Turkish Electricity Generation Review 2021 : Charts, Questions and Challenges

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[1] For code and data : https://github.com/barissanli/papers/tree/main/2021ElectricityReview

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Figures

Introduction

As of 17th January 2022, EPİAŞ made available all generation data for Turkish electricity system. This data does not contain small scale autoproducers. Whether and which kind of rooftop generation is included is another detail. As far as the data is concerned, it includes unlicensed (distributed) solar and other data. From this article's perspective the official data is the data published by the energy market regulator EMRA. The EPİAŞ data set analyzed should be accepted as is. Traditionally, official data is expected to be published by March. In this regards, I would like to thank EPİAŞ for making available such a large dataset.

Demand and generation is used interchangeably. This is technically not correct. Generation minus exports is the closest number to demand. But the reader can create her own analysis from the code and the data. This analysis will take the whole data as a sample.

Annual Data

In terms of production, hydroelectricity("hydro"), coal, gas, wind and solar development since 2016 is as follows:

Table 1 Generation of various resources in TWh (billion kWh)

year	Total Production	Hydro	Coal	Gas	Wind	Solar
2016	268.7	66.8	90.9	88.2	15.3	0.0
2017	292.0	58.1	96.1	109.2	17.7	2.2
2018	299.2	59.7	111.8	90.1	19.8	7.8
2019	299.6	88.6	112.9	54.9	21.5	9.6
2020	300.8	77.7	106.0	68.0	24.4	11.2
2021	326.1	55.5	104.1	107.3	30.9	13.3

In this paper, three parameters of annual data is to be investigated. They are sum, shape, share. One trick to follow and forecast Turkish electricity demand is to take a 8760 hours-1 Year(365 days*24 hours) moving sum of all the resources. This shows the change in trends from a year ago as well as the new trends.

Since 2018, Turkish electricity demand was stagnating at the border of 300 TWh. We see a big change in this trend by the end of 2021 1st quarter (2021Q1). The short lived surge seems like saturated by the end of year.

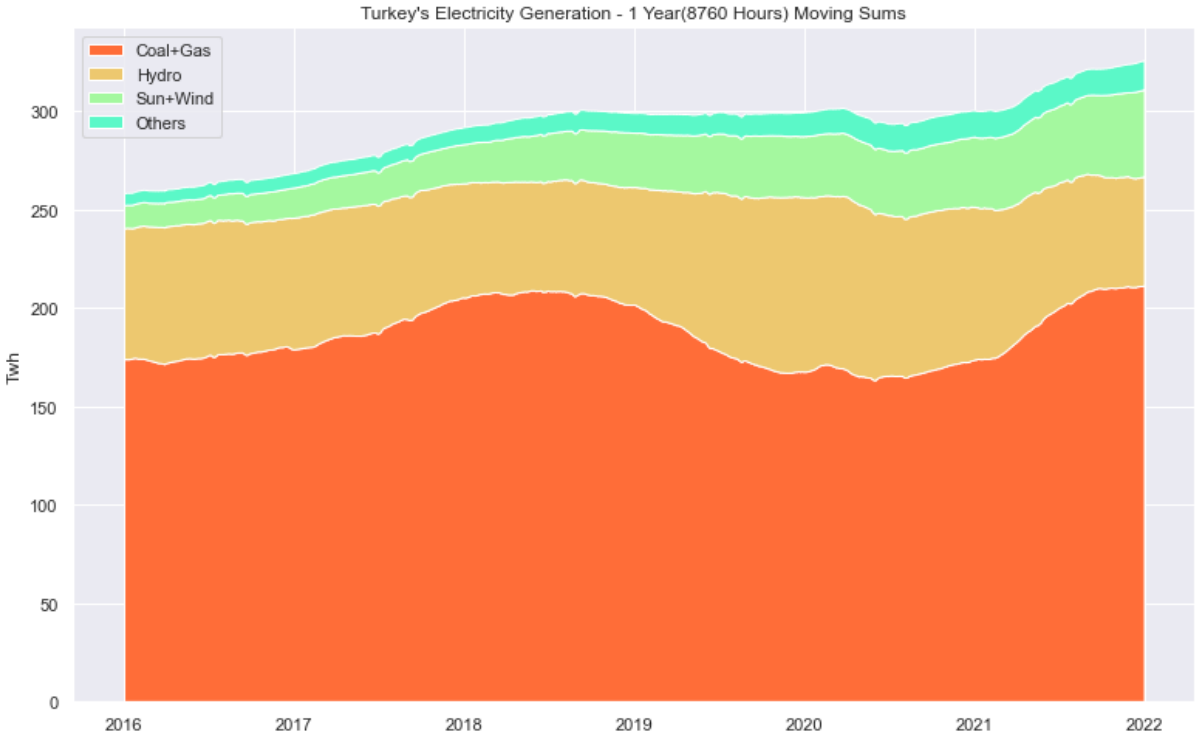


Fig. 1 Turkey's electricity generation in moving sums of 8760 hours

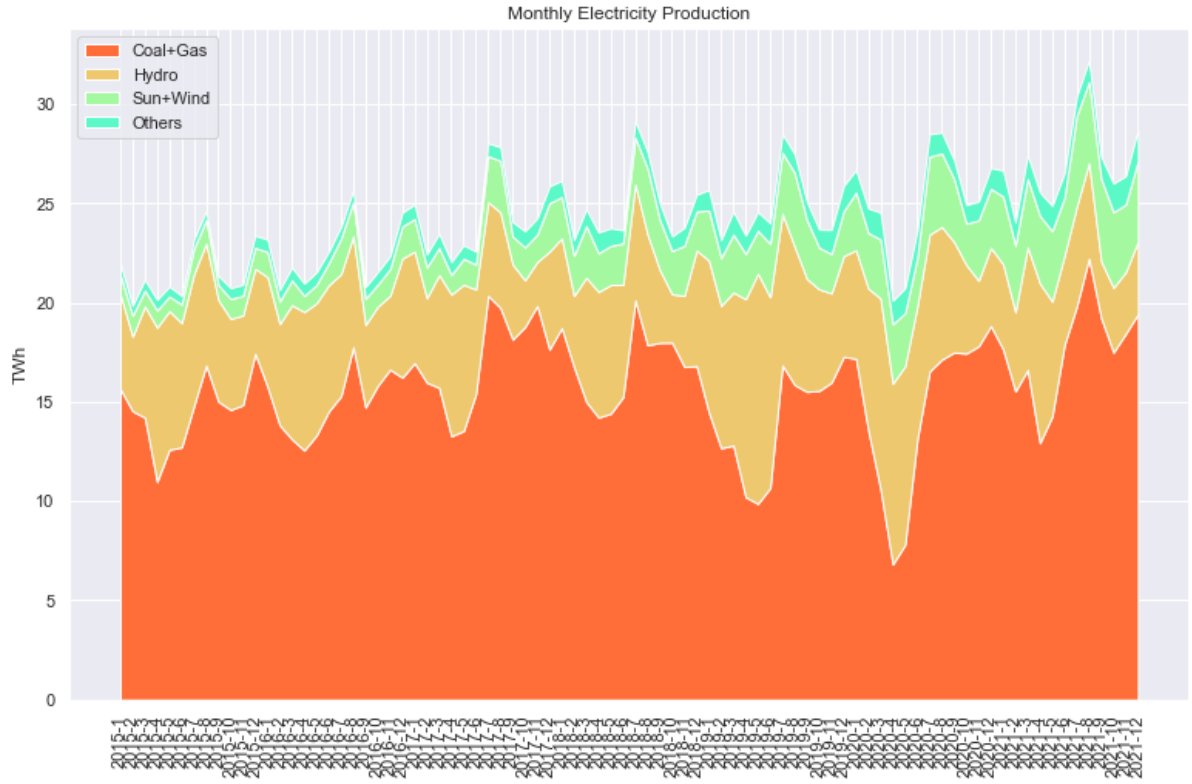


Fig. 2 Monthly electricity generation data

In monthly data, the effect of Covid is much more visible. Lock downs starting from April 2020 has cratered the monthly demand. However 2021 July-August was extremely hot. This also created an unseen peak in the summer of 2021.

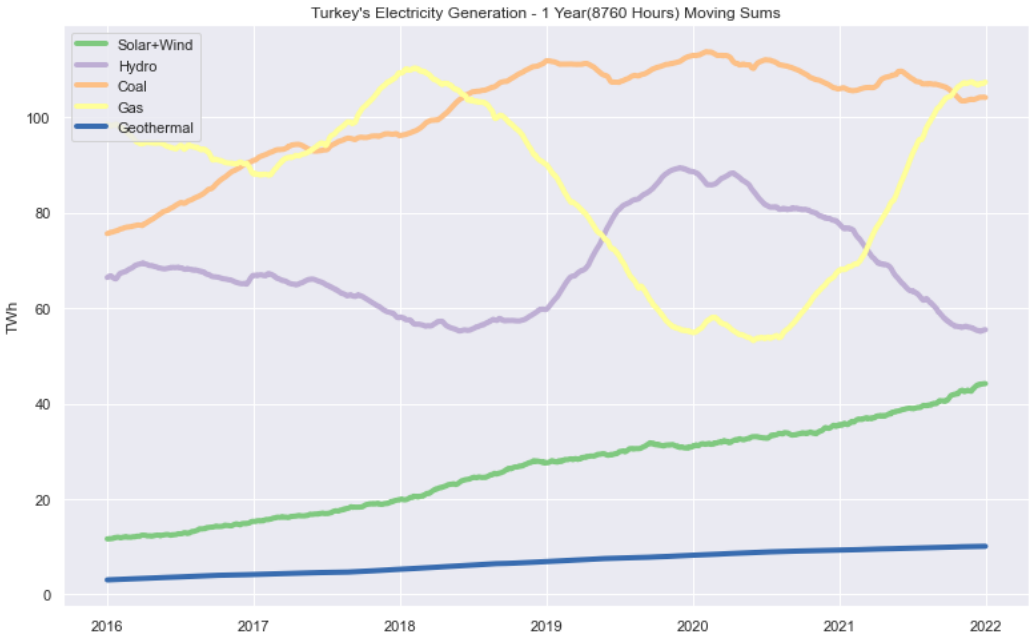


Fig. 3 Generation of resources (8760 hours moving sums)

In terms of resources, one can easily spot hydro and gas interplay. But one interesting trend is the closeness of solar and wind to the hydro levels. Coal generation however, looks as if it has reached a plateu.

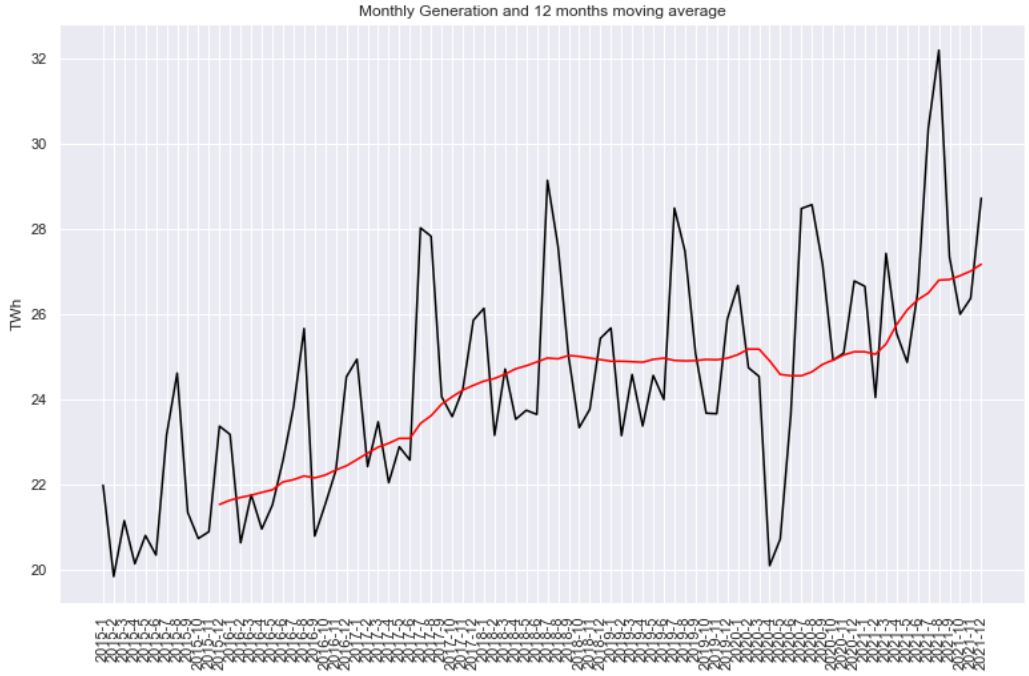


Fig. 4 Monthly generation and the 12 months moving average

How Covid Effected the Demand: Big Picture?

The other interesting parameter is the shape of yearly generation patterns. This will also reflect the demand pattern. In the following graph, each years' total generation is normalized by its average. The red line and area are from 2020.

In the previous years, the histogram of yearly generation has two peaks. The higher peak is generally summer, and the lower peak is winter. But for 2020, the cavity of April and May has shifted the distribution and position of peaks. Because of lock downs, for 2020, there are more less than average loads (Normalized Generation<1).

Yet, 2021 shows a return to the original shape.

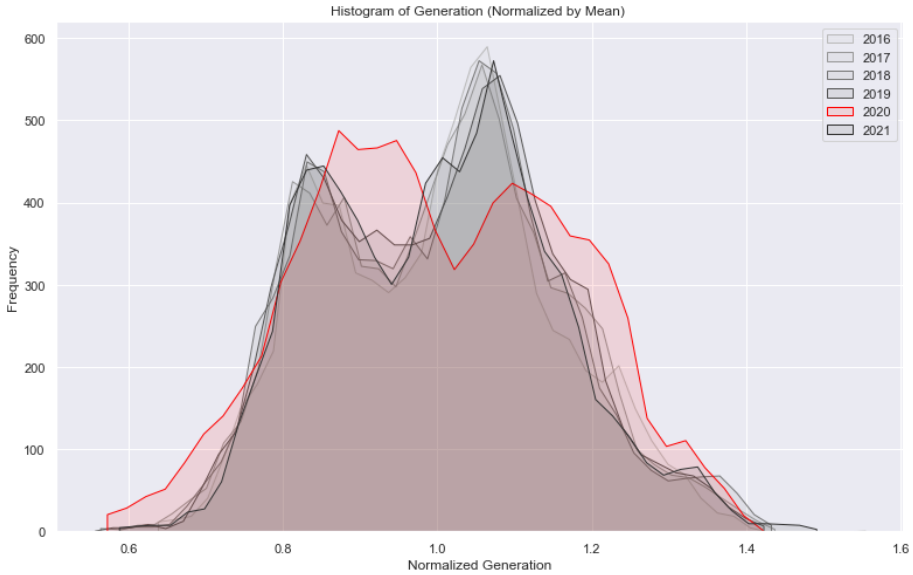


Fig. 5 Histogram of yearly generation normalized by average daily load

A Visible Change in Peaking Hours in 2021

Load duration curve is generally a standard measure of load distribution. The hourly loads for that year is sorted from highest to lowest. It hints about baseload need, as well as the requirements for peaking plants.

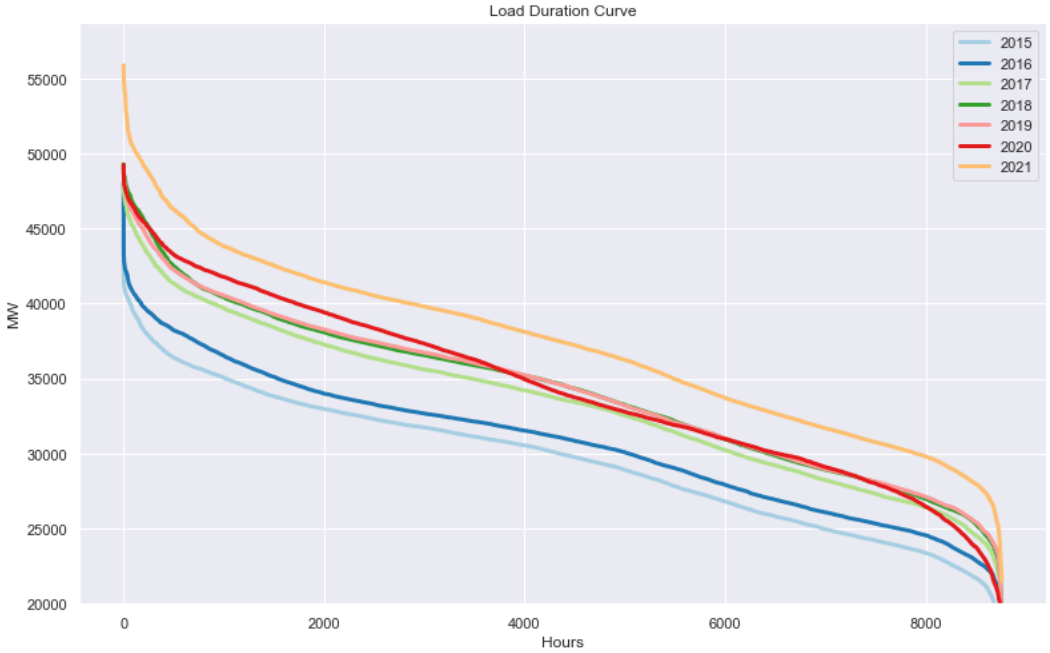


Fig. 6 Load Duration Curves for 2016-2021

In the load duration curves, we see 2015-2016 showing a normal load increase YoY (Year on year). 2017, 2018, 2019, 2020 are practically exhibiting the same patterns nearly from tip to toe. The 2021 is a distinct year. The curve shifted upwards showing a demand increase. Both base load and peaking plant needs have increased.

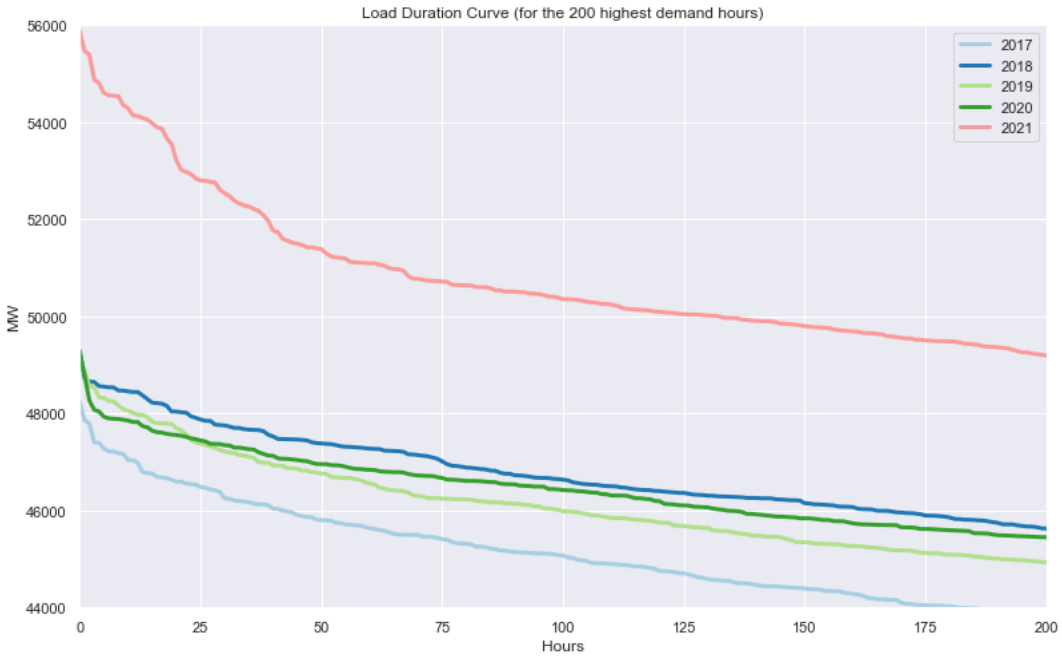


Fig. 7 Load Duration Curves - Highest 200 Hours

But there is more in details. If we zoom the load duration curves' highest generation hours, 2021 differs a lot. In 2021 there were more hot days and hours than the previous 5 years. Especially the highest 75 hours for 2021 has not been experienced for 2015-2020. The main reason should be the prolonging of hottest period in Turkey.

Effect of Drought on Natural Gas Consumption

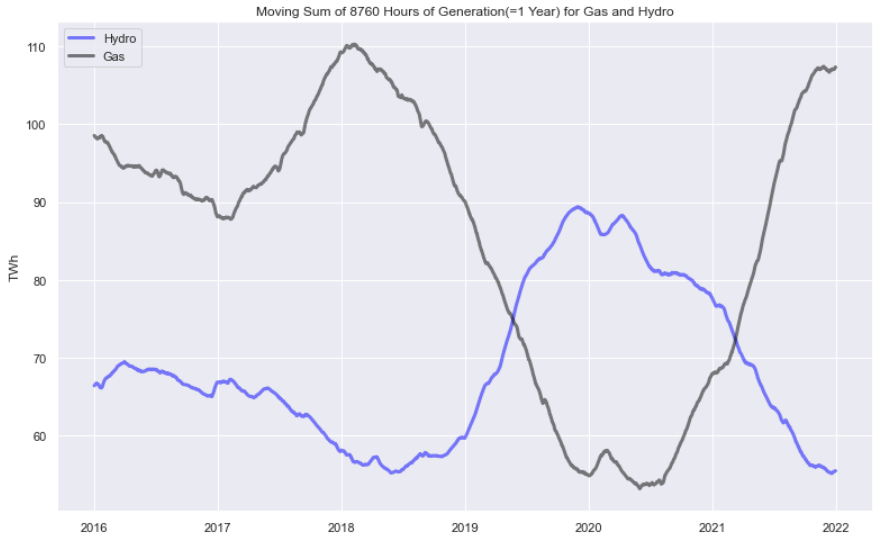


Fig. 8 Hydro and natural gas generation in moving sums

There is certainly an interaction between hydro and natural gas. This is illustrated in the graph above. But what is the real impact of hydro drought and wetness on generation interaction. Based on end-of-year basis the changes are given in the table below:

Table 2 Year-on-Year generation change in resources

year	Total Production	Hydro	Coal	Gas	Wind	Solar
2017	23.3	-8.7	5.2	21.0	2.4	2.2
2018	7.2	1.6	15.7	-19.1	2.0	5.6
2019	0.4	28.9	1.1	-35.2	1.8	1.8
2020	1.1	-10.9	-6.9	13.1	2.9	1.6
2021	25.3	-22.2	-1.8	39.4	6.5	2.1

From that table, we may conceive that hydro generation fluctuates 20-30 TWh per year. This roughly corresponds to 4-6 bcm (billion cubic meters) of natural gas generation. However, since coal generation has peaked, gas generation is also supplying part of the demand growth

Wind and Solar has Surpassed Lignite since 2020

Turkish solar and wind generation has surpassed lignite generation in 2020. This may be attributed to the covid. However the pattern seems to be consistent. Renewables will surpass lignite in 2022 for sure.

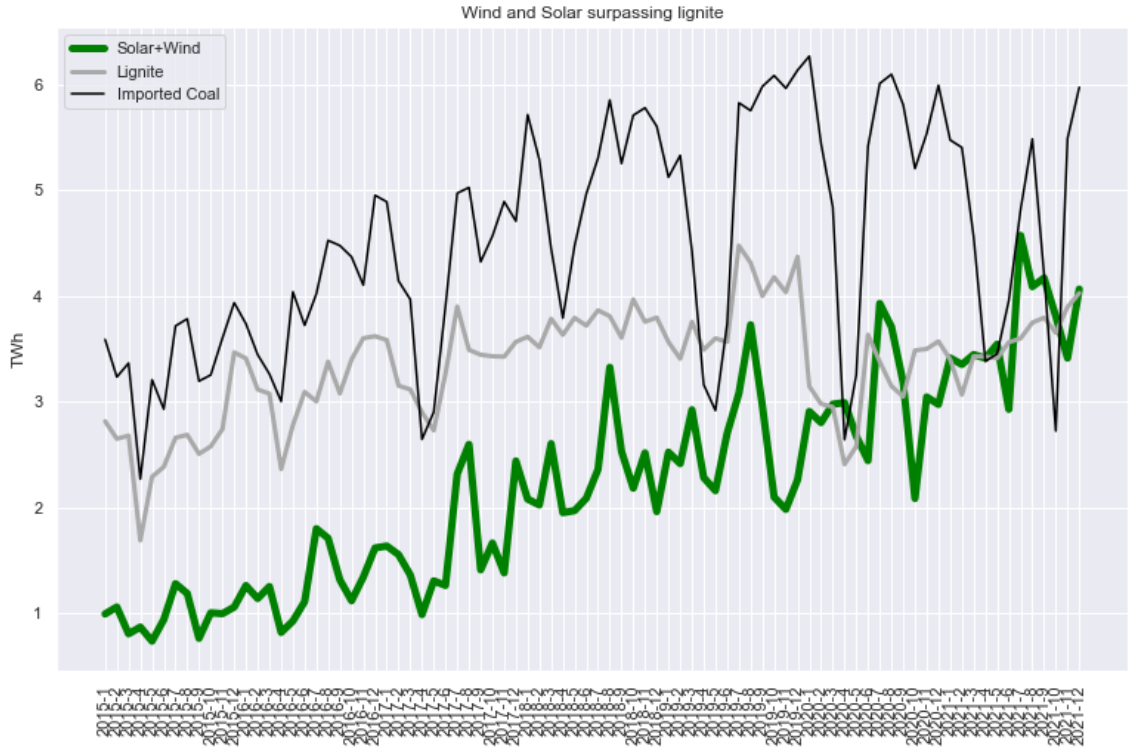


Fig. 9 Lignite, imported coal vs renewables

Share of Resources in Generation Mix

In monthly generation, the share of resources in generation is a mixed picture. Hydro and solar has a bigger share in late Spring-Summer-early Autumn period than other resources. Especially, solar contribution is

growing but not reaching the levels of 8% yet. Wind on the other hand is more predictable with being close to 10%. In the last months of 2021, wind has surpassed 10%. Now more than 10% of generation is to be expected from wind. But it should be noted that wind generation is more unpredictable than solar.

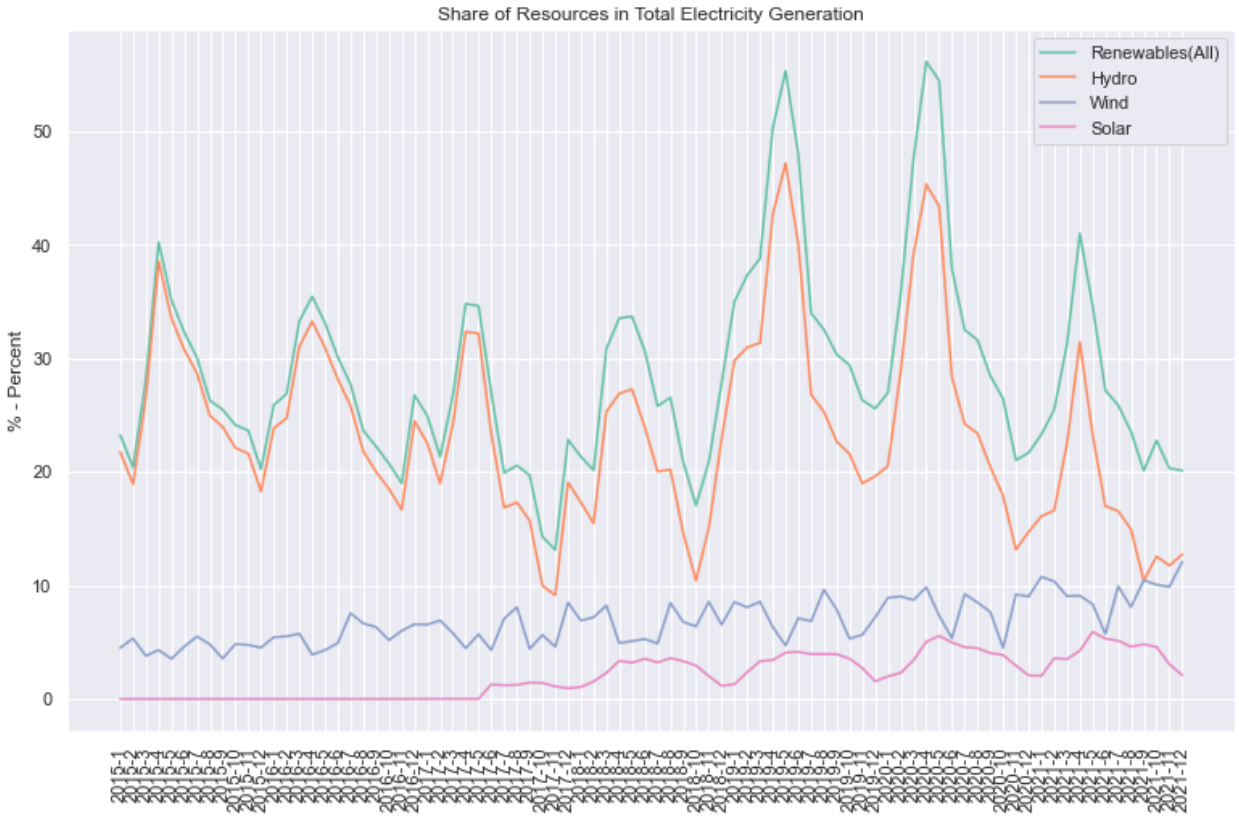


Fig. 10 Share of renewable resources in generation

For gas and coal, the story cannot be much different. During the covid period, natural gas share dropped below 10% in monthly generation. But then, it quickly regained its traditional band of 30-40%. Coal on the other hand suffered from regulations or not complying with regulations and dropped sharply in early 2021. But now this share is back to 35%.

There is not a big interplay between coal and gas as expected. The relationship was much more stronger between hydro and gas.

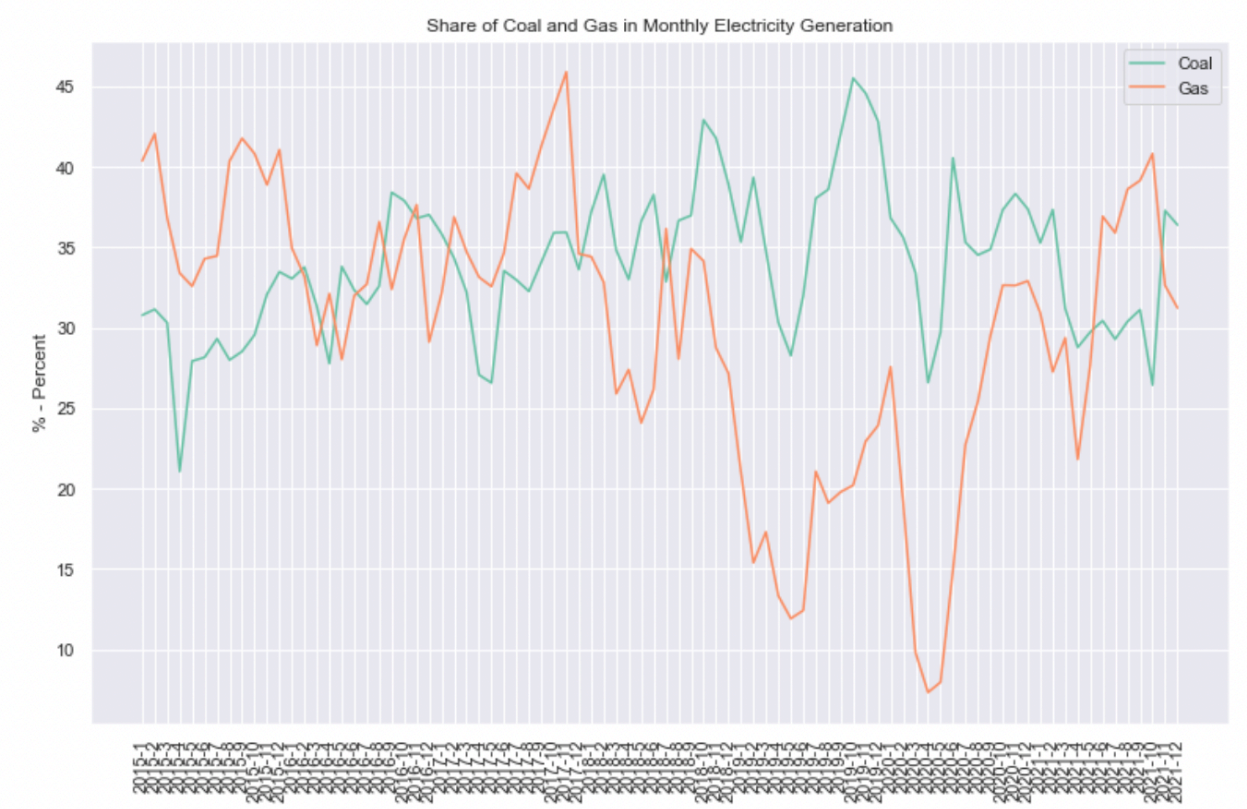


Fig. 11 Share of Coal and Gas in Monthly Production

Hydro Interaction With Other Resources

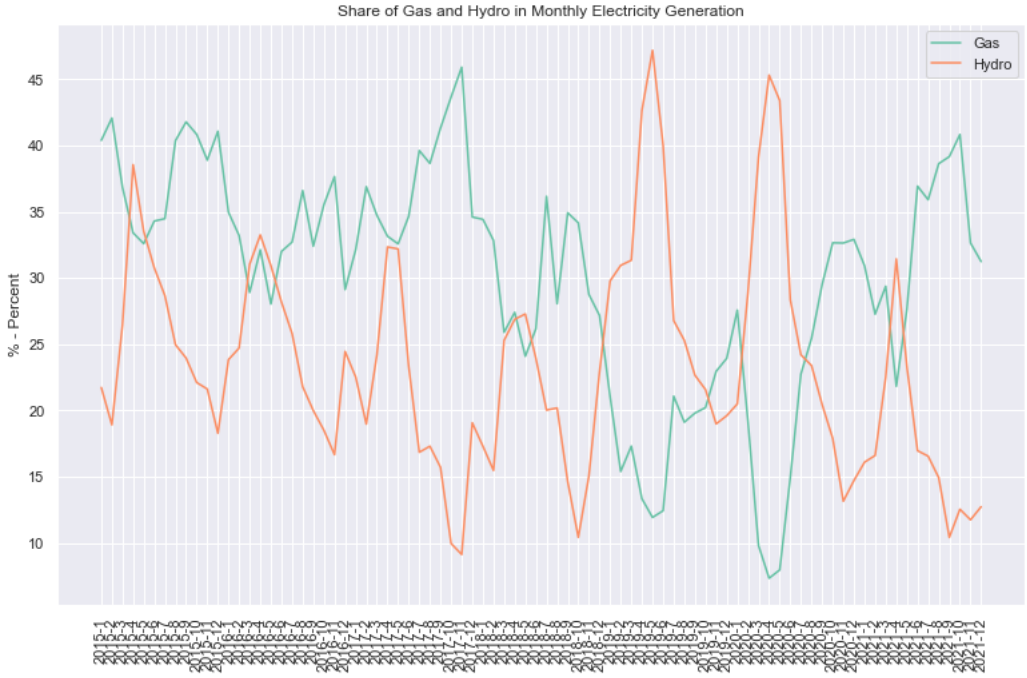


Fig. 12 Share of Hydro and Gas in Monthly Production

The hydro generation is -as expected- the waltz partner of natural gas. Share of hydro resembles a mirror image of gas. This relation was not always that strong with coal however. In 2019 excess hydro generation dented from coal's share. This is most probably imported coal. As hydro generation increases, prices drop and

imported coal may not find it profitable to generate. But in the 2021 the relationship is broken as previously explained. When hydro generation increases it drops coal generation. But when it is low, its share is not guaranteed.

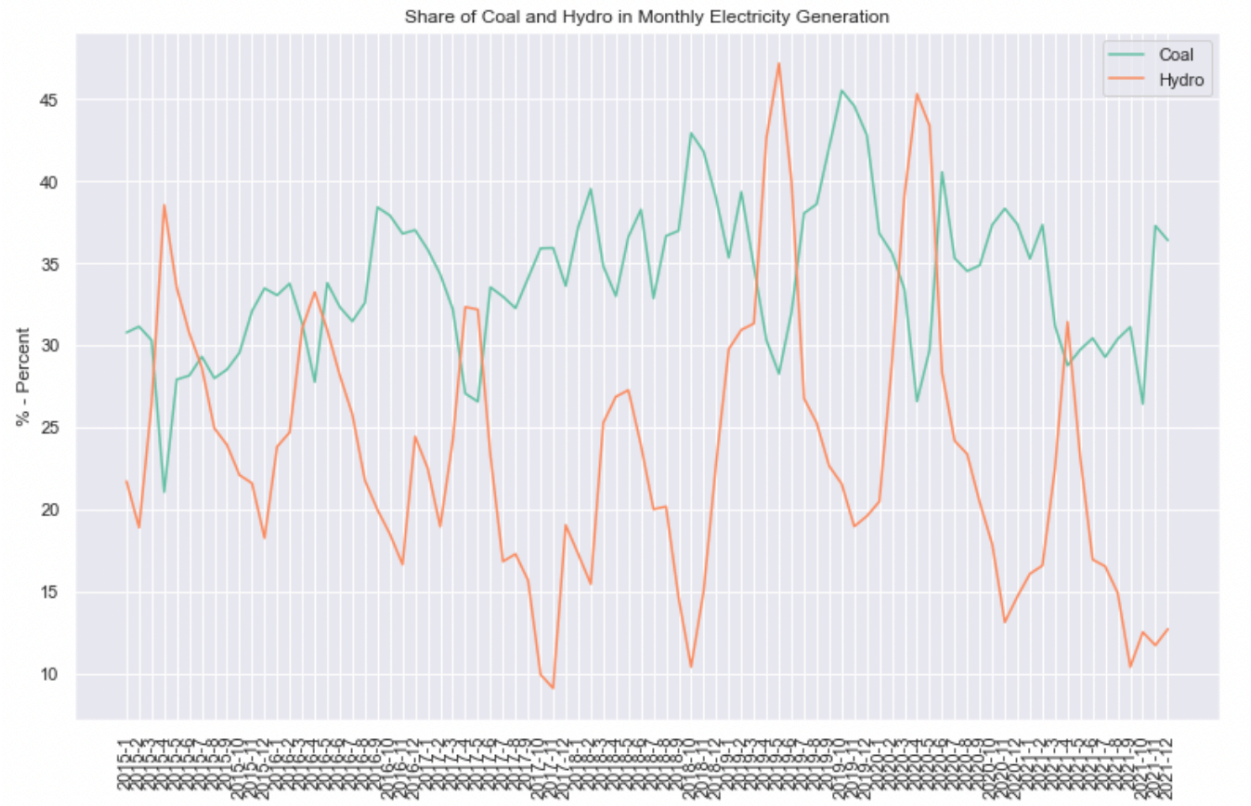


Fig. 13 Share of Hydro and Coal in Monthly Production

Summer-Winter Difference of Solar Generation

Solar generation differs from summer to winter. But this amount is open for questions. Since solar development is rapid and ongoing, we can not for sure pinpoint exact number. But in the calculations, for monthly generation 2.5 is the magic number. If solar is generation 2.5 TWh in July, it is most likely to be 1 TWh in winter.

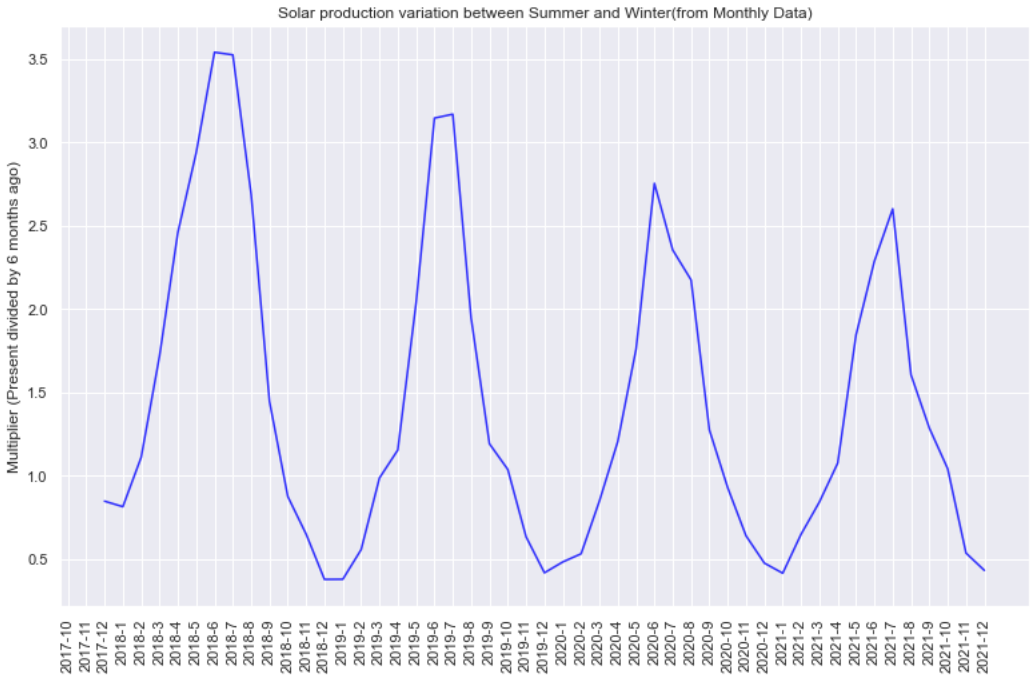


Fig. 14 Solar Generation Variation w.r.t. 6 Months Prior Generation

But our analysis continues with a 24 hour generation difference between summer and winter. In terms of 24 hour total solar generation, summer to winter difference can be between 5 to 6.

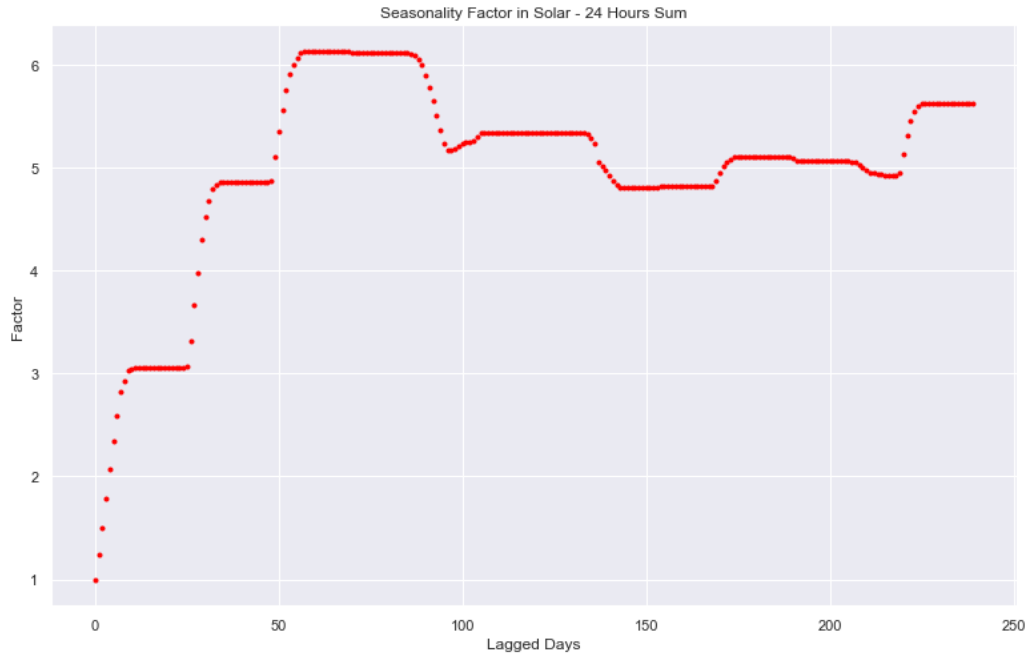


Fig. 15 Solar Generation Variation w.r.t. Previous Days(24 Hours)

Can Solar and Wind be the New Base Loads for Turkey?

In terms of hourly production, coal and renewable variance differs a lot. In the following graph, hourly generation of solar and wind, lignite and imported coal is drawn without any processing. It shows that not only wind and solar is quitter varying but its variance is also increasing as the installed power base increases.

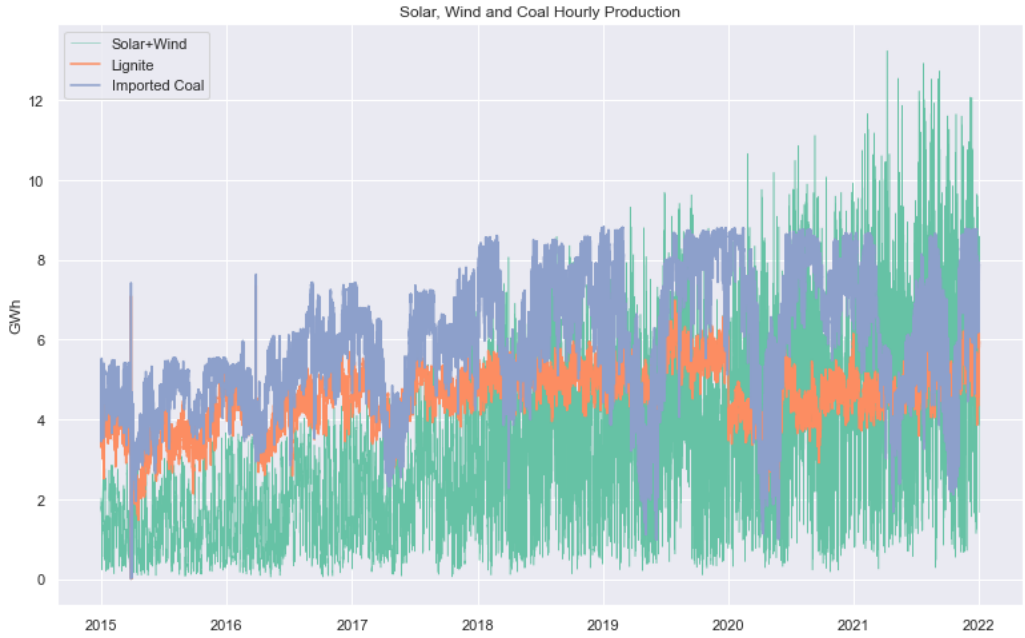


Fig. 16 Hourly solar-wind, lignite and imported coal generation

We can also check for the standard deviation of these resources in 24 hours. In the following graphic, solar and wind is seen as multiple times more variable than coal. It is not kWh per se that is important, but the controlling and stability of that kWh is crucial from system control perspective.

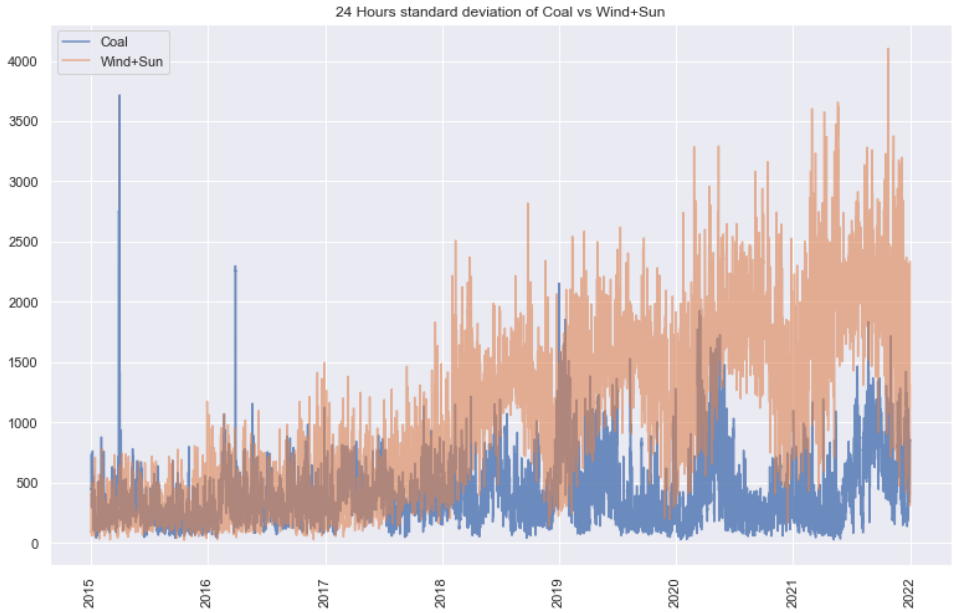


Fig. 17 Standard deviation in 24 hours for coal vs wind and solar.

6 hours is an important time slice for readiness of the reserve generation. Therefore, standard deviation within 6 hours is also graphed. Unfortunately, it is quite variable. However this is not a very big issue for a country like Turkey if hydro reserves are available. But cycling cost will be an important factor.

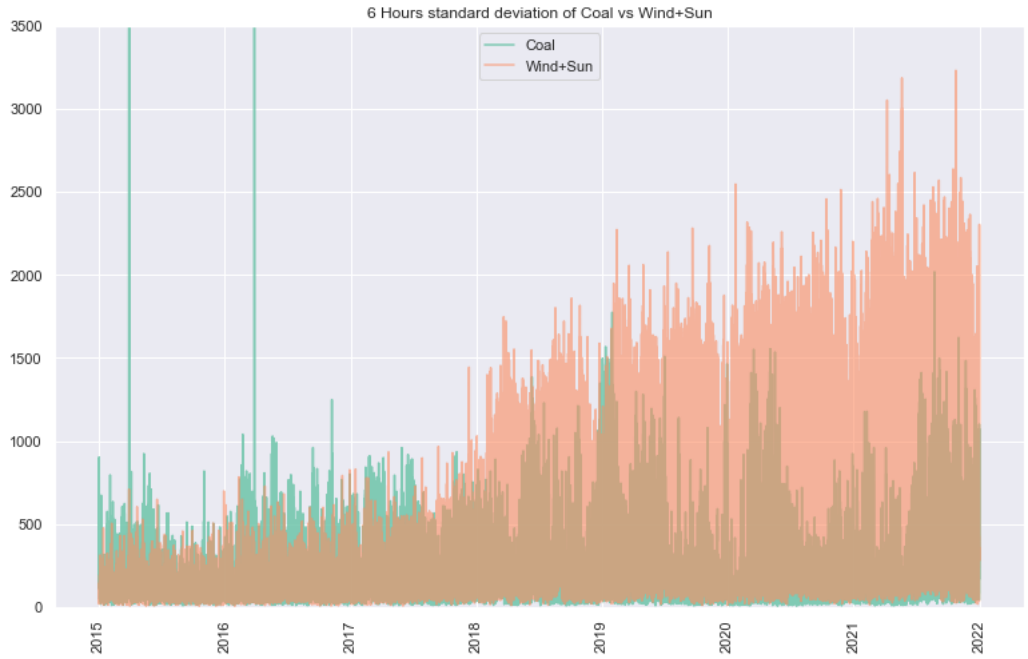


Fig. 18 Standard deviation in 6 hours for coal vs wind and solar.

Generation Profiles for Various Resources

The generation profile for resources shows us that, the real baseload has been coal for the Turkish System. Natural gas however was the swinging resource. The more compact a resource's histogram is the more stable is that resource. Wind and solar however has more low generation hours than other resources. This reflects the capacity factor.

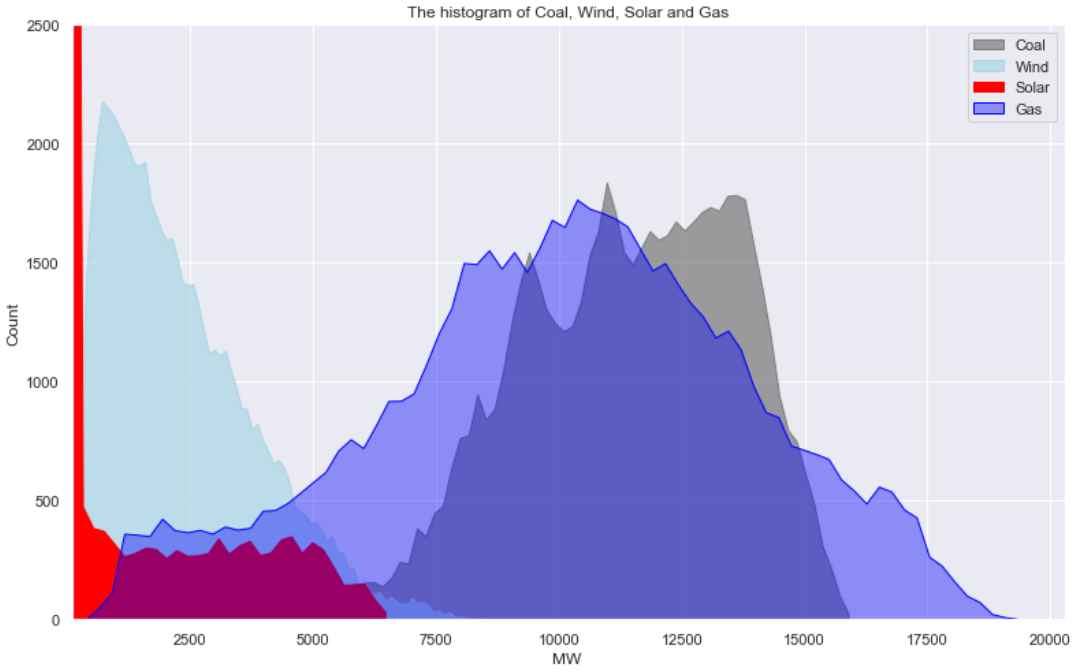


Fig. 19 The Histogram of Coal, Wind, Solar and Gas

Different Impact of Drought on Reservoir and River Type Hydro

The hydro reserves of Turkey is essential for stable management of the system. In terms of seasonal variance, the following graph may deceive us. Because reservoir generation data is the result of operation profiles. That means, there may be less rain but you may need more hydro, so you consume the reserves. Being clear on that issue is important.

There are two profiles of hydro generation: Wet and dry. Wet is the years that is leaning to the right. The normal profile is resembling wind from the previous graph: More generation time with less load. Consequently, the reservoir (big) hydro capacity is more frequently worked around 4000 MWs.

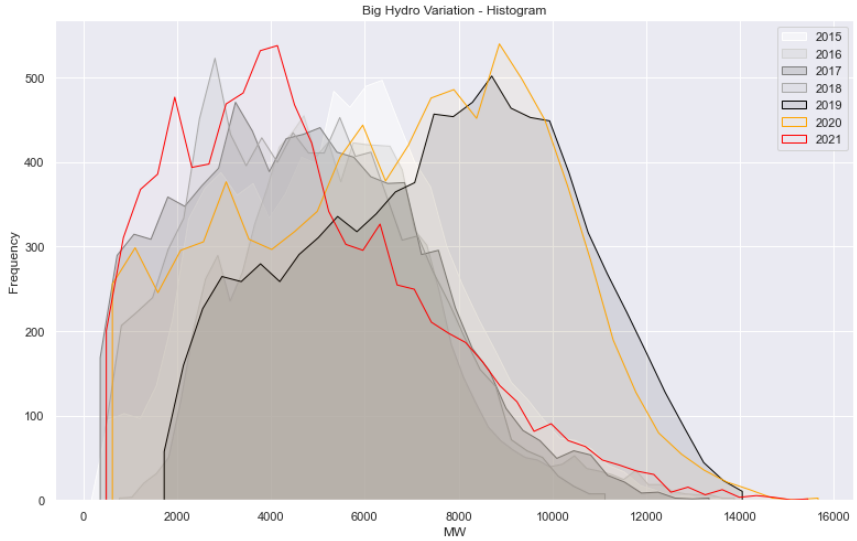


Fig. 20 Reservoir Hydro Histogram for Each Year

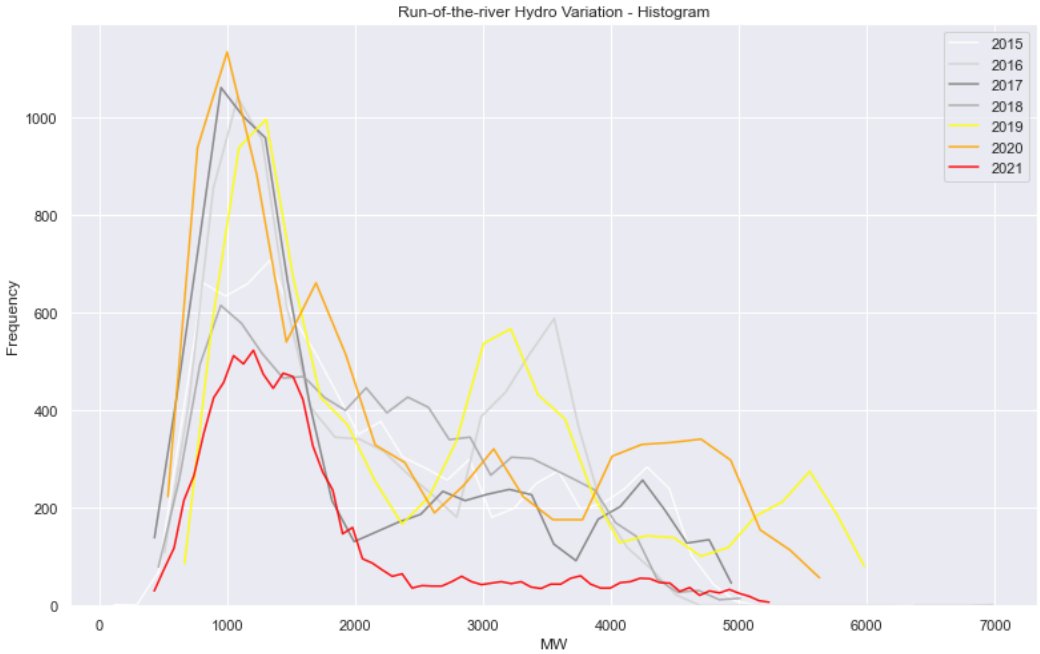


Fig. 21 Run of the River Hydro Variation

Run of the river ("river") hydro however has a long tail like wind. In certain years, these tails become fat like 2019 and 2016. So, river hydro exhibits two properties. One is the main property, the high peak on the left showing a quasi-steady work regime and a weather dependent excess generations without a pattern. This is the tail part of the curve.

Wind and Solar Variation

Wind histogram in Turkey has predictable pattern. From this perspective, it is more stable than river hydro. Also the slope going from median to peak generation is more smooth. As the generation in each year differs, currently we haven't observed a notable "wind drought" in Turkey.

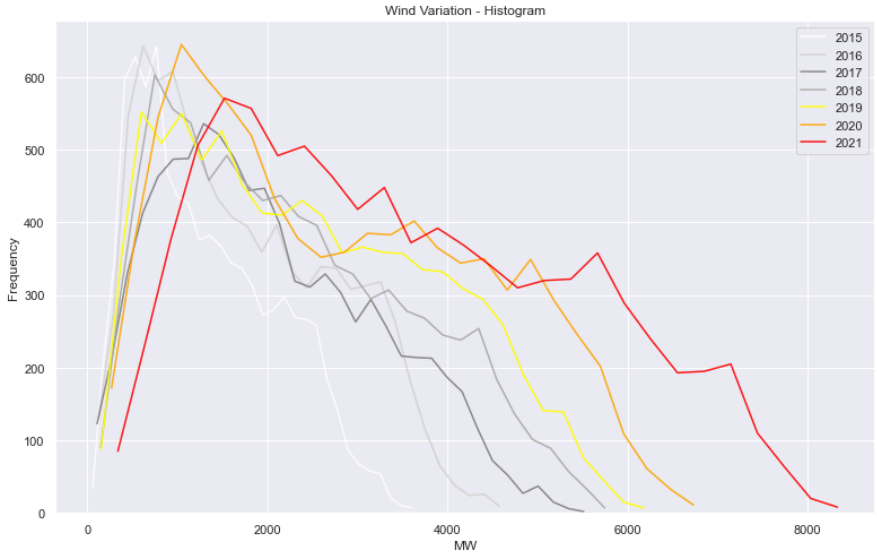


Fig. 22 Wind Variation - Histogram

On the solar side of the story, the production profile is also predictable. The variations between the years are not that different.

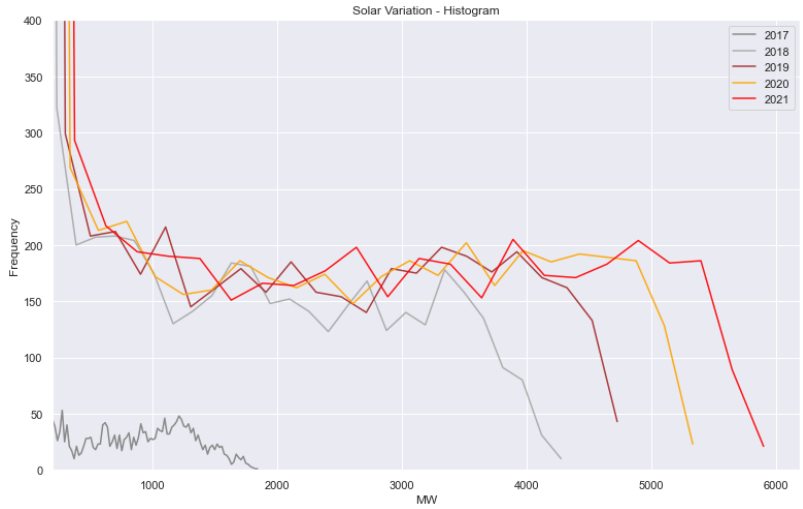


Fig. 23 Solar Variation - Histogram

Brief Explanation of Violin Plots

Violin plots are an attraction grabbing chart style. Basically the fattest part of the violin shows the more probable generation. A detailed explanation for violin charts are given by this page[2].

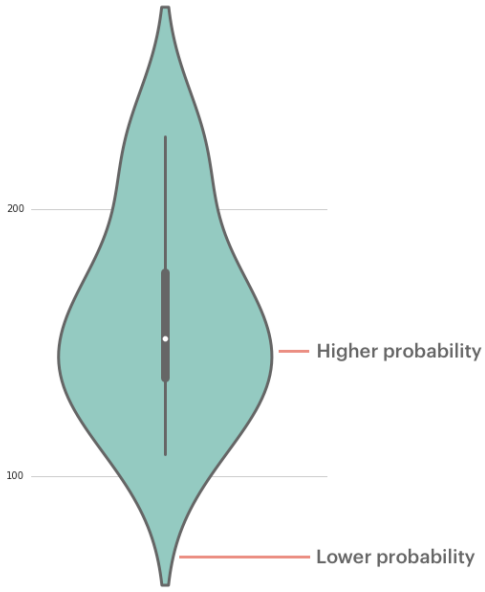


Fig. 24 Violin Plot- Probabilities

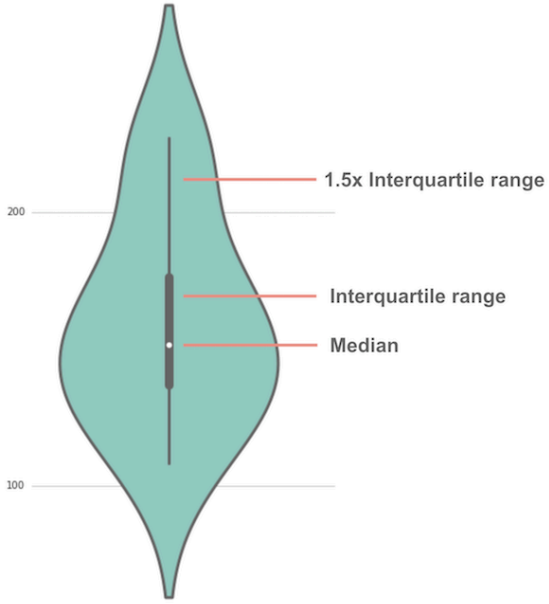


Fig. 25 Violin Plot - Quartiles and Median

As an example, the following resources are presented. Coal is more compact around 12000 MWs. The gas however more widespread around a spectrum of MWs. That means, like a balancer, gas comes to rescue. Sun and wind (renws) have more like a pear shape.

Fig. 26 Violin Plot of Coal, Gas, Wind and Solar, Hydro

[2] Carron, Joel. Violin Plots 101: Visualizing Distribution and Probability Density | Mode. Retrieved from https://mode.com/blog/violin-plot-examples/

Not All Thermal Resources are the Same

In the following graph lignite, imported coal and gas has been charted as violins. Lignite is generally producing around 5000 MWs since 2016. Imported coal has a wider pattern. Natural gas however is probably reflecting the price flexibility.

Fig. 27 Generation Pattern of Thermal Resources

How Imported Coal Generation Changed Over the Years?

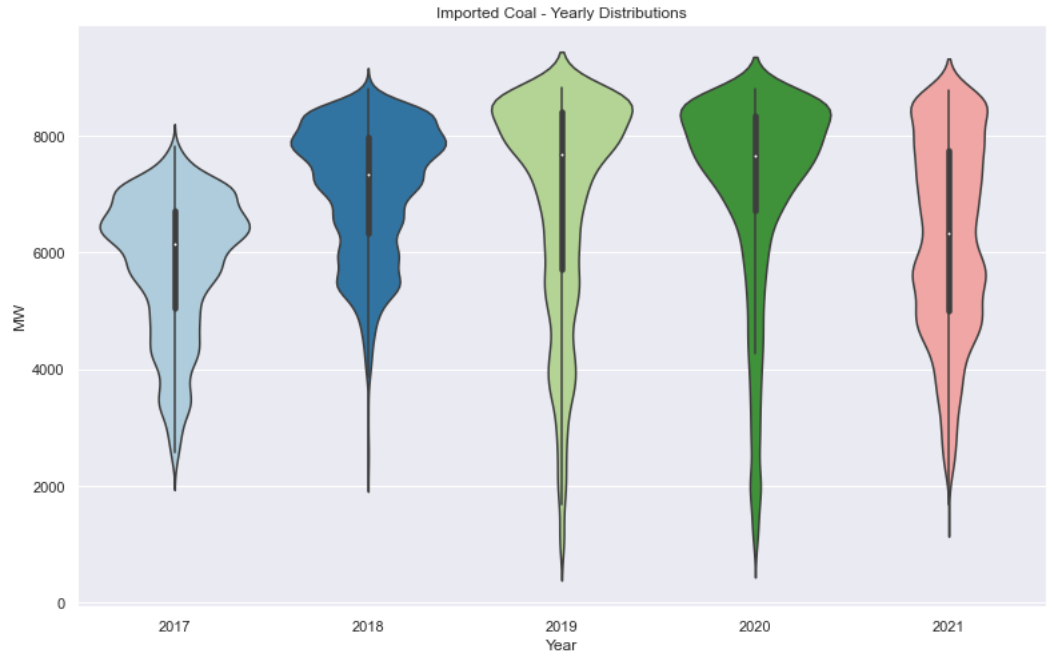


Fig. 28 Imported Coal - Yearly Violin Plots

Imported coal generation profile for 2017 and 2018 is something you expect from such resource. 2019 however changed that profile. This is due to high availability of hydro reserves and pricing. In 2021 however, it resembles gas generation pattern: A more distributed and lean profile.

Hydro – The Difference a Wet Year Makes

From the previous graphs we know that 2019 is a wet year. For a wet year, hydro violin plot resembles an upside-down pear. For dry years the pear-like formation is seen in the graph for 2021. 2020 however is more like a transition period. The direction of the pear is undecided. The drop in median generation (the middle white spot in each violin) is lower than 2017 in 2021. Dry years crush the violin from upper part and stacks most of the generation in the lower part of violin.

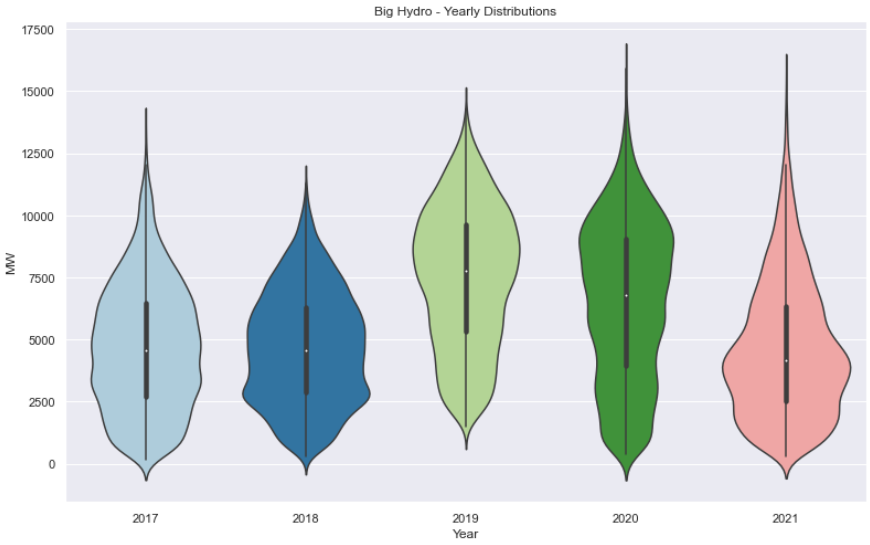


Fig. 29 Reservoir Hydro - Yearly Violin Plots

Gas – The Low of 2020

In the gas case, 2020 is very interesting. The lowest generation is seen at that year. Also it is either very high or very low generation, seen in the upper and lower bellies of the violin.

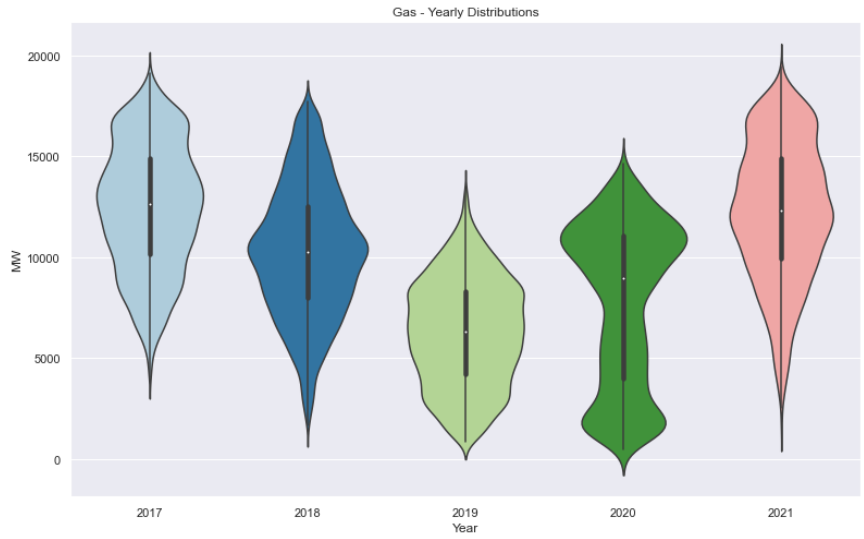


Fig. 30 Gas - Yearly Violin Plots

Wind – A Big Jump in Median Load

In wind generation we see a good increase in lower quantiles, median and higher quantiles. Although we do not have the full data, it may be due to an increase in utilization factors for a much wider range of wind speeds. Wind does not exhibit pear like pattern in 2021 as in 2017. Median generation for wind is above 3000 MWs in 2021.

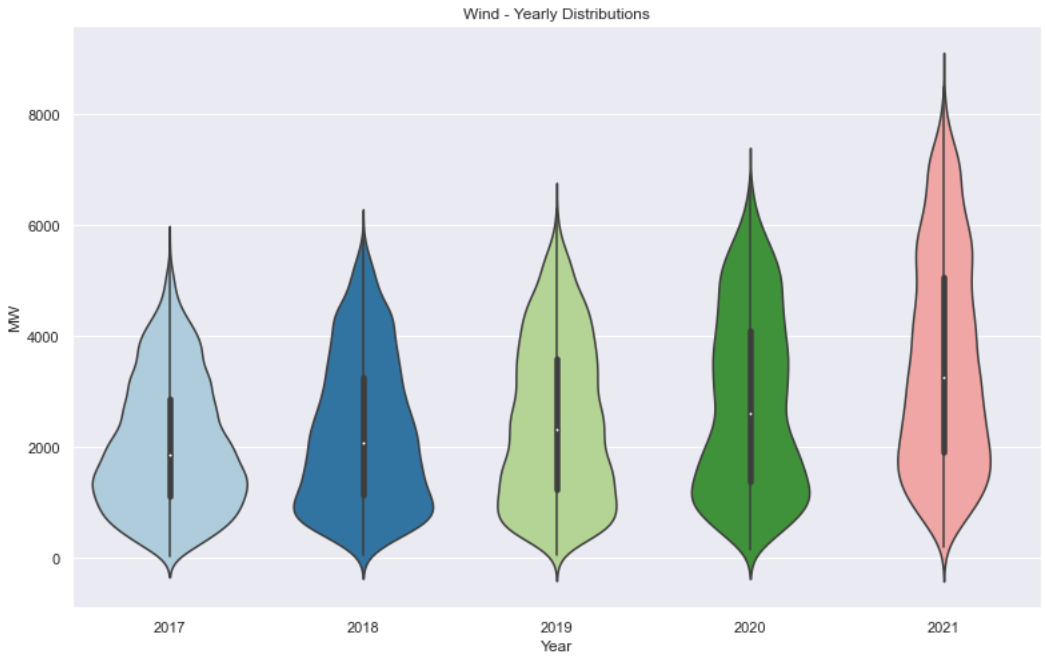


Fig. 31 Wind - Yearly Violin Plots

Which Resource is More Correlated with Demand?

As the main resources of Turkish electricity system coal, gas and hydro has been tested for their compliance with demand requirements. Until 2019 hydro and gas were the main pillars of changing demand with correlations close to 1.0, which means full correlation(or resemblance). However in 2020, gas lost that correlation. Hydro however, despite drought continues to be a load following resource, although with a dent.

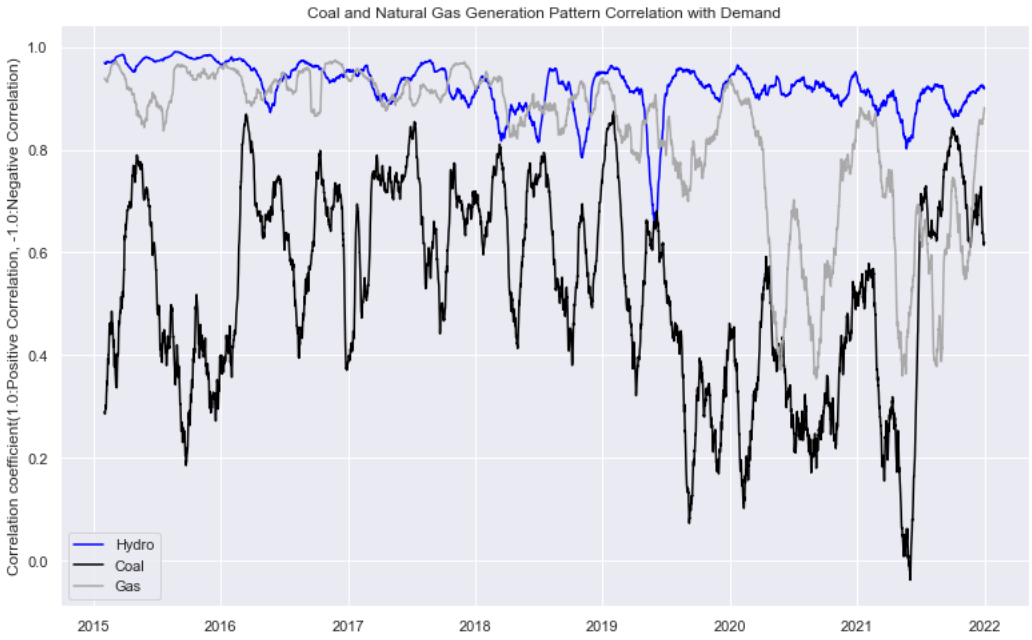


Fig. 32 Coal and Gas Generation Correlation with Demand

Coal on the other hand is not as successful as others in load following. Even in the 2nd and 3rd quarter of the 2021, coal followed load better than gas, which is practically should not be possible. This may be due to increasing demand.

Solar and Wind: Are They Concurrent with Demand?

Solar is especially an interesting resource and seasonally it is more load following than coal. Solar in Turkish system is correlated with demand, therefore has an ability to depress higher prices. Wind however, is not very linked with demand. Most of the time the correlation coefficient is not meaningful at all, showing a disjoint.

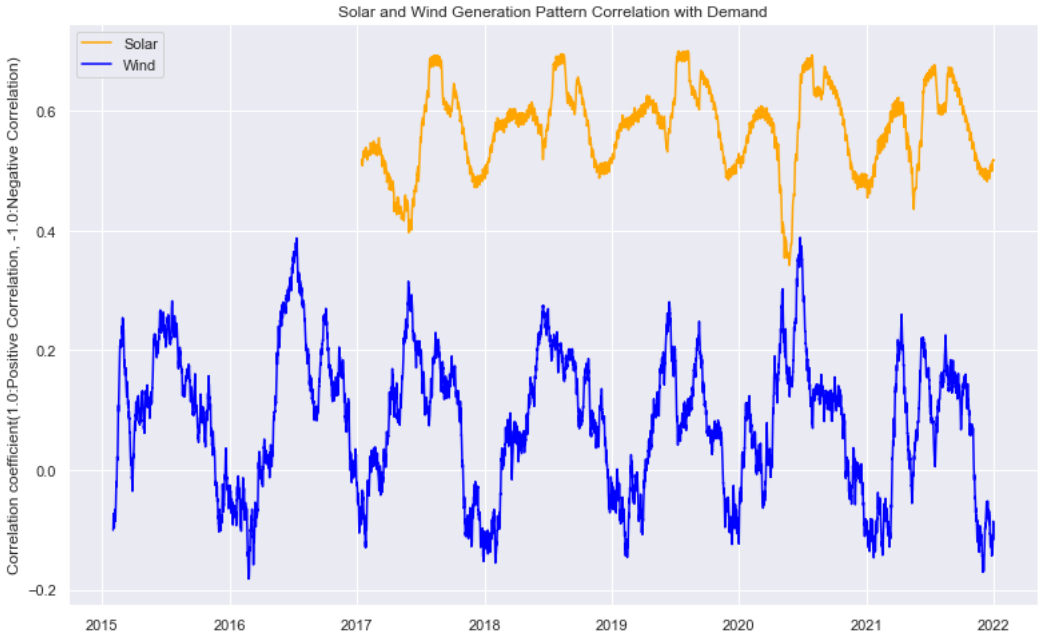


Fig. 33 Solar and Wind Correlation with Demand

Is Gas a Bridge Fuel?

The short answer is not sure. Hydro on the other hand is more correlated with wind and solar. This may mean hydro generation is accompanying renewable generation like a helper. So does the gas. But this correlation is getting weaker as solar installed capacity increases. Interesting bit is the solar's negative correlation with wind, which is practically a good thing. They may be complementing each other.

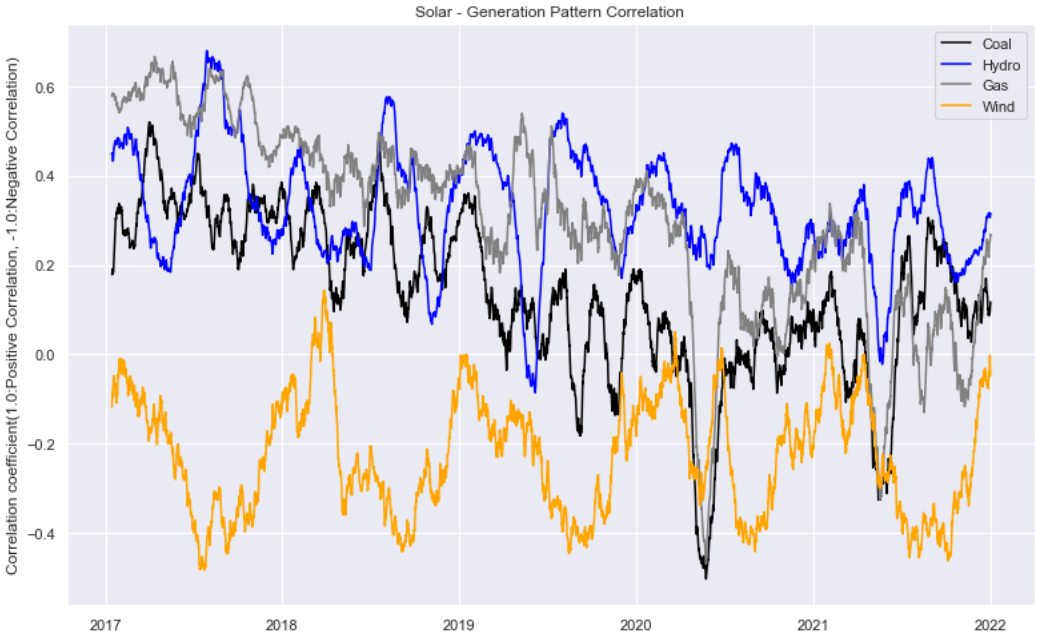


Fig. 34 Solar Generation's Correlation with Other Resources

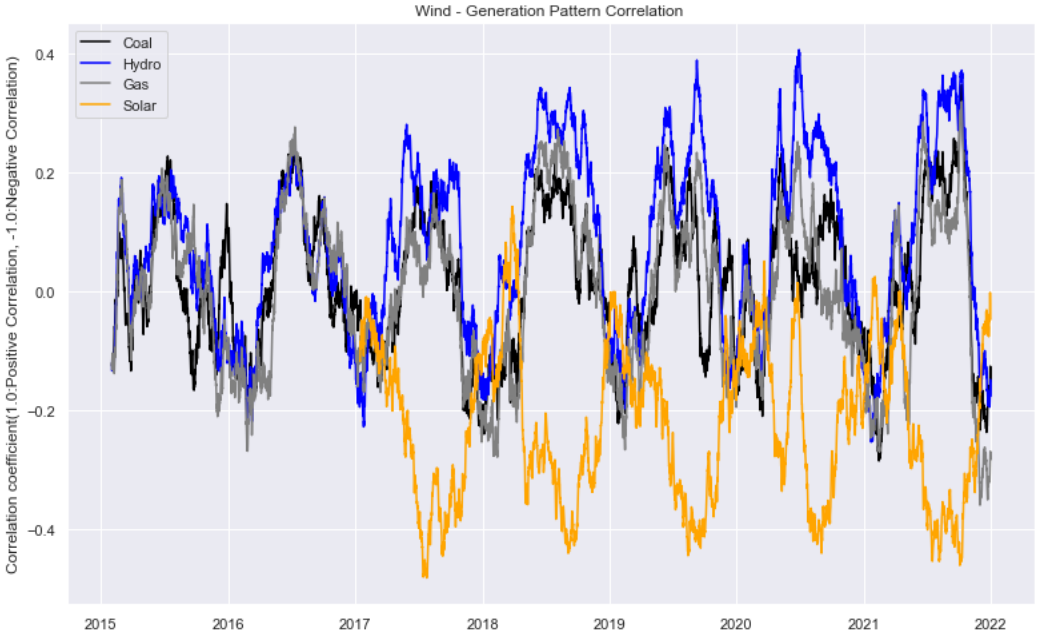
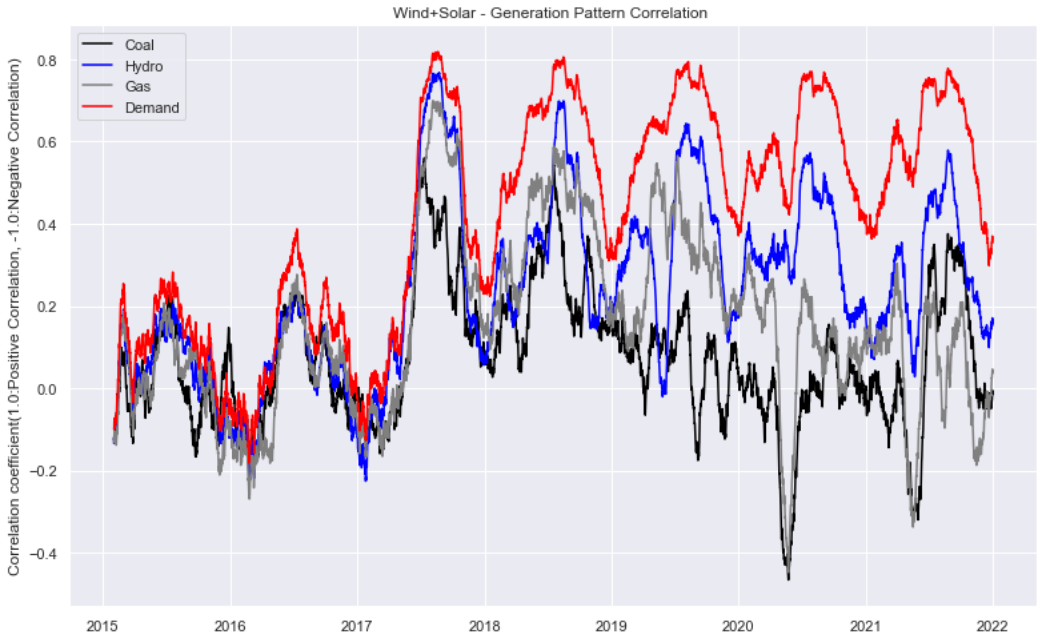


Fig. 35 Wind Generation's Correlation with Other Resources

Wind generation on the other hand has an increasing correlations with other resources, which may be due to seasonal effects.

Wind-Solar Better than Hydro?

Well, looks like they are better in terms of load concurrence. If we look to the correlation of wind and solar together against other resources, they are becoming more correlated with demand (red line), which is mostly due to solar. This is a positive message to increase both resources together.



The Loser in a Wind-Solar World

In the last part, we have to check whose shares are affected by solar and wind generation. In an ever increasing demand world, no one. But in terms of correlation tables, natural gas is more disturbed by renewable resources than coal. Run of the river hydro is a special case. These are the results for the last 5 years.

Table 3 Correlation of Resources for the Last 5 Years

	naturalGas	coal	coalgas	renws	renall	dammedHydro	river	solar	wind	gtotal
naturalGas	1.0	0.2	0.9	-0.0	-0.2	-0.1	-0.5	0.0	-0.1	0.6
coal	0.2	1.0	0.6	0.2	-0.1	-0.0	-0.5	0.1	0.1	0.5
coalgas	0.9	0.6	1.0	0.0	-0.2	-0.1	-0.6	0.1	0.0	0.7
renws	-0.0	0.2	0.0	1.0	0.3	0.1	-0.1	0.7	0.7	0.5
renall	-0.2	-0.1	-0.2	0.3	1.0	0.9	0.6	0.5	-0.0	0.5
dammedHydro	-0.1	-0.0	-0.1	0.1	0.9	1.0	0.4	0.2	-0.1	0.5
river	-0.5	-0.5	-0.6	-0.1	0.6	0.4	1.0	0.0	-0.1	-0.1
solar	0.0	0.1	0.1	0.7	0.5	0.2	0.0	1.0	0.0	0.4
wind	-0.1	0.1	0.0	0.7	-0.0	-0.1	-0.1	0.0	1.0	0.2
gtotal	0.6	0.5	0.7	0.5	0.5	0.5	-0.1	0.4	0.2	1.0

For 2021 however, increasing wind generation has started impacting natural gas and hydro. This may be due to an interplay of wind against these resources by the system operator for balancing. Another change is in solar. Solar also started impacting coal generation.

Table 4 Correlation of Resources for the 2021

	naturalGas	coal	coalgas	renws	renall	dammedHydro	river	solar	wind	gtotal
naturalGas	1.0	0.3	0.9	-0.1	0.0	0.1	-0.4	0.1	-0.2	0.6
coal	0.3	1.0	0.6	0.0	-0.1	0.0	-0.4	-0.1	0.1	0.4
coalgas	0.9	0.6	1.0	-0.1	-0.0	0.1	-0.5	0.0	-0.1	0.7
renws	-0.1	0.0	-0.1	1.0	0.3	0.0	-0.0	0.7	0.6	0.4
renall	0.0	-0.1	-0.0	0.3	1.0	0.9	0.6	0.6	-0.2	0.6
dammedHydro	0.1	0.0	0.1	0.0	0.9	1.0	0.5	0.2	-0.2	0.7
river	-0.4	-0.4	-0.5	-0.0	0.6	0.5	1.0	0.0	-0.1	-0.0
solar	0.1	-0.1	0.0	0.7	0.6	0.2	0.0	1.0	-0.1	0.4
wind	-0.2	0.1	-0.1	0.6	-0.2	-0.2	-0.1	-0.1	1.0	0.1
gtotal	0.6	0.4	0.7	0.4	0.6	0.7	-0.0	0.4	0.1	1.0

We are not sure about the persistence of this pattern since demand is keep growing. As more data accumulates, we will see more distinct patterns