RES penetration and electricity market prices in Greece 2021

The prices of the wholesale electricity market in Greece, but also in Europe in general, skyrocketed to unprecedented levels at the end of 2021, following the gradual escalation of gas prices, which now participates, but will participate in the future with high percentages in energy mix of power generation.

Figure 1 shows the evolution of gas prices monthly in Boxplot[1] format. There is a gradual escalation of its price from April 2021 which ends in the explosive prices of December 2021.

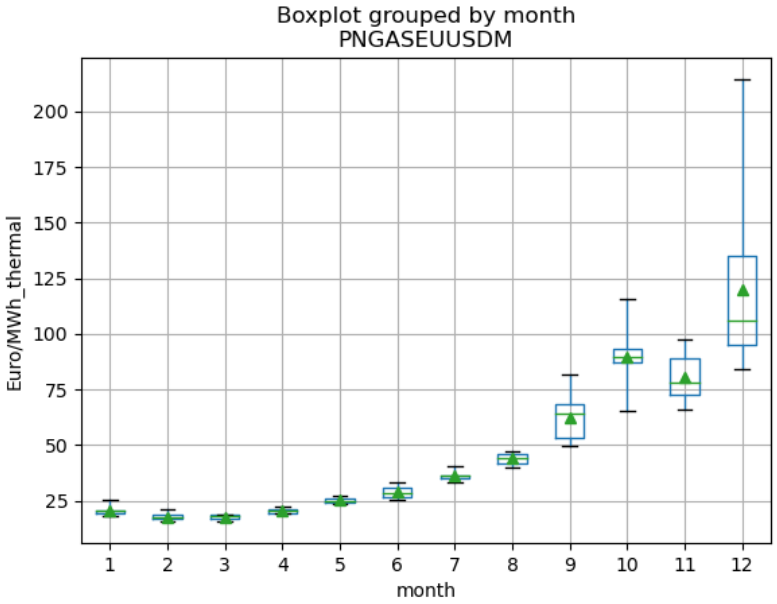


Figure 1 Evolution of gas prices monthly in Greece in 2021[2] (euro/MWh_thermal)

Figure 2 shows the Market Clearance Prices[3] (in the figures referred to as DAM or MCP) in Boxplot format, on a monthly and hourly[4] (intraday) basis. From the monthly graph we understand the strong correlation between MCP and gas price as expected.

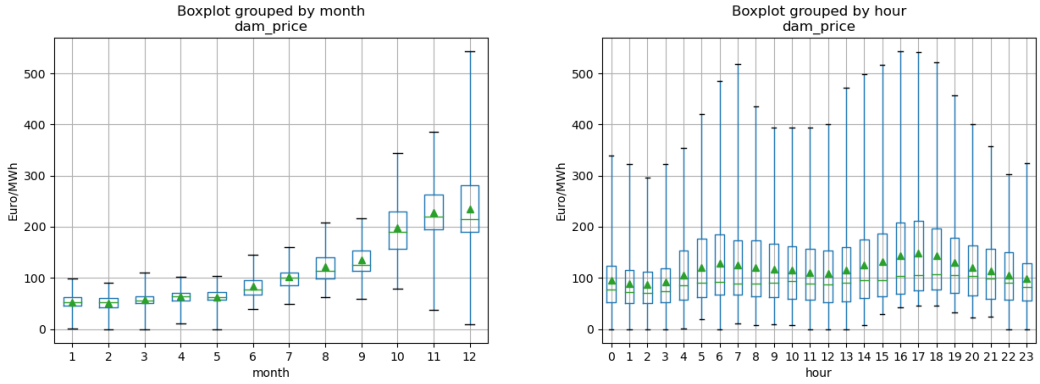
[1] The Boxplot charts used in this study show the mean value of the monthly or hourly distribution (green triangle), the quantiles of Q25 and Q75 (blue rectangle), its median or Q50 (green dash) and the minimum and maximum values (black whiskers).

[2] https://www.desfa.gr/regulated-services/balancing/daily-price

[3] The data used in the present study are freely accessible on the internet by ENTSO-E (MCP, energy mix), the Hellenic Energy Exchange (Next Day Market and Intraday Market) and IPTO (Balancing Market). Full data for all three markets are available from the end of 2020 onwards.

[4] The time zone used in the study is UTC (Coordinated Universal Time)

P.K. Chaviaropoulos, February 2022



(a) (b)

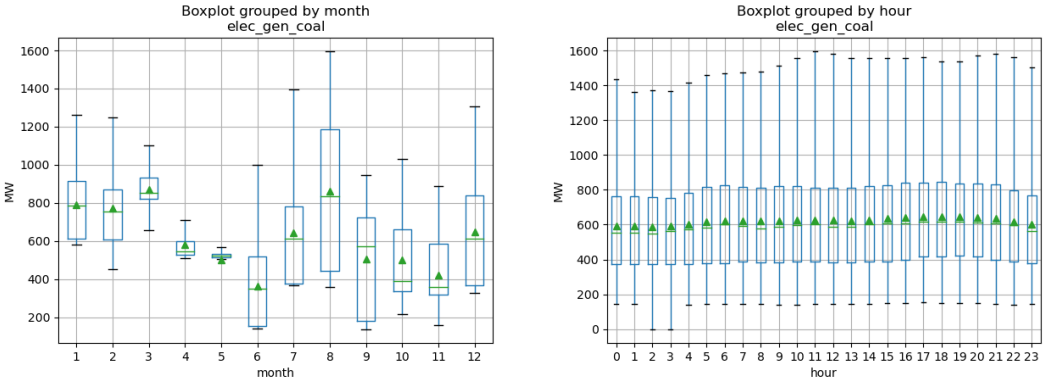
Figure 2 Market Clearing Prices in Greece in 2021. (a) monthly, (b) hourly

The questions asked in this study are:

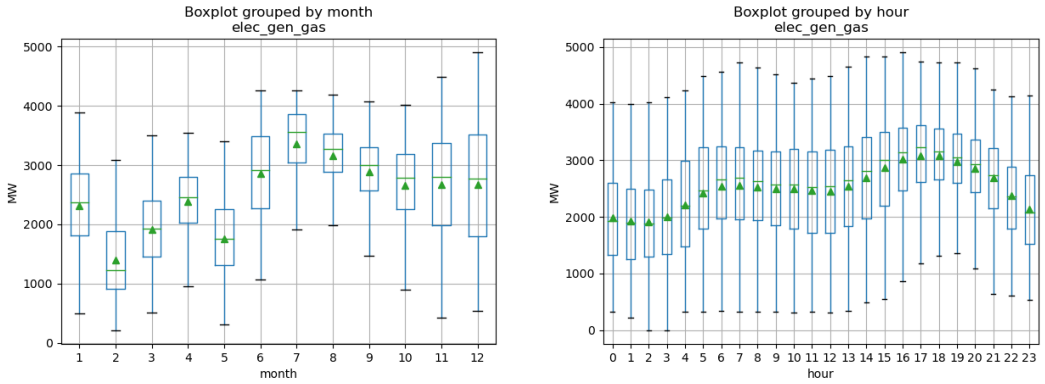
1. What was the effect of the penetration of RES variables, wind and photovoltaic, on the formation of MCP?

2. What would be the MCP values if these RES variables were not in our energy mix?

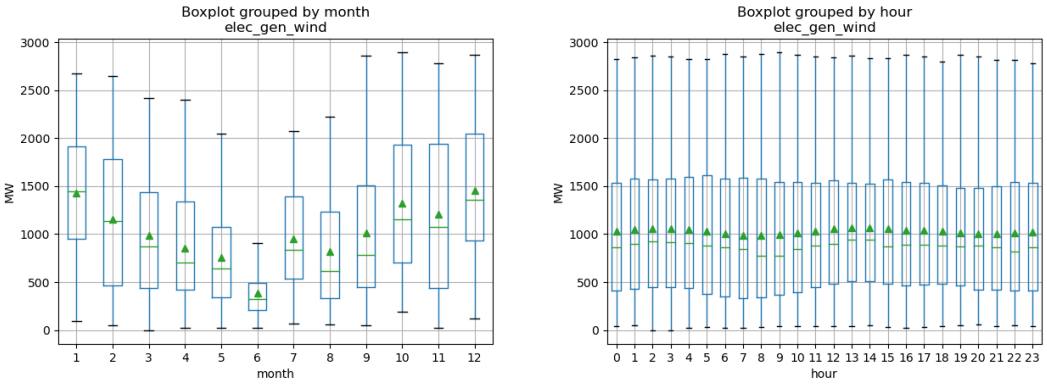
Before answering these questions, let's look at the share of basic energy sources in the 2021 mix. Figure 3 shows relevant Boxplot diagrams for lignite, natural gas, wind and photovoltaic.



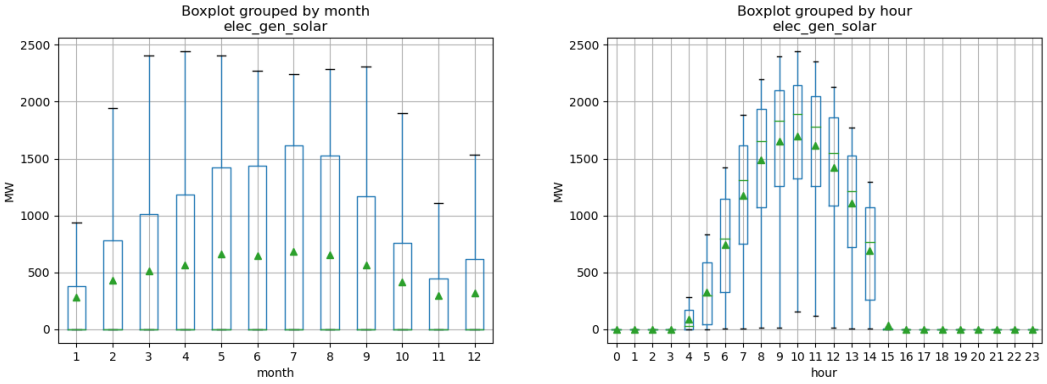
(a) Lignite



(b) Natural gas



(c) Wind



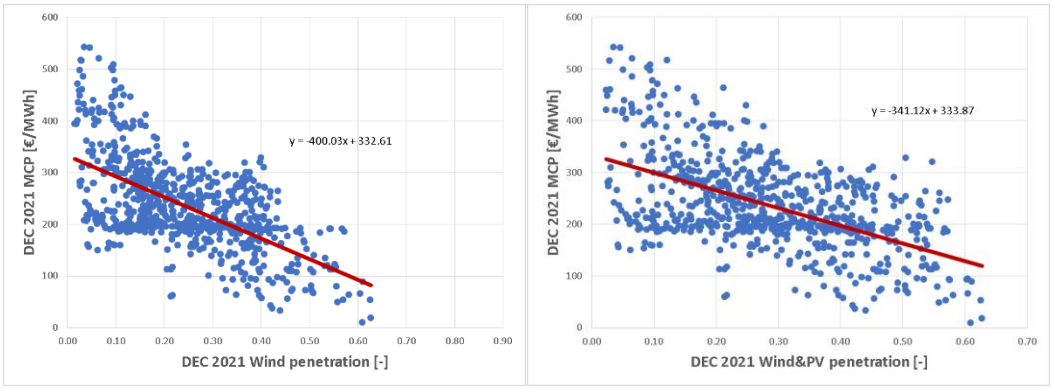
(d) Photovoltaics (PV)

Figure 3 Participation of basic energy sources in the power generation mix of 2021. (a) Lignite, (b) Natural gas, (c) Wind and (d) Photovoltaics

In the above figures we observe:

- The relatively small penetration of lignite in the energy mixture and its typical utilization as a base production (see hourly graph)
- The greater penetration of natural gas and its intraday fluctuation with the two local maximums, morning, and afternoon, as well as its strong intra-day correlation with MCP (see Figure 2)
- The high production of wind in the first and last months of the year with the intraday production being every hour stable over 800 MW with a probability of over 50%
- The highest production of photovoltaics in the middle months of the year, cooperating with great complementarity with the wind, and the characteristic intra-day production curve.

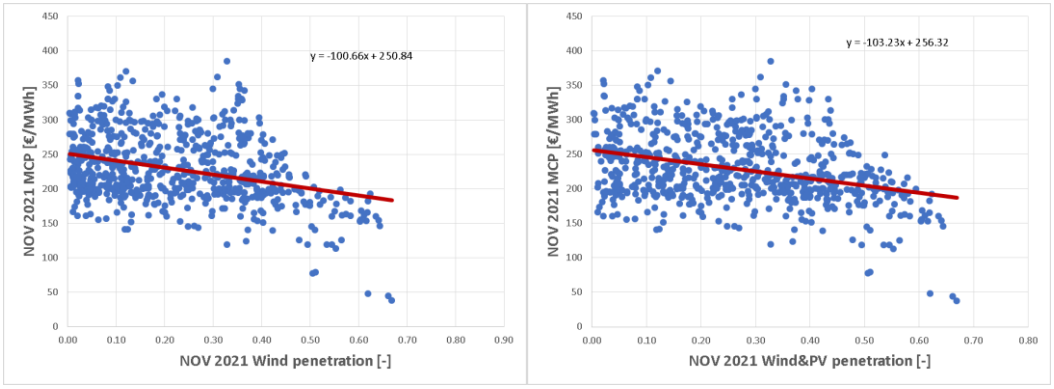
The answer to the **first question** on how the penetration of RES variables affected the formation of MCP, especially in December 2021 with its highest values, is given in Figure 4. The left image refers to the penetration of wind energy individually, while the right to the penetration of wind and photovoltaics at the same time. Penetration is defined as the ratio of the production of the considered energy source to the total load on an hourly basis (each blue dot of the diagrams corresponds to an hourly value).



(a) (b)

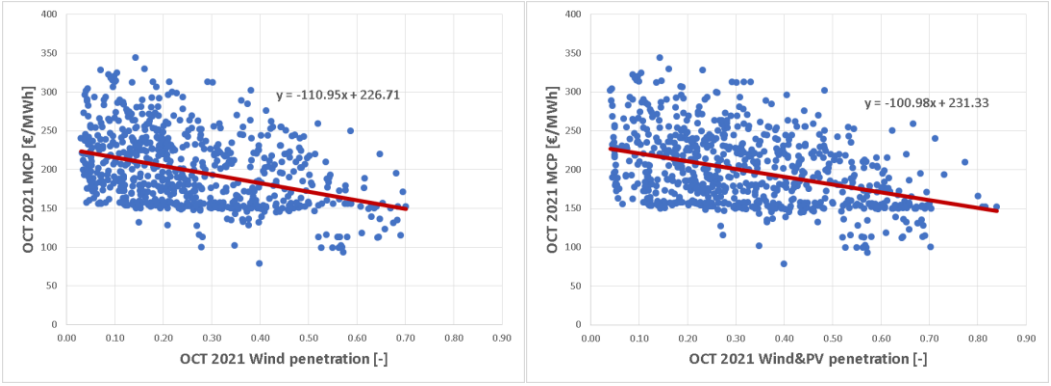
Figure 4 Correlation of MCP and penetration of (a) wind and (b) wind and photovoltaic for December 2021

The MCP-penetration correlation is strongly negative in both graphs. That is, when the penetration increases, MCP decreases. For wind farms by themselves the slope of the regression line (red line in the figures) is -400 € / MWh / penetration unit. That is, for each increase in the penetration of wind farms by 10% (0.1 in the diagram) MCP is reduced by an average of 40 € / MWh. This price is set at 34 € / MWh when photovoltaics is considered, for the specific period when their production is relatively small.



(a) (b)

Figure 5 Correlation of MCP and penetration of (a) wind and (b) wind and photovoltaic for November 2021



(a) (b)

Figure 6 Correlation of MCP and penetration of (a) wind and (b) wind and photovoltaic for October 2021

Corresponding charts for November and October 2021 are given in Figure 5 and Figure 6. The negative slope of the regression line is (in absolute value) smaller in these charts than in December, which is attributed to the lower average value of MCP or / and its smaller range of variation. Monthly averaged MCP prices per penetration bin for Wind only, PV only and Wind & PV scenarios are provided in Annex A for the full year.

The negative correlation of wind production with MCP is clearly reflected in Figure 7 for the second fortnight of December 2021, when the highest MCP prices of the year were recorded. The picture highlights the upward trend of MCP when wind production is declining and vice versa.

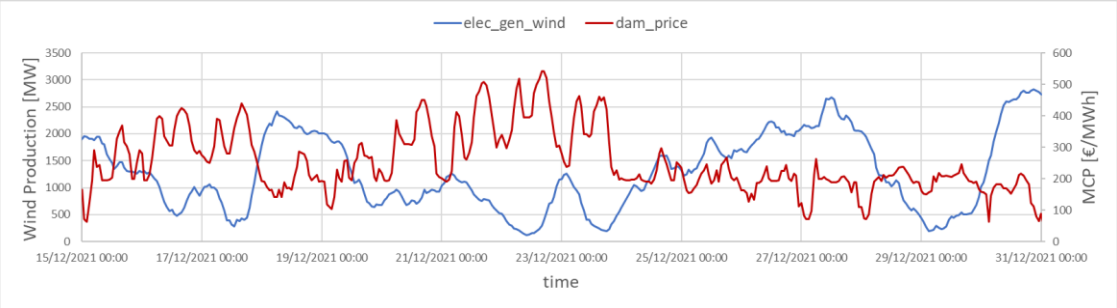


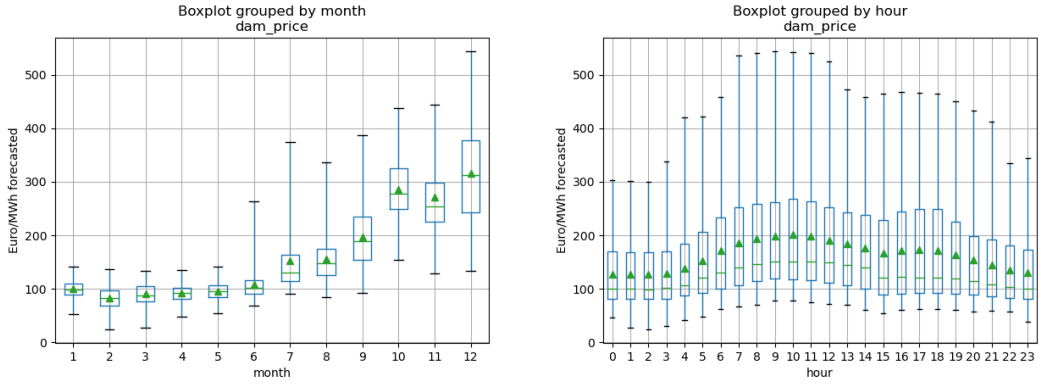
Figure 7 Timeseries of wind production with MCP in the second fortnight of December 2021

In conclusion, in periods of high penetration of wind and photovoltaic in the electrical system MCP is significantly reduced as RES replace corresponding quantities of natural gas, the penetration rate of which directly shapes MCP. Reasonably, the reduction of MCP for the sake of RES is greater in absolute terms in periods when gas is more expensive.

To answer the **second question**, what would the MCP prices be if variable RES were not participating in our energy mix, we used an electricity market price forecast software produced by iWind Renewables to quantify the revenue of energy storage units (independently or in combination with RES) which will pursue their income from the day-ahead, intraday, and balancing electricity markets. The forecasting tool estimates future prices in the electricity markets which are then used in the form of hourly time series to optimize the operation of the storage unit with the aim of maximizing its revenue.

Forecasting software is not based on a detailed electricity market model like that used by market operators but uses neural networks to correlate electricity prices with the basic system parameters that shape them. Such parameters for MCP are the price of natural gas and the CO2 tax, as well as the penetration rates of the individual energy sources in the energy mix etc. The model uses as input data known hourly parameter's time series and as output data the corresponding MCP time series to train its neural network. It then applies the trained neural network to the sought set of input data (different gas time series or different power generation mix) to evaluate their corresponding MPC values.

Figure 8 shows Boxplots for the Clearing Prices of the Market in Greece in 2021 if there were no wind and photovoltaic in the system. The prices were estimated with the computer tool described above, zeroing the hourly production time series of wind and photovoltaic, transferring their energy contribution to natural gas.



(a) (b)

Figure 8 Market Clearing Prices in Greece in 2021 if there were no wind and photovoltaics. (a) monthly, (b) hourly

Comparing Figure 8 with Figure 2, ie MCP 2021 without RES and with variable RES, we observe the increased average monthly and hourly MCP values that we would face in the scenario of zero wind and photovoltaic production. In the monthly chart all average prices are high, and in periods when the price of gas was relatively low. In the hourly chart, in addition to the overall increase in average prices, we observe the relative increase in prices in the morning-noon zone mainly due to the lack of photovoltaics.

Table 1 Monthly statistics of MCP for the real prices 2021 (with RES) against the scenario of zero production of wind and photovoltaic (w / o RES)

MONTHLY BASIS MCP [€/MWh]					
	MEAN VALUES			MAX VALUES	
Month	with RES	w/o RES	Increase	with RES	w/o RES
JAN	53	101	91%	98	141
FEB	50	83	65%	91	136
MAR	58	91	59%	111	134
APR	64	92	44%	102	134
MAY	63	96	52%	104	141
JUN	84	108	29%	145	263
JUL	102	152	49%	160	374
AUG	122	156	28%	208	337
SEP	135	196	46%	217	387
OCT	199	286	44%	344	439
NOV	229	271	18%	385	444
DEC	235	316	34%	543	544

Table 2 *Hourly statistics of MCP for the real prices 2021 (with RES) against the scenario of zero production of wind and photovoltaic (w / o RES)*

HOURLY BASIS MCP [€/MWh]					
	MEAN VALUES			MAX VALUES	
Hour	with RES	w/o RES	Increase	with RES	w/o RES
0	95	127	34%	340	303
1	88	127	43%	323	301
2	87	127	46%	297	301
3	92	129	41%	322	339
4	106	138	30%	353	420
5	121	153	27%	420	422
6	129	172	33%	486	458
7	126	186	48%	518	537
8	121	194	61%	436	540
9	117	199	70%	395	544
10	116	201	74%	395	542
11	111	198	78%	395	541
12	108	191	76%	401	524
13	116	184	59%	471	473
14	125	177	42%	498	458
15	133	167	26%	516	465
16	144	172	19%	543	469
17	149	174	17%	542	467
18	144	172	19%	521	465
19	130	164	26%	458	451
20	121	154	27%	401	434
21	113	144	27%	358	412
22	106	135	27%	302	335
23	99	130	31%	325	345

Especially for December 2021 the average price of MCP is estimated at 316 € / MWh in relation to its recorded price of 235 € / MWh.

The turnover of the wholesale market for 2021 (calculated on the sum of load and electrical losses) was 6.3 billion euros. If the wind and photovoltaic systems were missing, the corresponding price would be 8.8 billion euros, an increase of 40%. This means that the average MCP for the whole of 2021 if there were no RES variables would be increased by 46 € / MWh. The estimated average monthly charge of MCP for 2021 if the variable RES did not exist is presented in Figure 9.

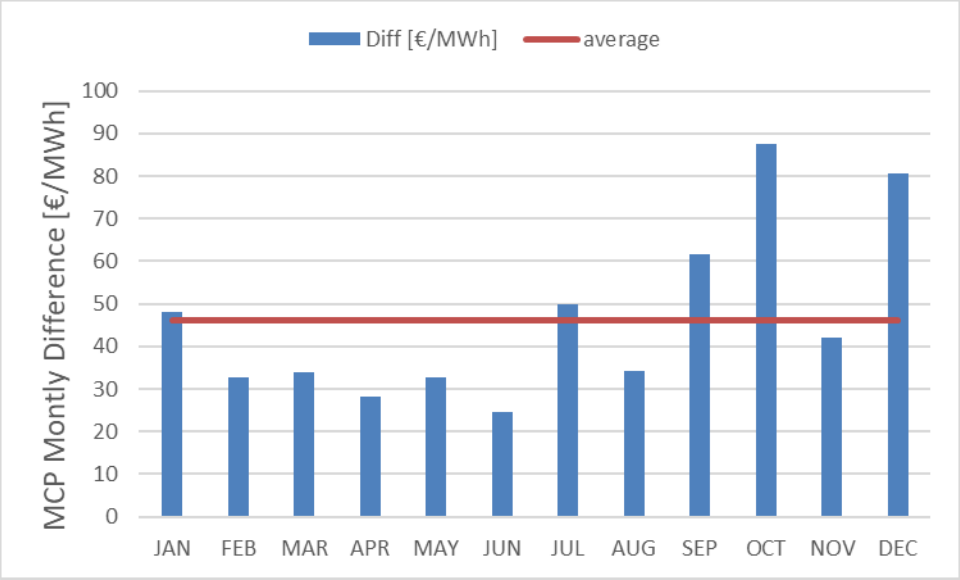


Figure 9 Estimated average monthly charge of MCP for 2021 if the RES variables did not exist

The results of December are in good agreement with the corresponding results of the AUTh research team, recently announced by the Greek Ministry of Energy. It is emphasized, again, that the results of the iWind forecasting model are not at the level of fidelity of modern electricity market models, such as that of AUTh. However, our forecasting model can assess with satisfactory fidelity the changes in market prices when the parameters that shape them change.

The conclusion regarding the two questions raised is that, if the penetration of wind and photovoltaics was not at the current level, then the energy crisis as reflected through the particularly high supply prices of natural gas would hit the Greek wholesale market even more. Average monthly MCP prices would exceed 310 € / MWh and the turnover of the wholesale market for 2021 would be burdened by 2.5 billion euros.

Annex A

Monthly averaged dam prices per penetration bin for Wind only (blue), PV only (red) and Wind & PV (green) scenarios.