location” bar.

The solar data for your school will appear on the right side of your screen (see Figure 13)!

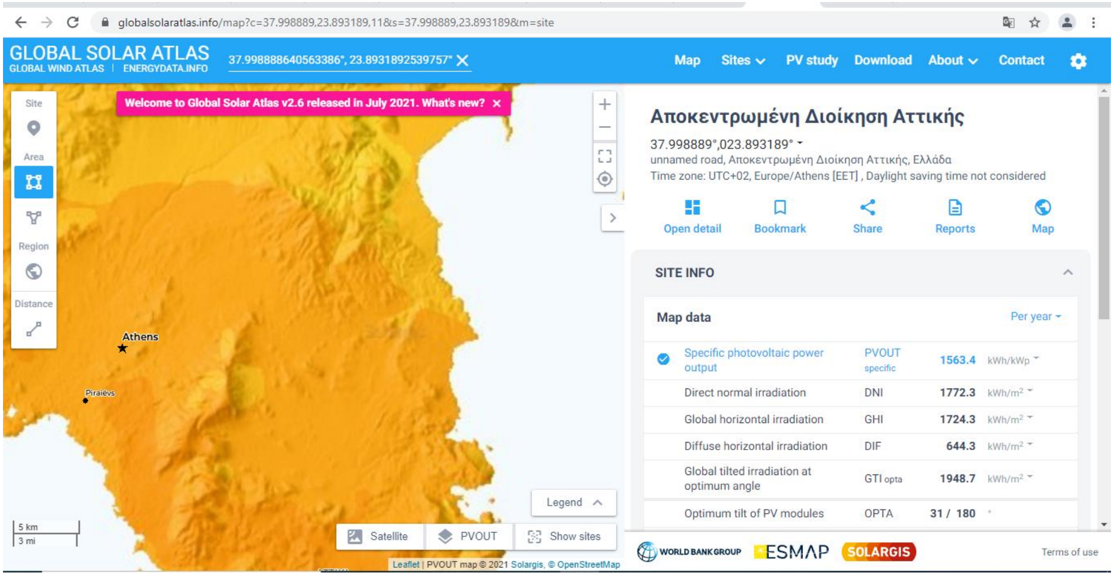


Figure 13: Google Maps Lat-Lon coordinates extraction

You can also select the type of the solar PV system to be placed in your school.

Consider that the solar panels will be placed on the rooftop of your school. Thus, you have to estimate the total surface area of the roof (or part of it).

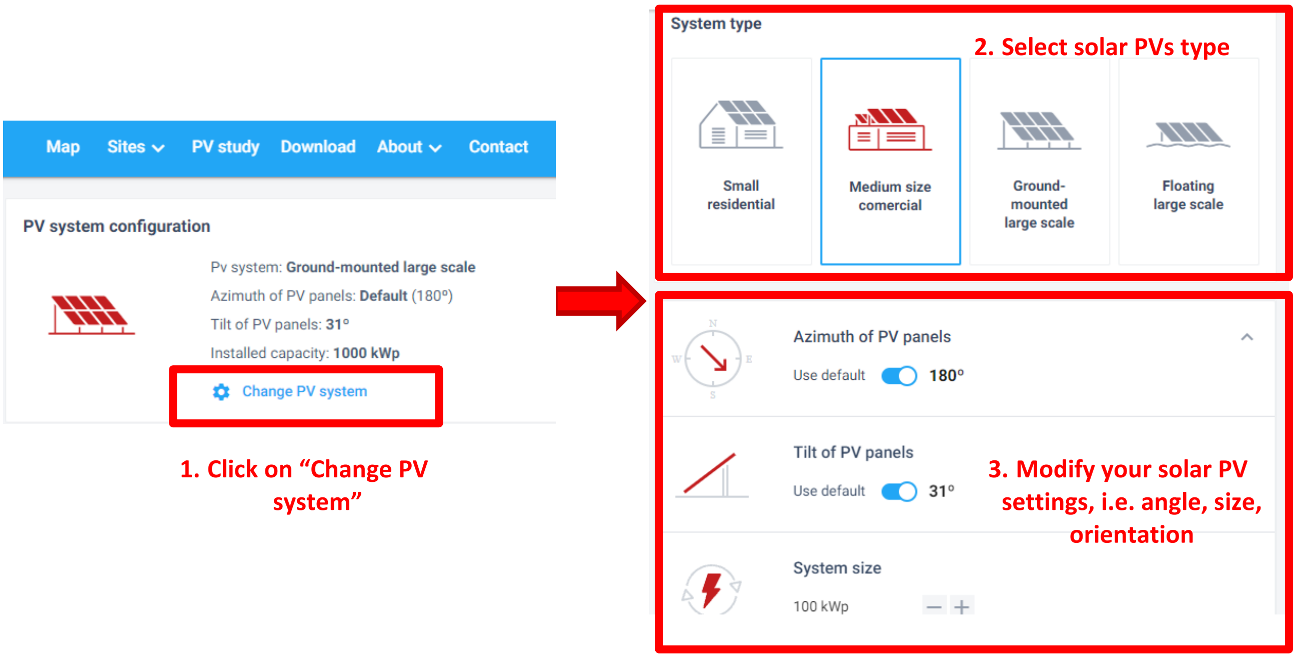
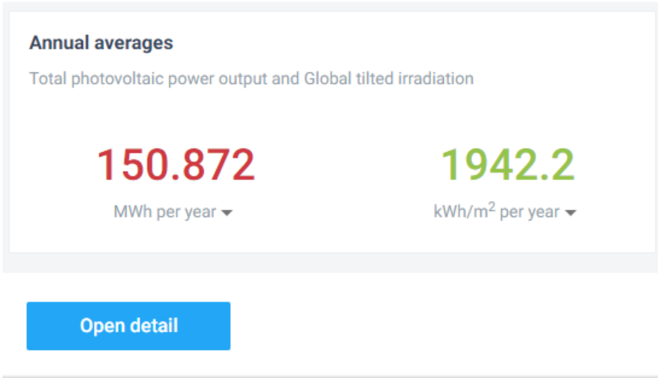


Figure 14: Set-up your school's PV system

Important Note: Do not forget to verify that the Installed capacity of the selected solar PVs fits on your school's rooftop!

Compare the annual produced energy with your school needs in terms of the annual electricity consumption!

Moreover, you can click on the "Open detail" button and see the full report for the incoming solar irradiation at your broader school area!



Discussion

Explanation based on evidence

Guide the teachers to encourage their students to provide correct explanations for the topic(s) investigated.

Describe ways and they can use to this end and give them directions how to discover them.

After completing step 6 above, students in small groups will answer the following questions and be prepared to answer them in a class.

- Do you think it would be cost-efficient to buy a solar panel installation? Why or why not?
- Explain why knowing the average amount of cloud cover in a given area would be important when deciding whether or not to use solar energy as a power source (see the graphs of the seasonal power output variability).
- What is the relationship between the seasons (winter, spring, summer and fall, or wet/dry, depending on location) and the amount of solar energy that a particular place receives based on your results?
- Explain how latitude affects climate zones and in turn, the produced energy by solar PVs.
- What would the lines on the average hourly-seasonal profiles look like for a location in the southern hemisphere? Why?

Consider other explanations

Direct teachers to facilitate the student groups to evaluate their own explanations in the light of alternative explanations, particularly those reflecting scientific understanding. Illustrate examples they can use and give them instructions how to locate them.

Can we estimate the solar irradiation in the Mars and the Moon surface?

What parameters we must consider in order to make estimates and accurate calculations compared to the Earth surface? (atmosphere, distance from the Sun, shading – Moon etc.)?

https://midcdmz.nrel.gov/solpos/sampa.html Moon solar irradiance

https://www.nasa.gov/pdf/163008main_SESE_TeachersGuide__Part_dc3.pdf Solar irradiance on Mars

Students can read the above mentioned articles in order to estimate the theoretical differentiations when calculating the solar irradiance on either the Moon or Mars.

Reflection

Communicate explanation

Guide teachers to facilitate each student group to reflect on the previous experiences and to produce a report with its findings, presenting and justifying the proposed explanations to the other groups and the teacher.

Provide content which the teacher can use to help the students to get familiarized and to become efficient in scientific writing.

The teacher may ask from the students to prepare a short report in order to demonstrate and discuss their results. Also, students may be guided to follow the appropriate steps in terms of the report outline including:

An introduction and scope of the Activity

The study area (countries level) and data representation

The Methodology outline

Results and Discussion and finally,

Their conclusions

Follow-up activities and materials

Describe and direct the user to any follow-up activities or materials that can be used to wrap-up the hands-on activity.

These could include appropriate learning assessment and/or reminder materials (e.g., quizzes, games, other user-friendly tests), hints for further activities etc.

Solarcgis – More advanced solar irradiation estimates: https://apps.solargis.com/prospect/map?show-registration=1&s=37.940948,23.911057&c=37.953673,23.731155,11

Estimated solar energy production: https://re.jrc.ec.europa.eu/pvg_tools/en/#DR

Solar City Engine: http://solarcityengine.irena.org/#simulatorview/1

Sun roof solar power estimation:

https://sunroof.withgoogle.com/building/42.399692/-71.128802/#?f=buy

North Virginia Solar Map: https://nvrc.maps.arcgis.com/apps/webappviewer/index.html?id=ef5c5dc969f341cc986cd431d94cdfe9

Estimate solar power potential: https://learn.arcgis.com/en/projects/estimate-solar-power-potential/ (ArcGIS Pro using free trial)

Estimate solar energy during eclipse: https://www.jpl.nasa.gov/edu/teach/activity/measuring-solar-energy-during-an-eclipse/

Sustainable contact

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References (if any):

Assessment (if any):