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ER57

Automne 2022

Project 1

Powering the whole world using solar energy from Sahara desert

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1) Introduction

The goal of this project is to comment and analyse the tweet shown in Figure 1.

Figure 1 :World of statistics tweet

Is 1.9% of solar energy from Sahara enough to power the whole world? and if so, is it possible to do it and what are the impacts? This is what we will discuss in this document.

First, we will see what the value of energy consumption in the world is and what is the potential energy we can produce in Sahara using the sun, then we will deduce what is the minimum percentage of solar energy from Sahara needed to power the world. In a second part we will talk about the feasibility and confront different hypotheses of means to use and transport that energy from Sahara to power the world and end that part by talking about an actual project.

Finally, we'll discuss the environmental, societal, and economic impacts before a conclusion and personal recommendation.

2) Is the solar energy from Sahara enough to power the world?

a) World energy consumption

First of all, we need to know the total energy consumption in the world in order to understand how much we want to supply.

The energy consumption has continued to increase from year to year. after a 4.5% decline in 2020 due to the Covid-19 pandemic that leads to a decrease in human activities, we observed a 5% growth in 2021. This increase is higher than the average annual increase which is 2% per year (between 2002 and 2019). The growth in global energy consumption is not uniform across the globe. Indeed, this increase is different depending on the country. For example, we have +4,7% in India and +9% in Russia.

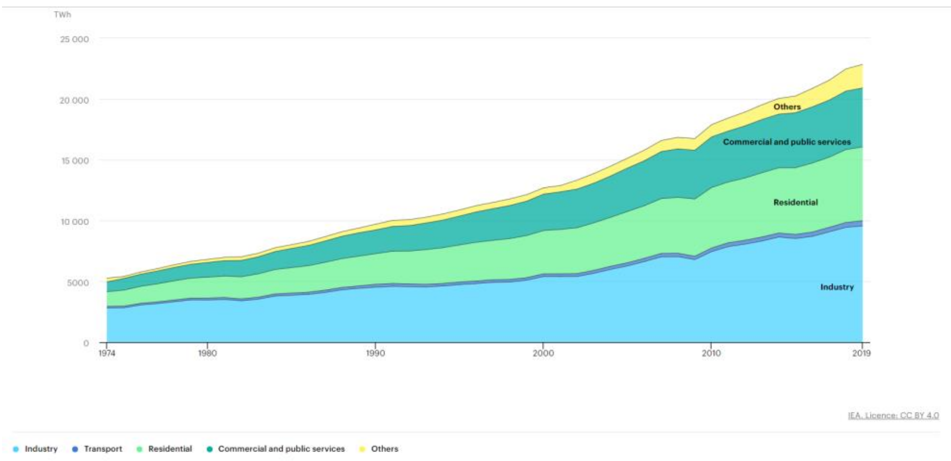

Figure 2 :World electricity final consumption by sector, 1974-2019

The Figure 2 from [2] shows the Global world consumption in TWh and by sectors, so we can see that the industrial sector is the one that is consuming the most, that's why we saw a decrease in energy consumption during the Covid-19 pandemic.

As we can see in Figure 3, The consumption is different depending on the country. And the Figure 4 shows the distribution of electrical energy sources. Basically, the energy source the most use is coil with 28.8%.

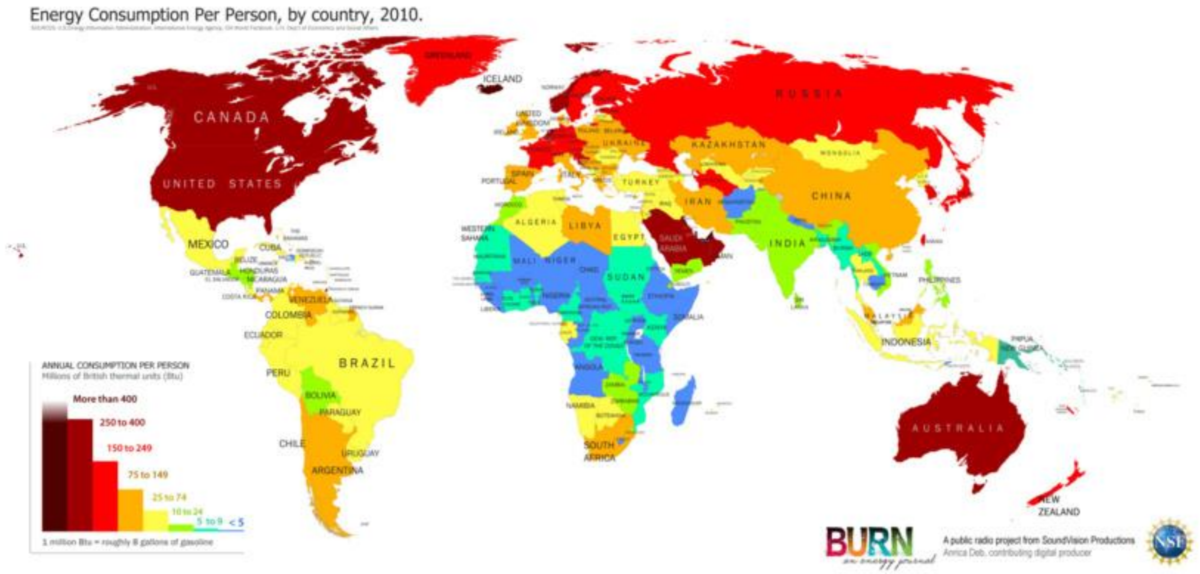

Figure 3 : Energy consumption in each country

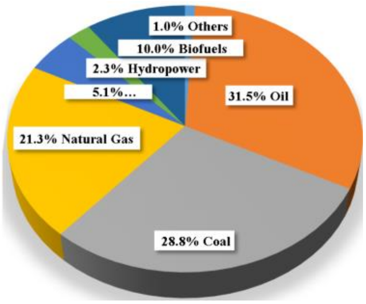

Figure 4 : Distribution of electrical energy sources

Because in the Figure 2 (that comes from [2]) we only have the data till 2019, in the following we are going to use date from [3] which gives us 25, 343 TWh in 2021.

b) Sahara's solar energy and comparison

Looking at Figure 5, we notice that the solar irradiance (which represents the luminous intensity of the sun's rays in W/m²) has the highest value in Australia and North Africa (where Sahara is located). The electrical energy we can get from that irradiance using PV modules depends on a lot of features, such as the type of PV module we use (monocrystalline or polycrystalline), the size of the installation we want to make, the inclination and direction of the photovoltaic panels, the fact that the panels are connected in series or parallel…

Using the simulation website "Global Solar Atlas", we can find a normal direct irradiance (DNI) of up to 2700 W/m². For comparison, in Paris, it is around 1045 W/m². (Of course, we can't convert all that irradiance in electrical energy, it depends on the efficiency of the PV module that generally do not exceed 20%. The rest is returned to the environment as heat.).

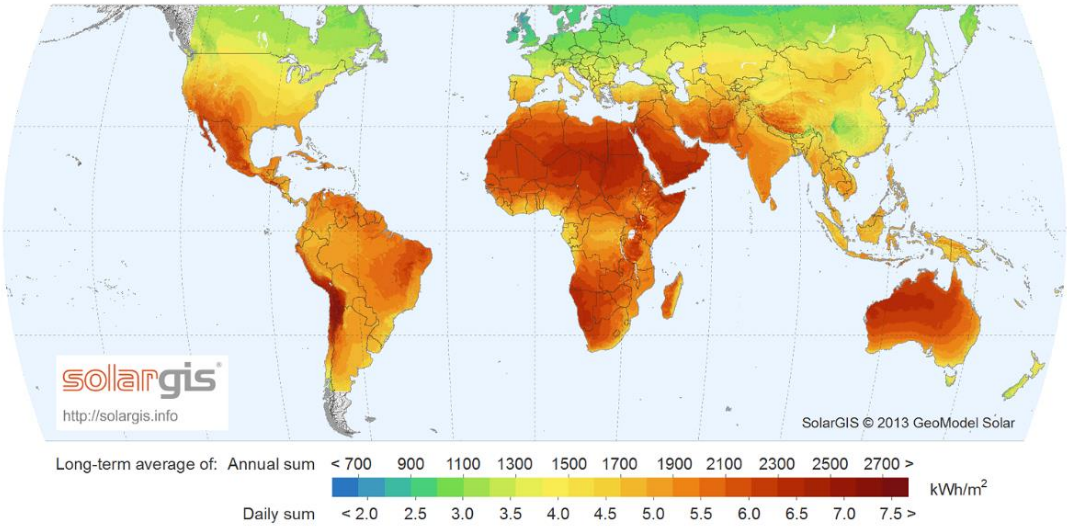

Figure 5 : World solar irradiance

Let's make some calculations:

Still using "Global Solar Atlas" to make a simulation for a 100kWp installation (which represent on average 502 m²) and using the parameters shown in Figure 6, we can get 210 MWh/year.

Figure 6 : Simulation for a 100kWp (502m²) in Egypt

Knowing that the surface of the Sahara is 9,2 million km² ($9{,}2 \times 10^6 \times 10^3$ m²) and that a 100kWp installation represent on average 502 m²:

$$\frac{9{,}2 \times 10^6 \times 10^3}{502} \boxed{= 18\ 326\ 693{,}23}$$

It means that we can put 18 326 693 photovoltaic installation of 100kWp in the Sahara Desert.

Now knowing that a 100kWp installation in Sahara is able to gives 210,616 MWh/year:

$$18\,326\,693 \times 210{,}616 \times 10^{6} \boxed{= 3{,}8598 \times 10^{15}\ \text{Wh/year}}$$

The Sahara Desert can produce $3{,}8598 \times 10^{15}$ Wh/year which is much higher than the annual consumption of energy in 2021.

$$\frac{25,\ 343 \times 10^{12}}{3{,}8598 \times 10^{15}} \times 100 \boxed{= 0{,}65\%}$$

0,65% of the solar energy from Sahara would be enough to power the whole world. That is in case we use several 100kWp installations but in reality, we would have one or two big installations so that percentage should be a little higher.

According to Mehran Moalem, PhD, UC Berkeley, Professor, Expert on Nuclear Materials and Nuclear Fuel Cycle [7]: solar panels covering a surface of around 335km2 would actually be enough to power the world (2015). So 1.2% of the Sahara Desert would be enough. 1.2% of Sahara represents less than 1.9 % of its energy so it would be possible to use only 1.9% of solar energy to power all the 25,343 TWh. But we don't have to forget that the energy demand increases every year, and, because of global warming, the output of photovoltaic panels increase as well each year.

12 years ago, David MacKay (scientist from the department of physics at the university of Cambridge) said that "All the world's power could be provided by a square 100km area in the Sahara". On the Figure 7, we can see the representation of the energy consumption using the North Africa map. (De=Germany, EU = Europe).

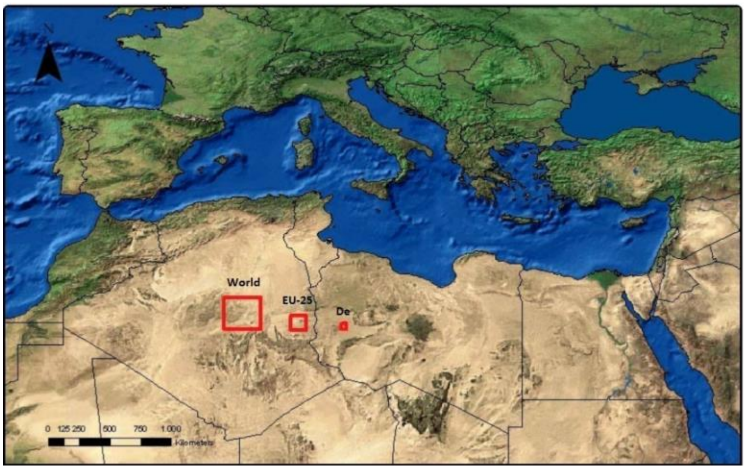

Figure 7 : Representation of the energy consumption using the North Africa map (from IFLScience)

3) Feasibility

We now know that 1.9% of solar energy from Sahara is enough to power the world but it is not that easy. The question is: Is it feasible? How would the energy be transported and transmited?

a) Panels and transport

First, the need to buy or produce solar panels that could handle the desert conditions can be meet by using silicon panels because this material can resist hight temperature and it is the most used in African projects at the moment. But it will need to be cleaned often because of the sand that the wind has blown on them and which could reduce its efficiency (working conditions for maintenance will be discussed in the following sections). Also, the cleaning would require a lot of water and would be seen as a waste of water.

The solar panels output a direct current (DC). Outside the network transports and distributes the energy in alternative current (AC), from this moment here are 3 hypotheses: Firstly, we could use power inverters (DC/AC converters) which make it possible to pass from a direct current to an alternative current in order to then be able to inject the power into the AC electrical network using eventually undersea cable to transport it to Europe. The problem with that solution is that the longer le line or cable are, the more the level of losses increase. So, we could not have all the power that we harvested from the solar panels. That means that maybe we'll have to collect a value of power that is higher to the one needed to power the world in order to compensate the losses.

Second, it is possible to connect batteries directly to the solar panel to recover DC energy and then transport the batteries in trucks to other countries in the world. But it will be very expensive in petrol for the vehicles and will increase the pollution due to the vehicles. It is also possible to use another means of storage such as hydrogen for example.

The first proposition is shown in Figure 8.

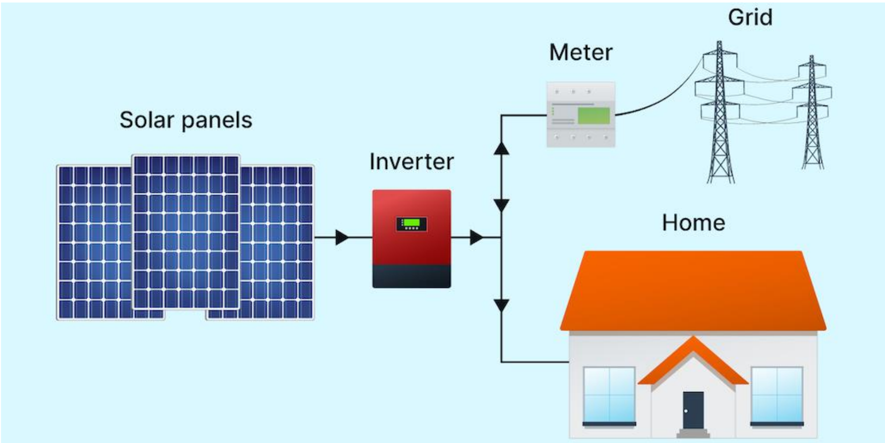

Figure 8 : Transport of energy from solar panel

The third alternative, which is the most difficult to achieve, is to create an electrical network totally in DC power, to transport the energy directly in DC power without the need to go through inverters.

This is a very controversial subject at the moment. More and more people are working on the idea of creating a totally direct current electrical network to facilitate the insertion of renewable energy into the network. But many say that this is not the right solution because if we have always used AC current, it is not for nothing. Indeed, it is much easier to cut the alternative current because it naturally goes through 0. Moreover, it is possible to use transformers to increase or lower the voltage level. The use of transformer is not possible in direct current (DC). Furthermore, some companies such as SuperGrid Institute, for example, are actively working on the development of DC technologies in order to advance the creation of a new DC power grid. One of their arguments is for example that, over greater distances, the losses are less important in DC than in AC as shown in figure Figure 9, this is why the question of DC makes sense for very large distance, which is the case for us in order to transport the energy produced by the solar panels in North Africa to other countries.

Obviously, an international DC electrical network would be very difficult to achieve because it would be necessary to put very long cables under the sea, and the longer the cables are, the more expensive it is. The submarine cables are also more expensive because the materials used are different to those use by the transmission lines. It must be more resistant. However, a network in DC not international but only for the surrounding countries is possible.

Then certainly, the construction of a DC network is long and very expensive but at the end, there would be a good return on investment after a few years. Because we would have less losses and in addition, it will save us the cost of the inverters and losses.

What is unfortunate and which could totally eliminate this alternative is that the technology is not yet mature enough to propose elements that would allow us to use a DC network.

Nevertheless, as more and more people are working on the idea, it could at least be more possible in 2040.

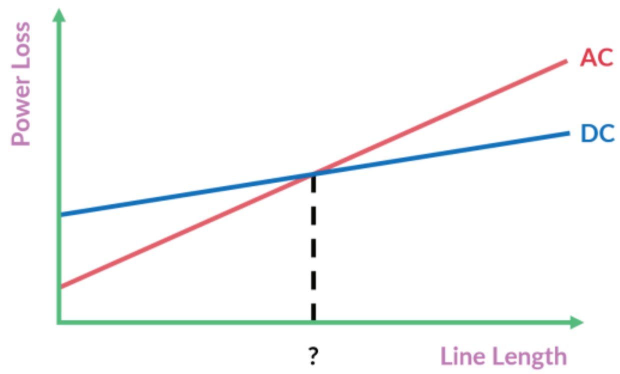

Figure 9: Power losses over distances for AC and DC (SuperGrid Institute [9])

The 3 solutions have disadvantages, for the AC network, those are the losses, for the DC network this is the lack of technological maturity and for the storage it is the pollution caused by the transport.

The Figure 10 shows a summary of these different hypotheses.

	AC electrical grid	Storage	DC electrical grid
Advantages	*Experiences (know how to do)	*No inverter *No calble or line transmission	*No inverters *Less losses over long distances
Disadvantadges	*Losses over long distances *Use of inverter	*Pollution created by vehicules for the transportation *Big consumption of oil	*Technology not mature enough *Expensive at the beginning

Figure 10 : Summary of different possibilities for transport

The solution including electrical grid are not possible for the countries that are too far (for example in America), but we could use a storage solution for those countries.

As solar energy is not a stable energy, we need to keep the frequency stable on the grid by keeping the production of energy exactly equal to the consumption and for that we could use regulation using automatic controller or using new technologies such as the grid forming.

To extrapolate the energy consumption for 2040, we take a +2% increase, which is the average increase per year. using an excel table, we get a value of 36,9199 TWh for 2040.

Year	Comsumption 5 TWh)
2021	25,343
2022	25,84986
2023	26,3668572
2024	26,89419434
2025	27,43207823
2026	27,9807198
2027	28,54033419
2028	29,11114088
2029	29,69336369
2030	30,28723097
2031	30,89297559
2032	31,5108351
2033	32,1410518
2034	32,78387284
2035	33,43955029
2036	34,1083413
2037	34,79050812
2038	35,48631829
2039	36,19604465
2040	36,91996555

Figure 11 : Excel table for the consumption in 2040

Using the same calculation that we used in the precedent part, we can determine that 0,956% of the solar energy from Sahara would be enough to power the world.

$$\frac{36{,}9199 \times 10^{12}}{3{,}8598 \times 10^{15}} \times 100 \boxed{= 0{,}956\%}$$

The societal, environmental, and economic impact are as important as for the technical part in terms of feasibility. This is what we will talk about in the next part.

b) Environmental impacts

Sustainable development is a subject of growing concern, and we are constantly looking for solutions that would allow us to use green energy sources to reduce the rate of pollution on the earth. So, when we are told that it is possible to power the world with solar energy, we may first think that it is a very good way to improve our carbon footprint.

But covering the Sahara with solar panels could have several consequences. First the light color of the sand in Sahara is useful to reflect the light and heat of the sun into the air. If we cover the floor, light and heat would be absorbed so the ground temperature would grow a lot and it is already really hot in North Africa. And if the air is too warm, it would rise to higher altitudes and condenses as clouds which will then fall as rain. The increased heat in the desert will be carried around the world by weather systems, causing more unstable weather in areas like North America or Asia. Normally if we only cover 1.2% of the Sahara Desert with solar panel, it won't get to create a cloud of rain, but the temperatures will still rise at lot, and it could be very difficult if not impossible for people to come for the for maintenance and for the population ti live.

The planet works in a balanced way. The Amazon Forest, for example, depends on the sands that have a lot of minerals blown from the Sahara for nutrients. Without these, the Amazon will not receive enough nutrients to survive.

The production of solar panels is not really environmentally friendly at the moment. The current production process uses semiconductor manufacturing technology that generates pollution. At the current small levels, it is not much of an issue but at 25 TW, it definitely would be a issue and solutions would need to be found to neutralize those toxins and reduce the pollution. The current solar panel production technology also uses large quantities of energy and that can become a factor to consider for sustainability.

To finish, as we said earlier, we must consider the transport of energy, if we want to power other countries, we have to transport that energy to them. If a storage solution is used, for example, the pollution caused by transport vehicles of batteries is largely to be taken into account.

c) Societal and economic impact

According to Amin Al-Habaibeh, a professor at Nottingham Trent University who has researched the idea, if all the sunlight hitting the desert were converted into electricity, it would provide 7,000 times more energy than Europe's total energy demand.

If this were to happen, the governments of the countries of North Africa could take advantage of it by selling electricity to Europe at a very high price or by negotiating for other advantages. it could change the agreements between the north Africa and European countries. as for African oil which is today coveted by the whole world. Africa could also perceive it as a curse, because of the corruption and political tensions around.

According to the Forbes magazine [6] The cost of the project of covering 1.2% of Sahara with solar panels will be about five trillion dollars. It is approximately 1/4 of US national debt, and equal to 10% of world one year GDP (Gross domestic product).

The cost of a 1 GWe (Gigawatt electric) nuclear plant is about three billion dollars. the cost of 17.3 TW (demand in 2015) nuclear power will be fifty-two trillion dollars or ten times that of solar. Nuclear power has the highest power density of any generation and lasts longest. So, where the space is limited or in spaces far from the sun, nuclear power makes sense.

The final cost depends on the panels we choose to use (size, material, panels are connected in series or parallel), the cost of inverters if we choose to connect it to the network or batteries if we choose to transport it using batterie, the price for the people working on that (higher if we choose to make a new DC electrical grid)…

At least, at the ends, this would create a lot of jobs, and this is something that is really needed in North Africa. Unemployment, and particularly that of young people and women, is today a major challenge for the countries of North Africa (Algeria, Egypt, Libya, Morocco, Mauritania, Sudan and Tunisia). In addition to a high unemployment rate (12.1% in 2019 according to the ILO), North Africa has today one of the lowest employment rates in Africa (40.1 % on average compared to 58.8% for the rest of the continent in 2019. Young people and women are the main victims of this situation: In 2019, North Africa had 30.2% of unemployed young people compared to 13.6% according to the world average (ILO).

If more people are employed, the economic activities of North African countries will increase, which is good economic news for these countries. However, if the project is carried out by Europeans or Americans, they could take advantage of the low cost of African labor and end up exploiting North African peoples. Also, it would be difficult to make all the Europe countries agreeing on 1 proposition and that would create a lot of political debates.

To finish it would have consequences on people and animals that lives there because the increasing of the temperature in the region.

d) Actual Project

d-1) Morocco project

The largest solar power plant in the world is in Morocco. Morocco inaugurated in January 2016 in Ouarzazate in the middle of the desert, a gigantic solar power plant, the largest in the world ever built.

Solar panels recover over 480 hectares, the equivalent of 600 soccer field in 2016. The power plant is the pride of the country. Morocco is gradually implementing an ambitious project to develop renewable energies. A project developed thanks to new sources that are: wind, geothermal and solar (That project started in 2009).

Figure 12 : Solar power plant in Morocco

The construction of this solar power plant symbolizes the new policy that the country is pursuing. This location was chosen for its maximum solar radiation of 320 days a year. Construction sites use a thermodynamic technique to generate electricity. In the facility, there is 500,000 mirrors. These focus the sun's rays, then heats the liquid in tubes attached to the mirror and convert it to vapor. The vapor turns a turbine to generate electricity. What is impressive is that the panels always follow the movement of the sun so the efficiency can be maximise.

600,000 Moroccans can be supplied with electricity thanks to this central in 2017. In fact, the first power plant is only part of a larger project. A few meters away, earthworks have already begun for the construction of three other plants of the same size.

In 2018, the plant is 2,000 hectares of solar panels that cost 9 billion euros.

It is cut into 4 parts in order to test several technologies, a first part with the mirrors as said before. The second part with photovoltaic panels using semiconductors. The third part with mirrors but connected to batteries for storage and to finish the last part using thermo-solar technology with tower.

d-2) Desertec project

The Desertec project was initially planned with the aim of using the Sahara's sunshine to produce electricity and distribute it, mainly to European countries.

This project wanted to ensure the diversification of European energy supplies from renewable energies. It aimed to cover nearly 17% of Europe's electricity needs from 2050. It was planned within the framework of a partnership between Algeria and Germany, it would however not have seen the light of day because the banks would have refused to finance it because of its investment cost "exceeding 450 billion dollar".

The project consisted of connecting several large thermodynamic solar power plants to the electricity distribution network that supplies Europe, but also North Africa and the Middle East. In a second step, other types of renewable energies would probably have been connected to this network.

It could have helped North Africa and in particular Algeria to get out of its dependence on oil by exploiting the potential of the Sahara. the goal was also to reduce greenhouse gas emissions and to diversify energy.

As for Morocco, the central ambition was to use tower centrals, parabolic centrals, and mirror centrals, as well as thermal storage solutions.

For transport: a new type of High Voltage Direct Current (HVDC) line had been imagined. This technology should have made it possible to transport electrons over long distances with much less line loss (3% per 1,000 km), compared to conventional alternative current lines, and almost without electromagnetic pollution.

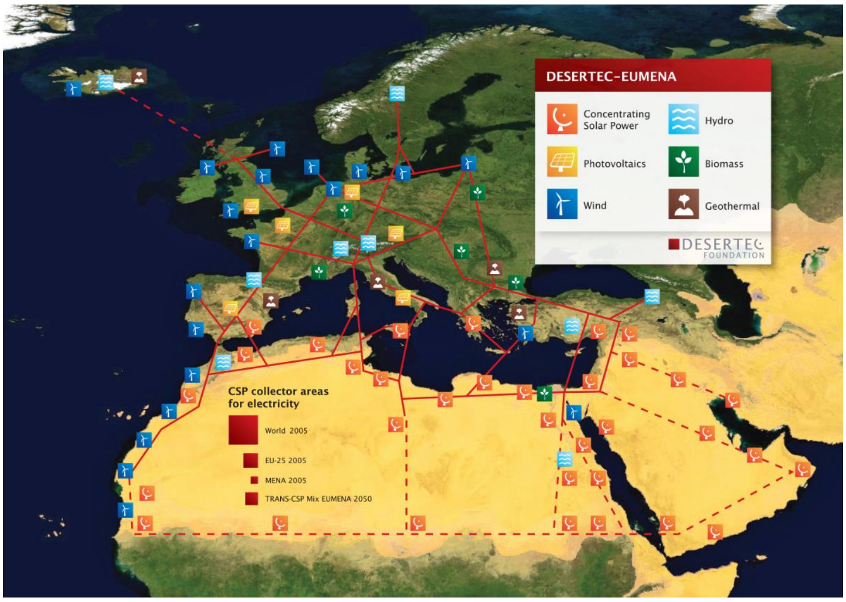

Figure 13 : Sketch of possible infrastructure for a sustainable supply of power to Europe, the Middle East and North Africa

4) Conclusion, recommendation, and comparison

To conclude, I would say that the idea of powering the whole world using solar energy from the Sahara is an idea that needs to be explored. Indeed, the Sahara is one of the regions of the earth with the highest irradiance and succeeding in exploiting this energy will be a great advancement for humanity to move towards sustainable development and reduce our carbon footprint.

However, it's not that easy, even if a very small percentage of the Sahara's solar energy is enough to power the world, we have to take into account the different means of transporting energy to other countries, their advantages, their disadvantages and choosing the best compromise in terms of value for money. It will not be possible with today technologies to transport the energy to the whole world using cables but only for the countries around (South of Europe and South Asia). For the countries that are too far we'll have to think about other solution for the transportation such as the several means of storage. Of course, social and environmental issues must be considered as much as technical issues. The design of such a project is not without consequences, indeed the installation of such a large solar power plant can pollute by its construction and generate, if it is too large, changes in the natural balance of our planet.

The implementation of such a project can be seen as a way to become more independent and more developed for the countries of North Africa but it can also be seen as a new problem which will put the countries into endless political debates like for oil.

Personally, I think that this project can be an important step forward and I would recommend continuing it. I think for now the best alternative for transport is to use inverters to connect the solar power plants to the AC grid considering the losses (only for the nearest countries). It means that a greater surface of the Sahara will be used to compensate the losses, but it will still not be a change in the balance of the planet because the surface remains despite everything very small compared to the size of the desert of the Sahara. I think it could even create employment and improve the economic situation of North African countries, as well as make them less independent of oil and allow them to develop more.

In 2040, things will be different because, as we have calculated, world consumption is likely to increase, which means that a greater part of the Sahara Desert will be necessary. In addition, the total irradiance will also increase due to global warming, however perhaps it will increase less quickly because by using renewable solutions we'll pollute less and slow down global warming. Finally, technological maturity will be much more developed in 2040 because now more and more people are starting to work on new technology for DC networks, also new types of storage or new means of transporting energy in AC.

Solar energy is the most interesting energy to exploit in this region because of the high rate of sunshine. But in other regions of the world, it would perhaps have been more interesting to use other types of renewable energy. Indeed, the emergence of renewable energy push more and more person to work on that. Even if the wind power is much debated at this moment, because of the fact that it kills the birds, that it makes a lot of noise and make the landscapes ugly according to some people. The performance of a wind turbine remains much higher than that of solar panels (around 65%).

If there is however a promising renewable energy, it is hydroelectricity. It is very promising because it uses only the force of water to operate, it does not require a lot of technology or equipment (depending on the size), does not require much maintenance and finally its performance is very interesting (from 70 at 80%).

The largest hydroelectric power station is in China (Three Gorges Dam), it is an installation of 22.5 GW and produces 111.79Wh per year. One disadvantage is that there is not water everywhere and the construction can be very long (from 1994 to 2012 for this one). But again, it depends on the size, it is possible to exploit very small waterfalls as there are many for example in the mountains in Morocco.

5) Self-evaluation

I think this project allowed me to learn a lot more about solar energy but also about renewable energy in general and how energy is transported. There are many more parameters than I thought to take into account. I often think only of the technical issues while totally neglecting the environmental or social and economic issues.

If I had to do it again, I think I would spend more time on the technical feasibility despite everything because it is the part that requires the most data and the most concentration. However, I worked best on the first part because that's where I started and moreover, I had to do some calculations in that part.

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