SOLAR ENERGY CHALLENGE

A solar energy company is considering to build a new solar farm in one of the five following cities: Barcelona (Spain), Ghent (Belgium), Berlin (Germany), Nancy (France), and Nicosia (Cyprus). The company has has seeked your advice to find out which city will provide the highest revenues based on the solar potential and decide where to build their next solar farm.

Question 1: What are the main indicators to consider in this specific case and how would you use these indicators? Please discuss and explain the methodology you will use to solve the case.

The selection of the appropriate place for installing a solar farm depends clearly on the monthly solar potential. The solar potential is described by the amounts of global horizontal irradiance (GHI) and beam normal irradiance (BNI). Photovoltaic (PV) and solar concentrating power (CSP) applications convert GHI and BNI for electricity production. High solar potential over a specific region corresponds to the extensive generation of electric power from renewable energy sources. Therefore, a straightforward methodology to solve the proposed challenge by the company is to compare the long-term monthly GHI and BNI among the 5 European cities. The monthly averages of GHI and BNI at each calendar month describe the long-term monthly potential in a given place.

Key words: Monthly solar potential, global horizontal irradiance (GHI), beam normal irradiance (BNR), electric power

Question 2: Which data would you use to solve this case (type of data and source)?

Since ground-based solar radiation measurements are unavailable at the desired regions, satellite data for global horizontal irradiance and beam direct irradiance is the alternative option. This data could come from Copernicus.

Key words: ground-based solar radiation, satellite data, Copernicus

Question 3: Where would you find the data? Please indicate the link of the page where you would download the data from (note that do not need to actually download the data as it is provided to you).

Public available, free-of-charge, monthly data can be retrieved through the Copernicus Radiation Service (CAMS-Rad). The data is downloaded directly in a '.csv' format from the SODA portal (http://www.soda-pro.com/web-services/radiation/cams-radiation-service).

Key words: Copernicus Radiation service, public, free of charge

Question 4: The Excel provided is a formatted and simplified version of the data you could download using the Copernicus service identified in the previous question. The first and third tabs include respectively GHI and BNI data in kWh/m2 for the 5 European cities considered in the case. Using the data in the Excel, create two comparative tables (one for the GHI and one for the BNI) showing the monthly average solar radiation indices over the period 2018 to 2020 for each of the five cities. Once you have made the tables, you can create graphs to aid you in the visualization and analysis of the data.
(Note that the dates are expressed in American format: month/day/year.)

The excel file includes monthly data of GHI and BNI in kWh/m^2 for 5 European cities, namely Barcelona (Spain), Ghent (Belgium), Berlin (Germany), Nancy (France), and Nicosia (Cyprus). The monthly data are averaged over each calendar month (January-December) to retrieve each city's long-term monthly mean solar irradiances.

The tables and graphs can be found below:

Global Horizontal Irradiance (kWh/m^2) (2018-2020)					
Month	**Barcelona (Spain)**	**Nancy (France)**	**Ghent (Belgium)**	**Berlin (Germany)**	**Nicosia (Cyprus)**
January	68	26	22	19	77
February	85	54	49	42	91
March	135	91	80	74	151
April	156	144	137	149	179
May	201	179	177	176	220
June	215	184	174	182	227
July	221	201	176	178	246
August	192	163	144	153	222
September	140	118	101	101	178
October	99	61	56	53	129
November	65	35	32	23	86
December	56	23	20	15	74

Table 1: monthly distribution of global horizontal irradiance for the selected cities

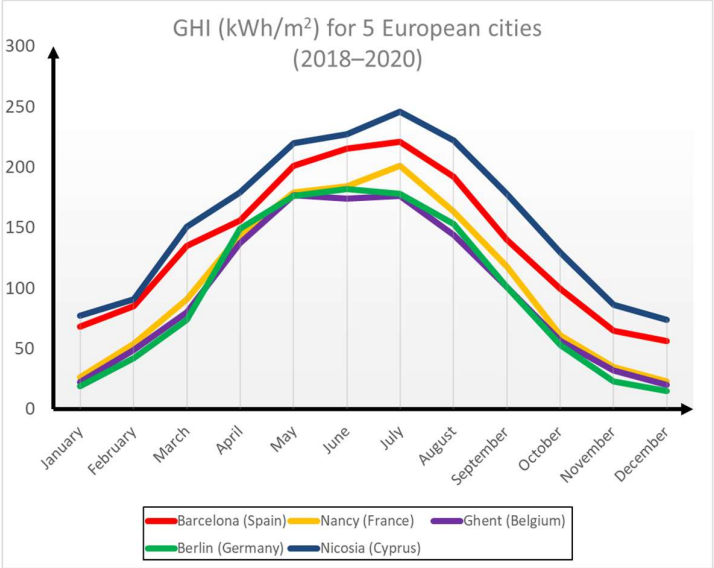

Figure 1: graph of the monthly distribution of global horizontal irradiance for the selected cities

Table 2: monthly distribution of beam normal irradiance for the selected cities

Beam Normal Irradiance (kWh/m²) (2018-2020)					
Month	**Barcelona (Spain)**	**Nancy (France)**	**Ghent (Belgium)**	**Berlin (Germany)**	**Nicosia (Cyprus)**
January	127	28	22	22	96
February	124	76	75	58	97
March	159	97	77	75	156
April	147	146	141	178	169
May	195	168	168	166	210
June	213	160	144	163	228
July	221	197	152	161	266
August	194	159	124	144	242
September	151	137	104	108	204
October	123	63	58	58	151
November	101	47	51	28	104
December	100	31	30	17	106

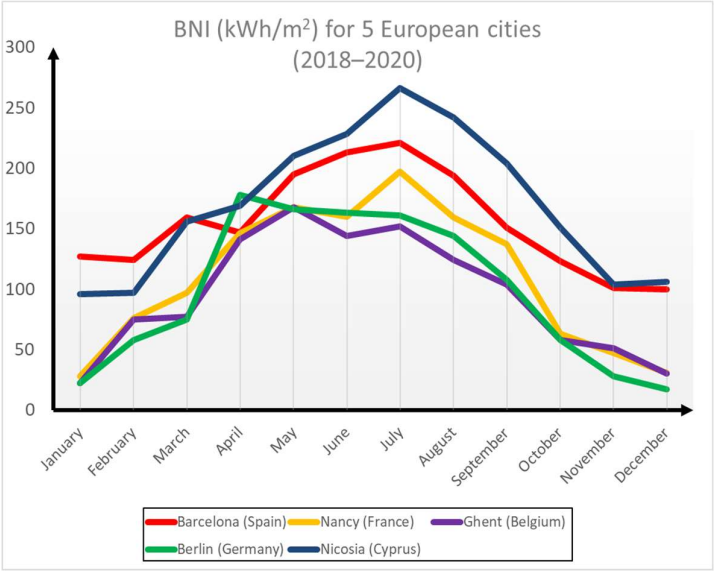

Figure 2: graph of the monthly distribution of beam normal irradiance for the selected cities

Question 5: Based on your previous analysis looking at the indices, which city is the best to install the next solar farm and why?

Following the previous analysis, Nicosia (Cyprus) is the 'best' city for installing a solar farm. GHI is higher for each month than the other cities extending from 74 kWh/m^2 (December) to 246 kWh/m^2 (July). BNI ranges from 96 kWh/m^2 (January) to 266 kWh/m^2 (July), significantly exceeding the monthly BNI of other cities in most months.

Question 6: Conclude on the advantage of using satellite data as opposed to measuring the solar radiation level in each city (time, cost, period available)

Ground-based monitoring is the ideal solution for retrieving high-quality solar datasets. However, the ground-based monitoring networks measuring solar irradiance are limited around the globe, including a non-adequate number of monitoring locations because of the costs of installation, continuous monitoring, and maintenance. Satellite data for measuring the radiation level in a given location is the best alternative option. Solar radiation datasets from satellites are easily accessible, free of charge, including time series at various temporal resolutions for more than 15 years. For example, the CAMS-Rad service provides solar data from 2004 with a temporal resolution ranging from 1 minute to 1 month.

Key words: quality, costs, monitoring, accessibility

Bonus question: Based on your personal knowledge and background, what could be the other elements to consider when deciding upon the city to install the next solar farm?

This is an open question that the students can discuss if they are done before time. They are welcome to discuss aspects related to cost of materials, workforce, political stability or such elements that would be considered in a cost benefits analysis.