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Analysis of energy production with different photovoltaic technologies in the Colombian geography.

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Abstract. This research has analyzed the photovoltaic technologies, Polycrystalline silicon, Monocrystalline Silicon, GIS, Cadmium Tellurium and Amorphous Silicon; in eight cities of the Colombian territory, in order to obtain a clear idea of what is the most appropriate for each city or region studied. PVsyst simulation software has been used to study in detail each photovoltaic technology, for an installed capacity of 100kW knowing the specific data of losses by temperature, mismatch, efficiency, wiring, angle inclination of the arrangement, among others

1. Introduction

Colombia is a country with a great diversity of scenarios in both climate and energy from the solar perspective. The cities are located in places ranging from almost desert, (Riohacha - Guajira) up to plateaus of low temperature (Tunja - Boyaca). An analysis of photovoltaic technologies in the different cities of the Colombian territory can give a clear idea of which photovoltaic technology is most suitable for each city or region studied. Using PVsyst simulation software, it is possible to study in detail each Photovoltaic (PV) technology [1], knowing specifics of losses by temperature, mismatch, efficiency, wiring, angle inclination of the array, among others, by analyzing the energy performance and not the area according to efficiency[2].

The selected cities have different characteristics in different areas of the country, climates, and hydrological conditions [3]. The selected zones in this study are:

- Arauca – Arauca.
- Bahía Solano – Chocó.
- Barranquilla – Atlántico.
- Bogotá – Cundinamarca.
- Bucaramanga – Santander.
- Guajira.
- Leticia – Amazonas.
- Tunja – Boyacá

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This study shows that a photovoltaic system in a city with a low radiation can produce more energy per square meter than other with higher radiation. This means that there is an opportunity to apply this technology in different thermal conditions of the Colombian geography.

2. Description of the study

Characteristics and coordinates of places taken as the basis for this analysis.

Table 1. Meteorological data of studied cities.

CITY-REGION	COORDINATES	AMBIENT TEMPERATURE (C)	WIND VELOCITY (m/s)	ELEVATION (masl)	ANNUAL SOLAR IRRADIATION (kWh/year)	PSH (h)
ARAUCA	7.08N 70.75W	24.76	3.2	360	1762.5	4.83
CHOCO-BAHIA SOLANO	6.29N 77.47W	24.5	1.8	60	1530.5	4.19
BARRANQUILLA	10.98N 74.78W	27.4	4.4	50	1922.9	5.27
BOGOTA	4.23N 74.49W	15.3	3.4	2650	1769	4.85
BUCARAMANGA	7.13N 73.13W	23.3	1.7	965	1881.5	5.15
GUAJIRA	12.01N 71.7W	26.1	6.2	30	2370.5	6.49
LETICIA	4.21S 69.9W	27.7	1.4	90	1670.7	4.58
TUNJA	5.54N 73.36W	12.9	1.8	2780	1837.6	5.03

Table 1 shows valuable data when determining in which region a photovoltaic installation would work better. The study of La Guajira region presents the highest value at Peak Solar Hours, so it is expected that the energy production there would be higher than in the rest of the cities studied.

As starting points for PV evaluation, and leaving photovoltaic technology as the only variable, the following considerations have been taken [4]:

- Installed capacity of 100W
- Inverters for grid connection KACO POWADOR 36TL
- Constant losses: dirt, ohmic, miss match, heat.

PVsyst allows different variants of simulation. The analysis has been made with 2 variants of design: with and without the speed of wind.

For the study of the behavior of photovoltaic technologies in different cities, the main photovoltaic modules used in the market have been taken as object of study [5]. The photovoltaic modules used for this study are shown in table 2.

The characteristic curves for each photovoltaic module, analysis of the behavior of each technology with variables such as temperature and incident radiation are available in the PVsyst software [6].

Table 2. Photovoltaic modules used in the study

Panel	Fabricant	Technology	Power (w)	Panel area (m^2)	Temperature coefficient of panel (%/c)	Module efficiency
JAM6-60-250	JA SOLAR	Monocrystalline	250	1,635	-0,44	15,54%
JAP6-60-250	JA SOLAR	Polycrystalline	250	1,635	-0,45	15,31%
FS-390	FIRST SOLAR	Cadmium telluride (CdTe)	90	0,72	-0,25	12,52%
DA100-A1	DUPONT APOLLO	Amorphous silicon (a-Si)	100	1,564	-0,25	6,40%
SF165S	SOLAR FRONTIER	CIS	165	1,228	-0,31	13,44%

Two case of study are analyzed, the case A presents the conventional analysis of PV energy production without consider the wind speed, oppositely the case B shows the effects of consider the wind speed.

3. Case study A: 100kW without influence of wind speed

3.1. Energy Production

The figure 1 shows the amount of energy produced by the arrays in case study A. In terms of the amount of power generated, the department of La Guajira has higher energy production in all technologies. On the other hand, the smallest photovoltaic energy production of the studied areas is Bahía Solano in the department of Chocó, corresponding to the data of lower incident radiation and high temperatures in the region.

As for Bogota and Arauca, they do not have equal energy production results due to the difference of temperature between these regions, that are completely opposite, being the low temperatures of Bogota more favorable for the performance (produces 4% more in monocrystalline technology and a 1.7% more in CdTe technology) and behavior of photovoltaic modules regardless of the type of technology used.

When comparing Bucaramanga and Tunja, it can be said that despite Bucaramanga has higher radiation, Tunja presents greater energy production on behalf of the temperature. There is a great difference between monocrystalline production (in Tunja produces 3.8% more energy than in Bucaramanga) and thin-film technologies, especially type Telluride CdTe (0.69% more than in Bucaramanga), making this last technology more suitable for warm climates.

Performance ratio (PR) is defined the relation between the energy actually produced and the energy that would have been produced by an ideal system operating continuously at standard conditions under the same irradiation [7] (Global incident on the plane). The figure 2 shows the performance ratio of case study A.

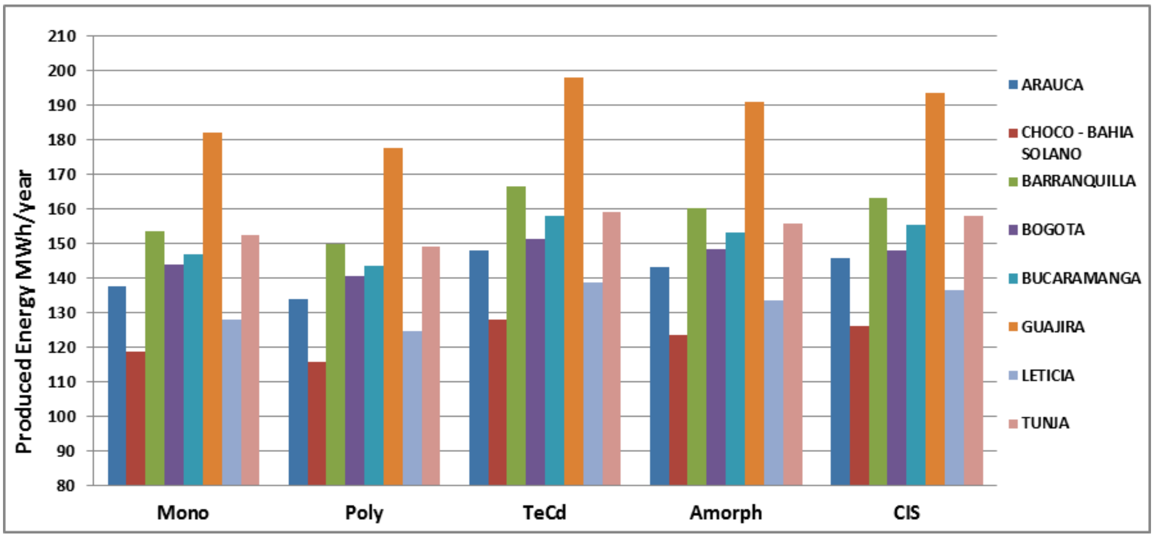

Figure 1. Produced energy of the arrays

3.2 Performance ratio

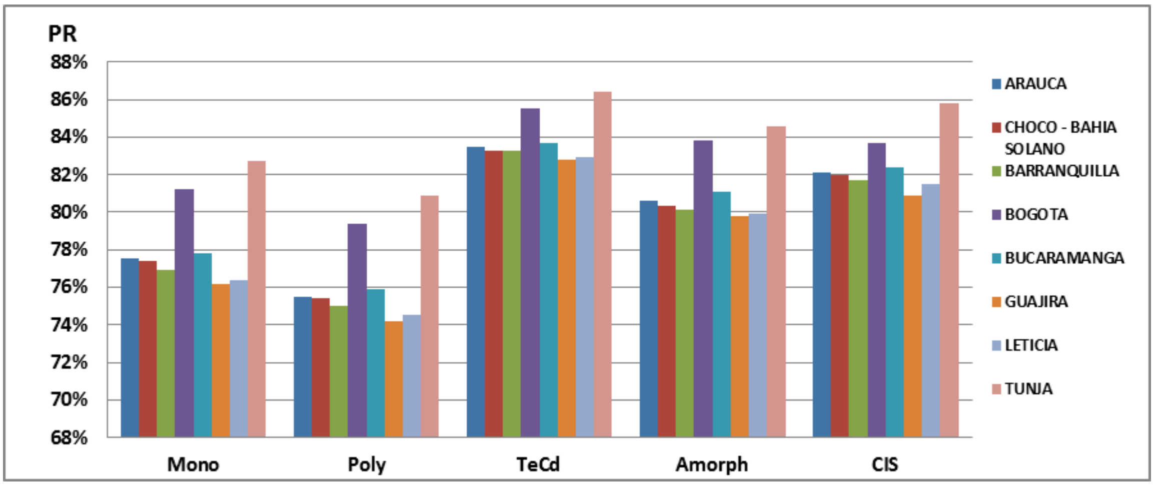

Figure 2. Performance ratio of different arrays

The city with the highest PR is Tunja, followed by Bogotá and Bucaramanga, which are the 3 cities with the lowest average temperatures respectively, so it is safe to say that this parameter is greatly affected by the temperature of the region where the photovoltaic array is installed. The PR increases in places of low temperatures.

In general terms, the technology resulting with higher performance ratio is the Cadmium Telluride type, which explains why it is the technology with the highest production of energy per installed kilowatt, followed closely by two other thin film technologies.

3.3 Temperature losses

The figure 3 shows the comparison of losses by temperature in la Guajira, the region with the highest temperatures, and the opposite case Tunja, with an average temperature of 12.9C.

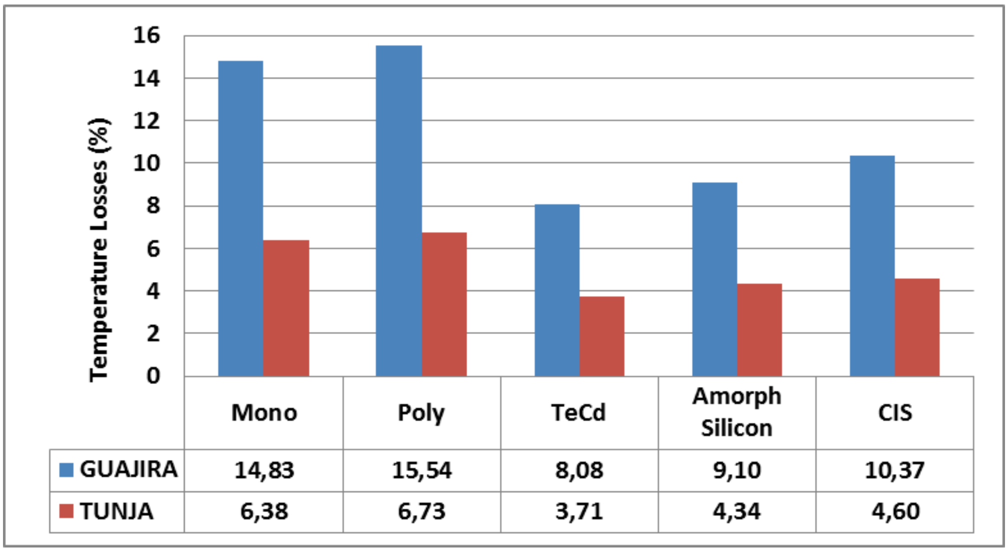

Figure 3. Temperature losses in Guajira and Tunja

4. Case study B: 100kw influenced by wind speed and comparison

In case study B, wind speed has been taken into account as a factor of thermal dispersion of the active surface of the photovoltaic modules.

Even though the wind speed affects the indicators mentioned in the previous case of study (case A), all of them maintain the same relationship between regions and technologies, so it proceeds to a comparative analysis between the 2 cases in order to study only the effects of the wind in the production and the performance ratio (case B). The figure 4 shows the comparison of energy produced of case A and case B in La Guajira.

4.1 Energy production

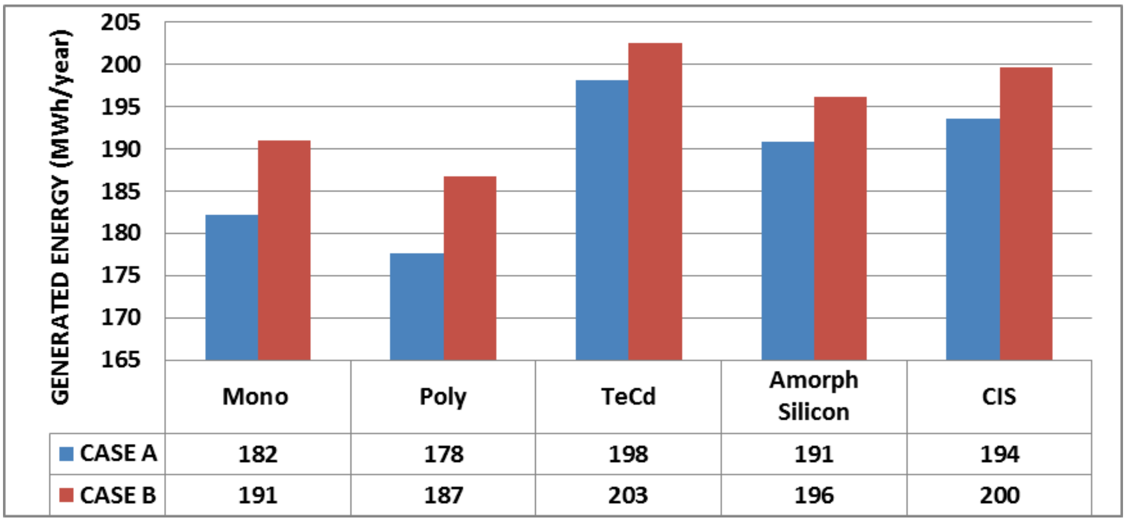

Figure 4. Comparison of studied cases in La Guajira

Taking into account wind speed, the temperature of the surface of the modules is affected in a positive way since photovoltaic panels increase its open circuit voltage as temperature decreases, as seen in figure 5.

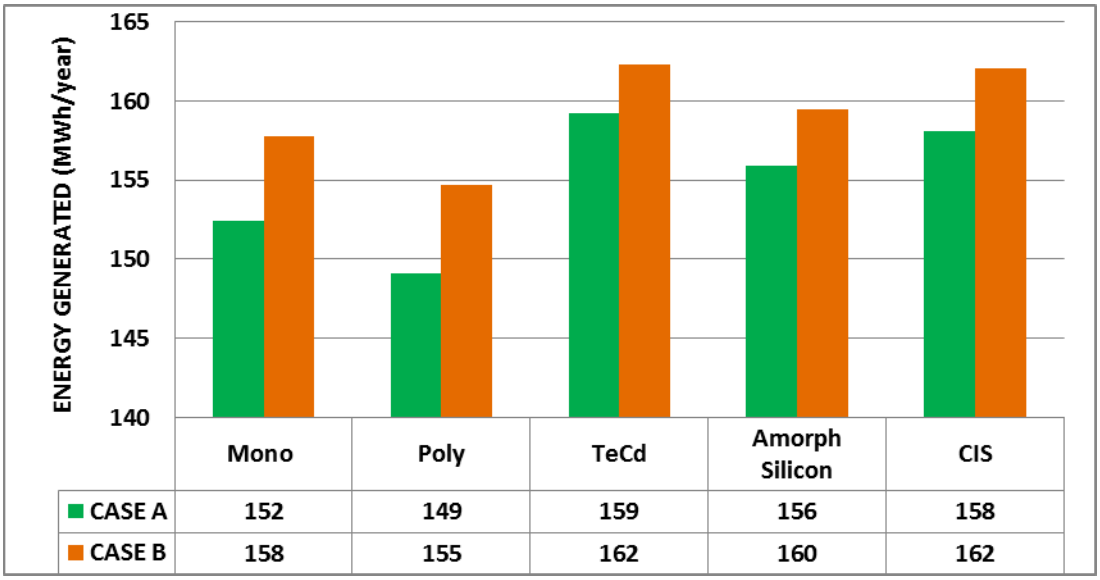

Figure 5. Comparison of studied cases in Tunja

Cities that have higher temperatures presented a higher percentage of increase in energy production because there is higher heat dispersion in trying to reach a thermal equilibrium between the surface of the module [8] and the wind.

4.2 Performance ratio

The figure 6 shows the PR comparison of cases A and B in Bahía Solano city.

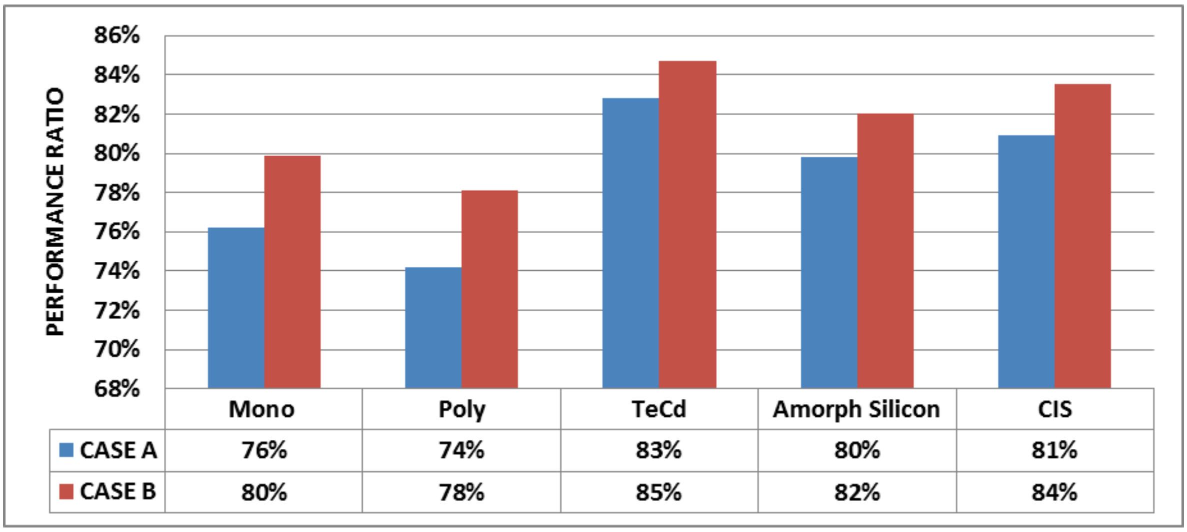

Figure 6. PR comparison in Bahía Solano

The figure 7 shows the PR comparison of cases A and B in La Guajira city. Stands out in particular La Guajira by having the best percentages of increase, due mostly to the high average wind speed in the region, which is around 6.2 m/s.

4.3 Temperature losses

The figures 8 and 9 show the temperature losses in of the arrays in Tunja and La Guajira cities respectively. Analyzing the behavior of the losses by temperature in Tunja and La Guajira, it is clear that the effect of wind reduces these losses, being evident again the importance of the coefficient of temperature [9] in the behavior of photovoltaic modules.

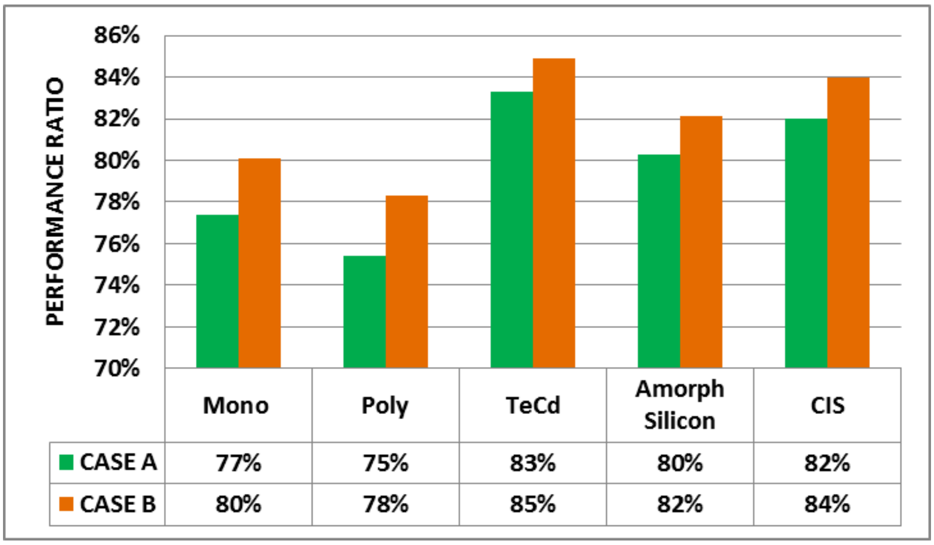

Figure 7. PR comparison in La Guajira

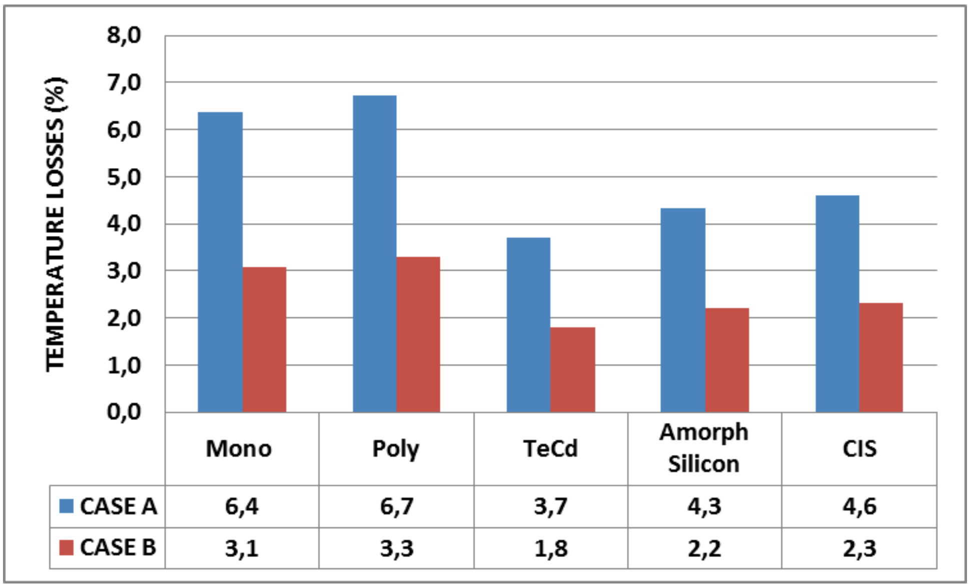

Figure 8. Temperature losses comparison in Tunja

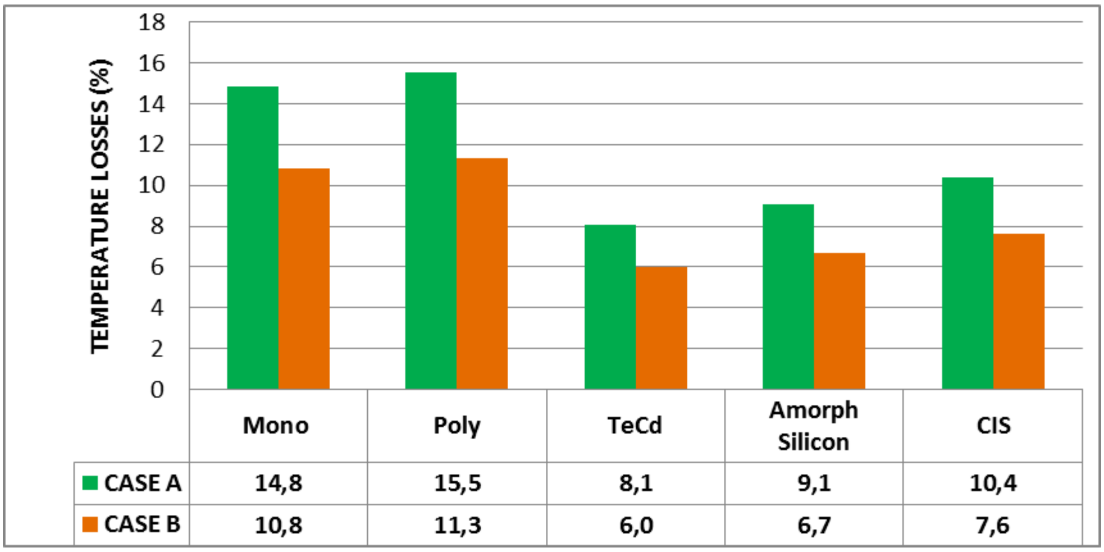

Figure 9. Temperature losses comparison in La Guajira

5. Conclusions

It was observed that thin layer technologies generally produce between 3 and 9% more energy than crystalline silicon technologies per installed kilowatt, since they are less affected by temperature which as seen in this document is one of the factors that affects energy production.

In this study was shown the importance of consider the effect of wind speed in the calculation of the performance and energy production of a photovoltaic array. With this consideration, the estimated production rises in average of 3,2% for polycrystalline modules, and 2,2% in thin film modules.

This study has shown, that due to the effect of the temperature in the PV energy production, a PV system in a cold city like Tunja, with an average of 5,03kWh/m², can generate a 3,8% more energy per square meter, than the same installation in a warm city with major solar resource of 5,15kWh/m², like Bucaramanga.

This analysis has shown that La Guajira is one of the places in Colombia with the greatest photovoltaic potential for photovoltaic energy production, thanks to high levels of radiation and wind speed.

Jungle areas in Colombia, as Leticia and Bahía Solano, are the regions with the worst photovoltaic performance, due to low levels of incident radiation, and high temperatures which meet the necessary conditions so that the photovoltaic arrays show low yields compared with other cities.

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