Introduction

ElectricityMap's mission is to organize the world's electricity data to drive the transition towards a truly decarbonised electricity system.

Generally, electricity can be produced from several sources, and each of them creates a different carbon footprint. Our goal is to organize the world's electricity data in such a manner so that these data can help a responsible company or even a concerned citizen know how much of their electricity was powered by greener sources. Our data can also help individuals and organizations know the greentest time to use electricity; hence reducing their own carbon footprint.

Power of our Data

Data Quality:

At ElectrictyMap data quality is our main focus. Here is a brief overview of the things we utilize as a check to make sure that our data is of the best quality.

1. **No missing values:** We make sure that there are no missing data points in our dataset. Various Machine Learning models or AI models created using our data will give more accurate and reliable results.
2. **Outliers/anomalies** are handled efficiently: We make sure that presence of any anomalies in the data are handled with care so that it does not change the meaning of the data.
3. **Relevant Columns:** In most cases, publicly available data are filled with irrelevant empty columns. This inturn makes the data unnecessarily chaotic. Through our various data pre processing techniques, we make sure our clients are provided with data that does not contain irrelevant columns.
4. **Meaningful Column Names:** Our data contains easy and meaningful column names which makes the overall data analysis and modeling process much easier.

Advanced Analytics:

Through various feature engineering techniques we develop customized attributes that can help a Data Analyst or a Data Scientist carry out advanced analytics using our data. For this particular use case, following analytics can be performed:

1. **Analysis based on Time of Day:** Time of Day attribute would help to know on average, on which time of the day (Morning, Afternoon, Evening and Night) greenest electricity is produced.
2. **Analysis based on Weekday:** Weekday attribute would help to know on average, on which weekday/weekend greenest electricity is produced.
3. **Analysis based on Week Number:** Week Number attribute would help to know on average, on which week number (between 1-52) greenest electricity is produced.
4. **Analysis based on Month:** Month attribute would help to know on average, on which month greenest electricity is produced.

We can also find out how the carbon footprint changes throughout the day with these above attributes.

Custom Made attributes:

Our data contains various custom made attributes which can help a Data specialist make various AI or Machine Learning models for predictions and analysis. For this particular use case, our data contains the following custom made attributes:

1. **Attributes based on Production Type:** Our data has information on the hourly electricity produced from various sources such as: Biomass, Fossil Gas, Fossil Hard Coal, Fossil Oil, Solar, Waste and Wind. Using our data one can tell how much electricity was produced from renewable and nonrenewable sources.
2. **Attributes based on Carbon Intensity:** Our data can tell you about the carbon footprint of the electricity produced from each source (renewable and nonrenewable).
3. **Attributes based on Percentage of Green, Non-green Electricity:**Our data contains information about how much percentage of the electricity produced daily were green, non-green or even neutral.

In simple words, you can use our data to know at which time of the day,week,month or year greenest electricity is produced!

Overview of the transmission network in Denmark [1] :

The transmission network in Denmark is divided into two separate transmission grids; Western and Eastern. The West Danish grid is connected to the European continental grid, whereas the East Danish grid is connected to the Nordic grid. The two areas have since autumn 2010 been connected through a 600 MW DC connection across the Great Belt. The Danish transmission grid can be seen in the diagram below, with the interconnectors to Germany, Norway and Sweden. [1]

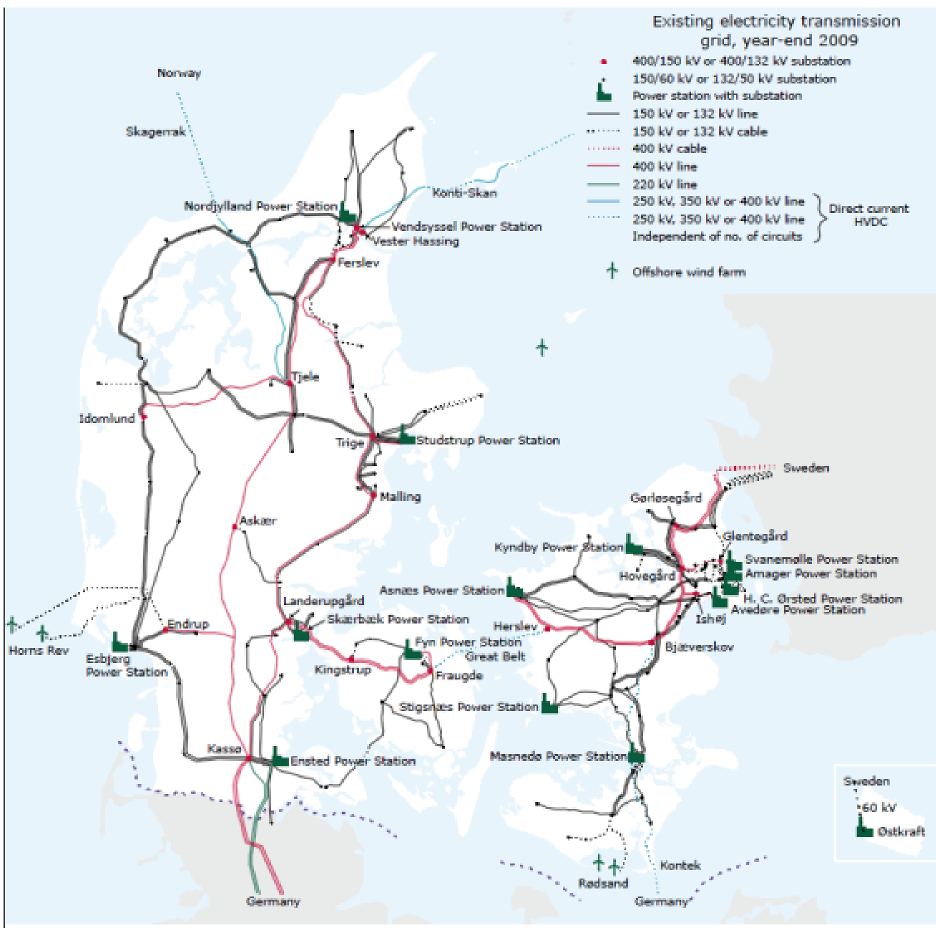

Fig:1 The Danish transmission grid

Denmark is part of the Nordic electricity spot market Nord Pool Spot, which besides Denmark covers Estonia, Finland, Norway and Sweden. Due to bottlenecks in the electrical grid in the Nord Pool Spot area the electricity market is divided into several price areas, where Denmark is divided into the two price areas; West Denmark and East Denmark.[1]

East Denmark is connected to Sweden by four AC interconnections with a total transmission capacity of 1,900 MW, and to Germany by a DC interconnection with a total transmission capacity of 600 MW. West Denmark is connected to Germany by AC connections where the total transmission capacity is determined by congestion in the surrounding grids and is normally 1,500 MW in the southbound direction and 950 MW in the northbound direction. West Denmark is connected to Sweden with a DC connection with a total capacity of 740 MW, and is connected to Norway with a DC connection of 1,040 MW.[1]

Hence there are two electricity zones in Denmark: East Denmark and West Denmark.

Dynamics of Carbon Footprint in Denmark

Using our data, we have carried out a Time-Series analysis to answer the following questions:

1. By how much does the carbon footprint of electricity in Denmark change throughout the day?
2. Why does the carbon footprint of electricity in Denmark change throughout the day?

By the power of our high quality data, we were able to easily find out the average carbon footprint of electricity produced in East zone of Denmark

For this specific use case we used the production data derived from east zone of Denmark from Jan 2020-Dec 2020

Tableau Dashboard:

1. **In this link you will find an interactive Tableau dashboard to see the variations in average carbon footprint throughout the day in a year.**
2. **In this link you will find an interactive Tableau dashboard to see the average change in carbon footprint throughout Time of Day, Week and Month in a year.**

Hourly Average of Carbon Footprint:

Fig:2 below shows how the carbon footprint of electricity produced in Denmark changes throughout the day on average, based on one year of data. From this analysis we can deduce that:

- On average, from the 1st-8th hour of a day the carbon footprint of electricity produced in Denmark is relatively lower.
- On average, from the 8th-22nd hour of a day the carbon footprint of electricity produced in Denmark is relatively higher.
- On average, the highest peak is noticed at the 11th hour of the day where the carbon footprint is 229.25 tn.
- On average, the lowest peak is at the 3rd and 4th hour of the day with a carbon footprint of 180.17 tn and 180.14 tn respectively.

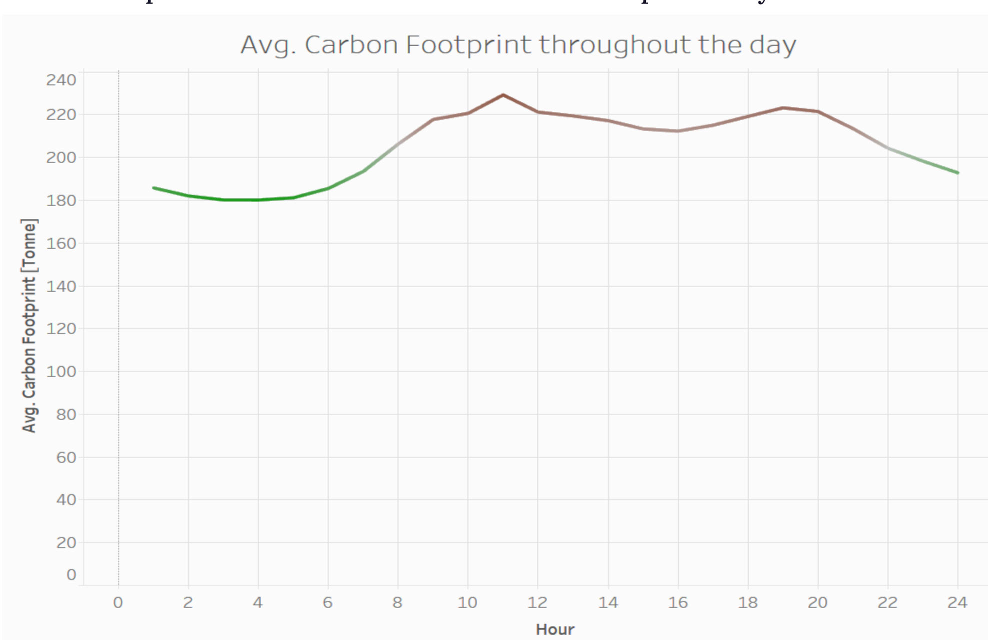

Fig:2 Average Carbon Footprint [Tonne] throughout the day

From fig:3 below we can find the answers to why the carbon footprint is changing throughout the day:

- From the 1st-8th hour, the carbon footprint of electricity produced in Denmark is relatively lower because in this slot, total electricity produced per hour is lower. Hence for obvious reasons, lower production would cause a lesser carbon footprint.
- From the 8th-13th hour, the carbon footprint of electricity produced in Denmark increases because in this time production increases.
- The interesting observation would be, on the 9th and 14th hour, the carbon footprint is very high. But the production of electricity in the 9th hour is lower than the 14th hour. But it still has the same carbon footprint! To know why this is happening we can refer to table:1

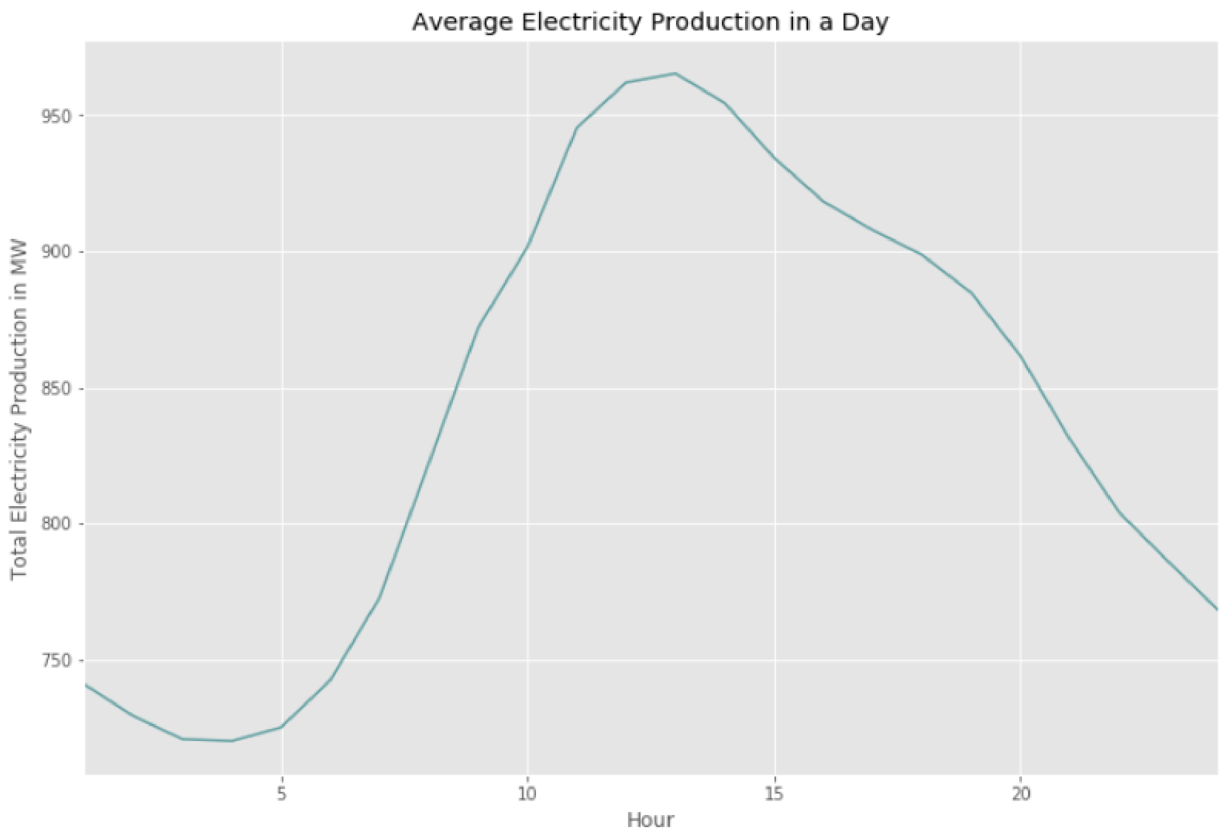

Fig:3: Average of Total Electricity Produced in a Day

hour	green	non_green	neutral
1	368.330601	201.707650	170.923497
2	366.590164	198.642077	163.983607
3	363.059946	197.190736	160.438692
4	362.043716	196.948087	160.997268
5	362.204918	196.672131	166.158470
6	365.516393	198.781421	178.076503
7	372.431694	203.275956	197.054645
8	389.590164	215.704918	216.893443
9	415.797814	229.035519	227.122951
10	444.062842	232.718579	224.732240
11	479.519126	242.745902	223.021858
12	508.612022	231.371585	221.975410
13	519.040984	230.038251	216.229508
14	516.942623	229.639344	207.822404
15	506.251366	226.592896	201.497268
16	488.330601	224.931694	205.016393
17	466.193989	227.327869	214.218579
18	443.677596	231.912568	223.079235
19	417.505464	237.494536	229.724044
20	397.008197	236.538251	227.983607
21	384.669399	227.371585	218.887978
22	379.961749	217.062842	207.081967
23	379.852459	212.207650	193.898907
24	378.336066	208.281421	181.693989

Table:1 Shows how much [MW] of the total production is green and non-green

Table:1 above shows that on average 229.03 MW of non-green electricity is produced in the 9th hour which is very similar to what is produced in the 14th hour. This indicates that although the average production is less on 9th hour but it produces the same amount of non green electricity as hour 14th. Hence they both have similar carbon footprint.

Change in Carbon Footprint:

Our data can also give insights on the average amount of change in carbon footprint between consecutive hours.

Fig: 4 below shows the average hourly change in carbon footprint of electricity produced in Denmark, throughout the day. From this analysis we can deduce that:

- In a year, on average the highest changes in carbon footprint is seen from:

  - 10th-11th hour, where there is an increase in carbon footprint by 8.88 tn.
  If we refer to table:1 we can see that from 10th to 11th hour the production from non-green sources increases and this is the reason why there is an increase in carbon footprint from 10th to 11th hour.

  - 12th-13th hour, where there is a decrease in carbon footprint by 7.91 tn. This again can be explained by the fact that the production from non-green sources decreases, and green sources increase. Hence change in carbon footprint also decreases.

- In a year, on average few of the lowest changes in carbon footprint is seen from:
  -3rd-4th hour, where there is a decrease in carbon footprint by 0.29 tn
  -8th-9th hour, where there is an increase in carbon footprint by 0.21 tn

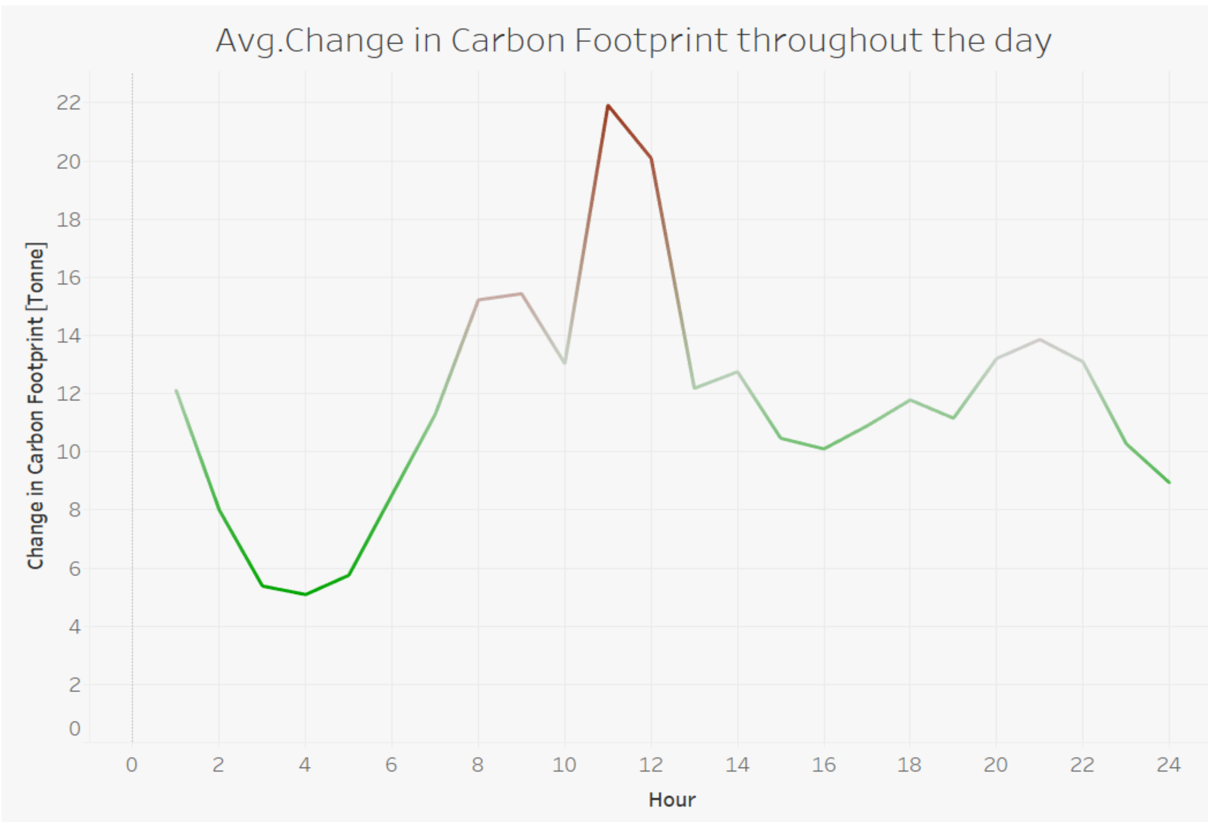

fig:4: Average Change in Carbon Footprint throughout the day

- We can also see that the hour slot that produced the highest amount of carbon shows a higher change in carbon footprint. For example: at 10th and 11th hour the footprints were some of the highest and they also show a higher change in carbon footprint between them. This is also the same with 12th and 13th hour. This is mainly due to the fact that there was an increase in electricity produced by non-green sources.

Average Carbon Footprint based on Time of day:

Our data can also give insights on the average amount of change in carbon footprint between consecutive different times of the day. Fig:6 below shows the analysis results.

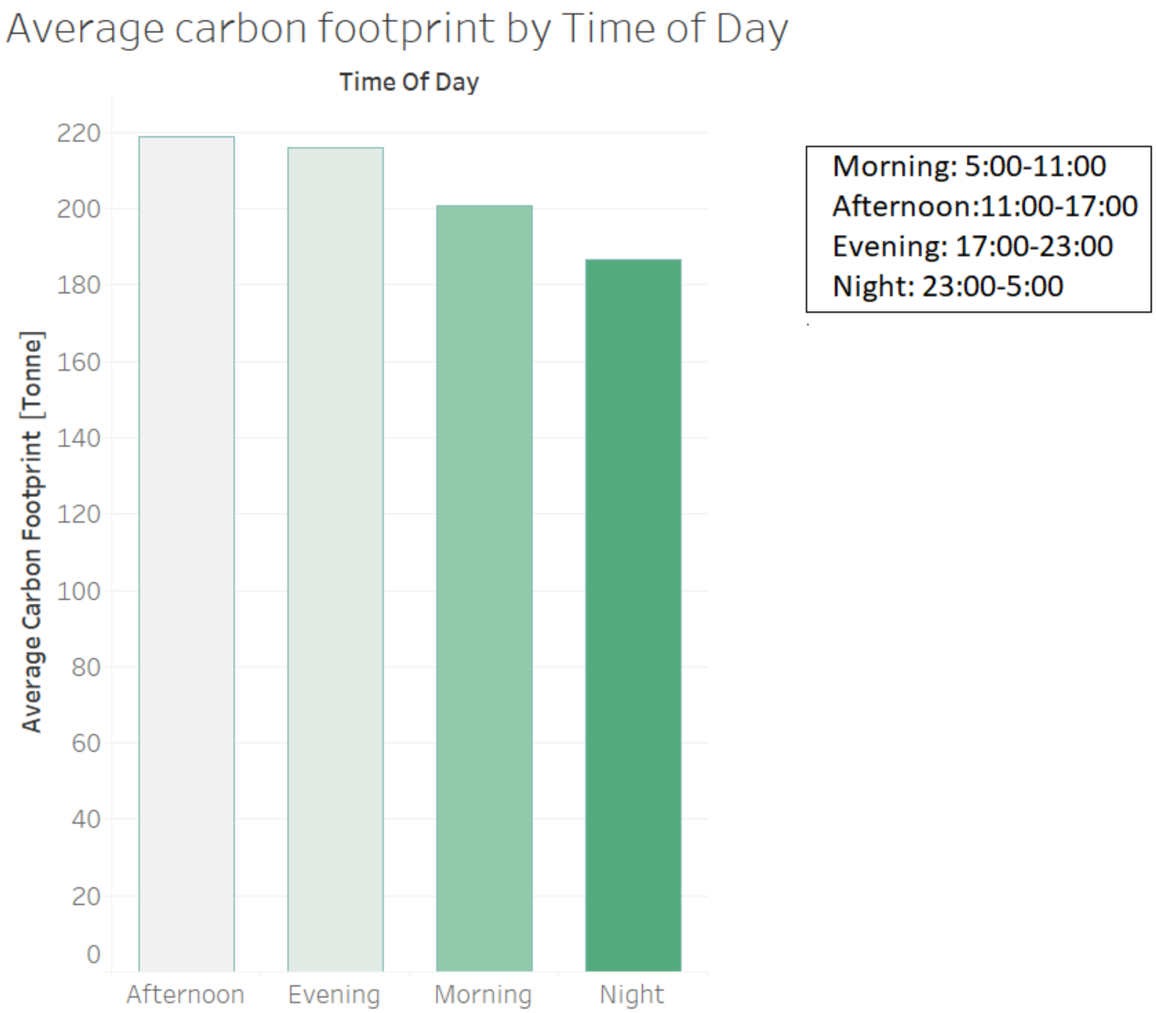

fig:5:Average Carbon Footprint by Time of Day

To summarize our analysis, we can use fig:5 and derive the following conclusions:

1. The average carbon footprint from 23:00-5:00 (late night/early morning) is relatively lowest. This is primarily because the relative production is lower this time. During the night, people are using less electricity, they are less active. Electricity demand is less, therefore supply decreases. Hence production is generally lower this time.

2. The average carbon footprint from 5:00-11:00 (morning) is higher than night. This is primarily because production increases significantly in this time (refer to fig:3). In the morning people begin to resume all their activities; hence using a lot of electricity at this time. Electricity demand increases, therefore supply increases. Hence production is generally higher this time. If we refer to table:1 we can also see that from 5:00-11:00 the production from non-green sources are also increasing. Hence the rise in carbon footprint.
3. The average carbon footprint from 11:00-17:00 (Afternoon) is the highest. This is primarily because production is at its highest compared to other times. Electricity demand is at its peak at this time. All the offices, factories, malls etc open up. People are using a lot of electricity at this time. Electricity demand increases, therefore supply increases. If we refer to table:1 we can also see that from 11:00-17:00 the production from non-green sources are also increasing. Hence the rise in carbon footprint.
4. The average carbon footprint from 17:00-23:00 (Evening) is the second highest. However, from this time of day, the decrease in carbon footprint starts. This is primarily because the production starts to reduce. In general the work hour ends, people go back to home and start to pack up for the day. Hence lesser demand for electricity; therefore supply decreases. Hence production decreases.
    - However, the carbon footprint is still the second highest because, from table:1 we can see that a very significant amount of electricity that is produced in this time comes from non-green sources.

Greentest Time in Denmark:

Our data carries huge potential to not only tell you about the amount of carbon footprint from each type of production; but also tell you at what time of the day, which week or even which months are the greenest to use electricity in general. This information can help your users know when is the greenest time to charge their EV. Furthermore, it can help your company in general to reduce its own carbon footprint.

In this section we are going to provide you with some insights on the potential of our data in terms of finding out the greenest time to use electricity in Denmark.

As we have previously discussed, electricity is produced from various sources. Electricity that is produced from renewable sources like Solar and Wind energy is considered green. On the other hand, non-renewable sources like Fossil Gas, Fossil Oil, Fossil Hard Coal and Waste energy produce non-green electricity. For our analysis we considered electricity produced from Biomass as neutral (neither green nor non-green). This is because its carbon footprint is somewhere in the middle of the both. Hence considering it as a neutral point; a constant to be precise, makes the analysis more reliable.

The electricity that we use comes from both renewable and non-renewable sources. Our data carries the power of retracing back to what percentage of the electricity produced each day comes from green, non-green and neutral sources. Hence making it easier to know when is the greenest time to use electricity. Using our data, we can give you the following insights on:

1. **Greenest Hour**
2. **Greenest Time of Day**
3. **Greenest Weekday**
4. **Greenest Time of day on a specific Weekday**
5. **Greenest Month**

Tableau Dashboard:

In this link you will find an interactive Tableau dashboard to see how on average the percentage of green electricity changes based on Hour, Weekdays, Months in a year.

Insights on Greenest Hour:

The great news is, it is very evident that a good percentage of the electricity produced in Denmark is green. However as a responsible individual it is always good to have an idea about the greenest hour of the day to use electricity.

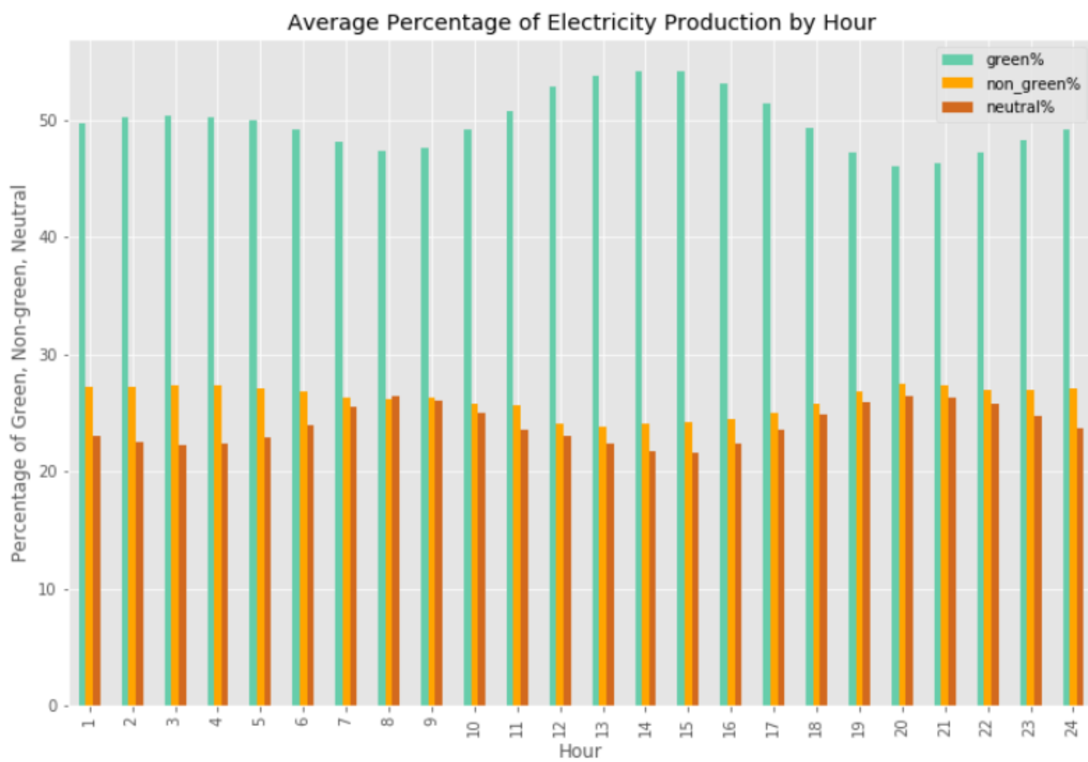

Fig:6: Shows Average Percentage of Electricity Production by Hour (based on % of green,neutral, and non-green)

hour	green%	non_green%	neutral%
15	54.182689	24.251613	21.565697
14	54.163899	24.061011	21.775089
13	53.769427	23.830536	22.400036
16	53.178910	24.494927	22.326163
12	52.872525	24.052125	23.075350
17	51.357632	25.043268	23.599101
11	50.727365	25.679601	23.593034
3	50.376759	27.361405	22.261837
4	50.284613	27.354316	22.361071
2	50.271832	27.240505	22.487664
5	49.956852	27.125862	22.917287
1	49.709800	27.222411	23.067790

	green%	non_green%	neutral%
18	49.370502	25.806216	24.823282
10	49.257472	25.814204	24.928323
24	49.242537	27.108982	23.648480
6	49.236131	26.776441	23.987428
23	48.329805	26.999837	24.670359
7	48.194858	26.305108	25.500034
9	47.685626	26.266858	26.047516
8	47.384529	26.235457	26.380013
22	47.252661	26.994288	25.753050
19	47.190473	26.843911	25.965616
21	46.293897	27.363541	26.342562
20	46.081758	27.455601	26.462641

Table:2 Shows Average Percentage Electricity Production by Hour (based on % of green,neutral, and non-green)

From fig:6 and table:2 above we can deduce the following:

- During the 15th hour of the day, on average the percentage of green electricity is at its highest.
- From 13th-16th hour, on average the percentage of greenest electricity produced is generally high.
- From the 20th and 21st hour, on average the percentage of greenest electricity produced is the lowest.
- Hence on average, in a year, the greenest time is generally seen during the 13th-16th hour of the day.

Insights on Greenest Time of day:

time_of_day	green%	non_green%	neutral%
Afternoon	53.150006	24.391238	22.458756
Evening	47.979194	26.557199	25.463607
Morning	48.587389	26.390265	25.022346
Night	49.678921	27.210440	23.110638

Table:3 Average percentage of the green, non-green and neutral electricity each day

Table:3 above shows how on average the green level of produced electricity changes throughout the day in a year. From the results above we can see that on average, the highest percentage of green electricity is produced during the afternoon.

If we were to plot a bar graph from these results, the graph would look something like the one given below in fig:7.

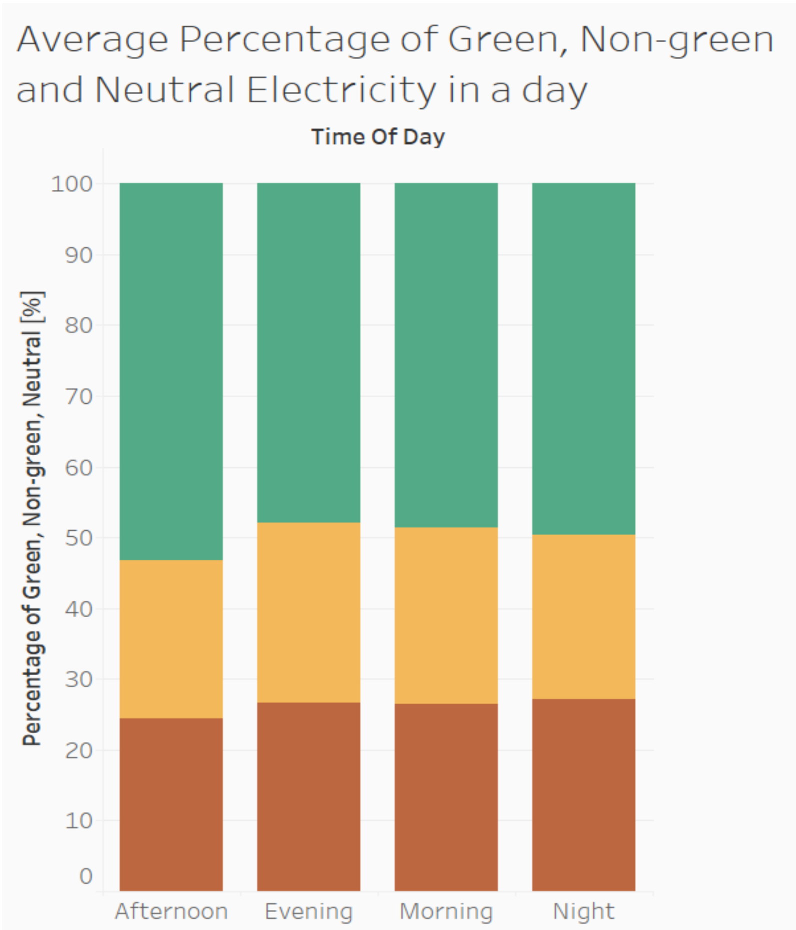

Fig:7: Shows how on average the green level of produced electricity changes throughout the day

From fig:7 above it is clear that on average greenest electricity is produced during the Afternoon (11:00-17:00,) when 53.15% of the total electricity produced is green, 22.46% is neutral and 24.39% is non-green. Hence the greenest time to charge an EV would be during the afternoon.

As for Night (23:00-5:00), it shows an average production of 49.68% green electricity and 23.11% neutral electricity. However, it shows the highest percentage of non-green electricity. Contrary to Night, Morning (5:00-11:00) shows a lower percentage of non-green production with 48.59% of green electricity. Hence the second ideal time would be morning where the percentage of green is at an acceptable level with a lower percentage of non-green electricity.

Insights on Greenest Weekday:

Fig:8 below shows that in a year, on average, greenest electricity is produced on Sundays and Saturdays. Lower level of non-green electricity is also produced on these two weekdays.

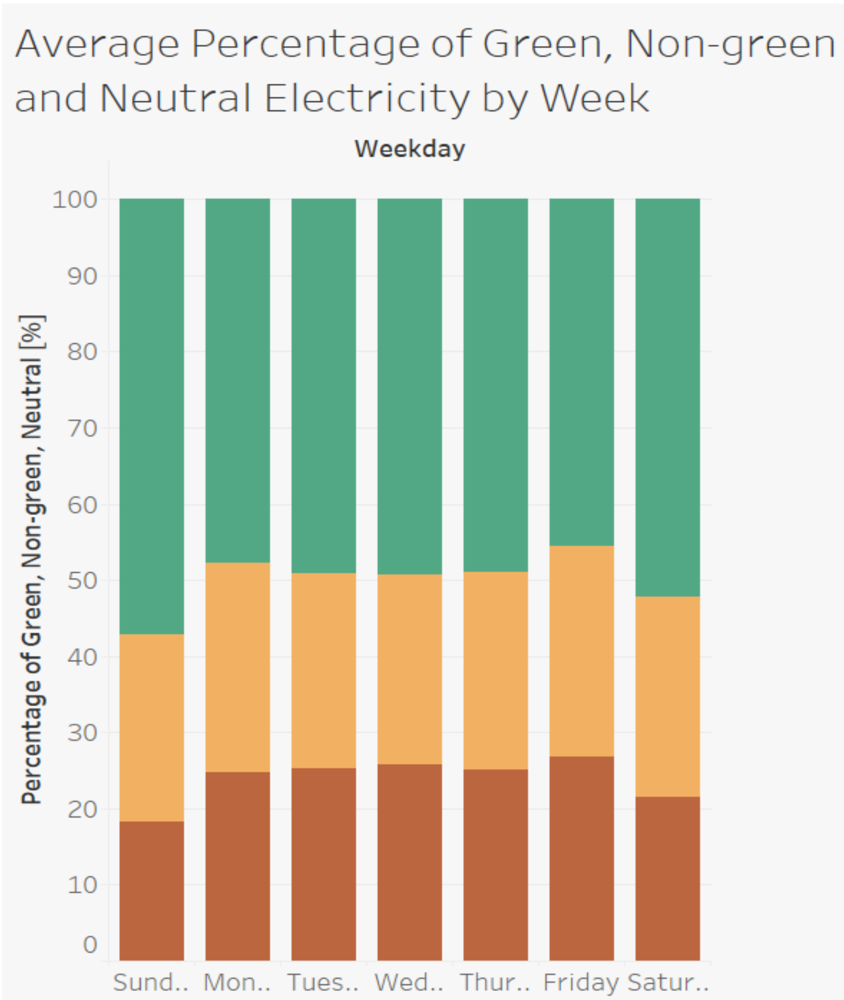

Fig:8 Shows the average percentage of green, neutral and non-green electricity by week

On an average, on Sundays 57.10% of the total electricity produced is green. As for Saturdays, 52.25% of the total electricity produced is green. Hence in Denmark charging an EV on weekends would produce a lower carbon footprint.

Insights on Greenest Time of day on a specific Weekday:

By combining our above findings our data can also give you an insight on which “Time of day” and on which “Weekdays” are the greentest time for your users to charge their EV.

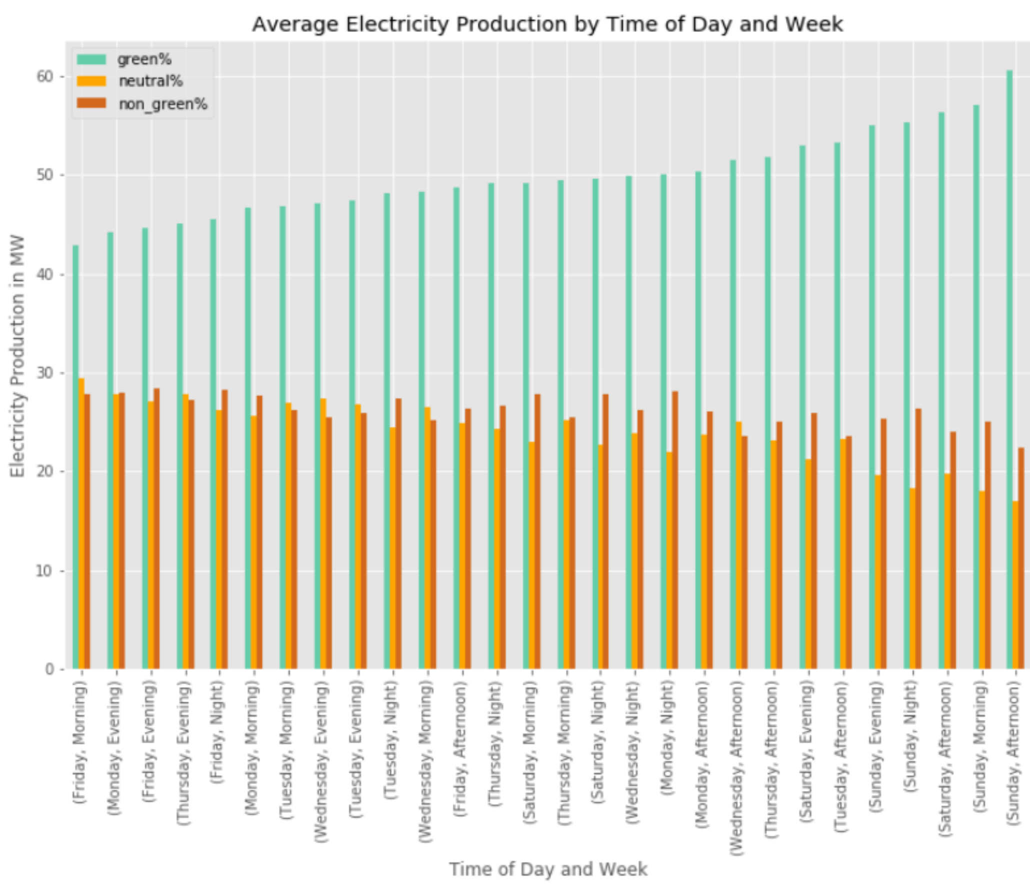

Fig:9: Shows Average Electricity Production by Time of Day and Week

From the figure above we can deduce the following:

- In a year, on average, on Sunday-Afternoon the percentage of green electricity produced is highest.
- Ideal time to charge an Ev would be Sunday-Afternoon, Sunday-Morning and Saturday-Afternoon.

Conclusion:

Our goal at ElectricityMap is to transform publicly available data into a powerful analytical tool. A tool that helps individuals or organizations make responsible decisions with the aim of reducing their carbon footprint.

The possibilities are endless when you have resources like the one we can provide. Using our data, various machine learning models can be created that can help forecast the optimal time to charge an EV. Users can also know how much of the electricity they are using to charge their EV is green.

To conclude, climate change is a global issue, but we must start by addressing it at the individual level. We can help you accomplish this with our data!

Reference:

[1] Peter S., Henning M., Thomas W., Anders N. A. (2013, July). *Overview of the Danish Power system and RES integration*. www.store-project.eu. URL: https://www.store-project.eu/documents/target-country-results/en_GB/energy-needs-in-denmark-executive-summary#:~:text=The%20West%20Danish%20grid%20is,connection%20across%20the%20Great%20Belt.