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Executive Summary of the Thesis

Prediction and Interpretation of bids in the Italian Electricity Market for Ancillary Services

Laurea Magistrale in Ingegneria Matematica - Mathematical Engineering

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1. Introduction

This Executive Summary introduces the results of a joint collaboration between **Politecnico di Milano** and the research institute **RSE - *Ricerca sul Sistema Energetico***, based on an extensive statistical analysis of the **Italian Electricity Markets**. These marketplaces have experienced drastic changes in recent years, mainly driven by the general desire to transition towards a more **sustainable economy**, supported by the diffusion of power plants fueled by non-programmable Renewable Energy Sources. Indeed, these units are able to produce much cheaper and cleaner energy than traditional thermoelectric power plants but are causing a sharp **increase** in the measures required for the **regulation of the Power System**, with balancing resources that have to be procured by the Italian Transmission System Operator on the **Ancillary Services Market (MSD)**. MSD is part of the so-called Spot market for electricity (the one managing short-term energy tradings), it takes place after the Day-Ahead and Intra-Day markets, and covers *ancillary services*, which is a term used to denote special services and functions adopted by the TSO to meet the demand for electrical energy in real time. Indeed, the market is used by the TSO to anticipate every possible imbalance that may happen to the Power System, and thus it has a very specific nature, being **restricted** to only a **selected subgroup** of Production Units, that have at least 10 MW in installed capacity and meet other specific safety prerequisites. In contrast to the previous markets, **MSD is not based on a merit order** and therefore it is generally characterized by higher prices than the Day-Ahead Market (MGP), where, however, the greatest portion of electrical energy is exchanged. Furthermore, the **participation** to the market **is compulsory**, meaning that all the units that are eligible for it have to bid at every hour. Eventually, the **unpredictability** behind the need for ancillary services generates a setting that is both quite complicated and intriguing to study, from a statistical standpoint.

1.1. Overview of the conducted work and prior literature

The scope of my work is to present an **initial overview** of the **context** of electricity markets and the **Power System**, subsequently moving to the **collection** of all the **relevant data** to analyse the Production Units that operate in

electricity markets, with a special attention to the aforementioned Market for Ancillary Services. I then move on to the **selection** of a set of **117 Production Units** operating on MSD, studying their *macro-behaviour* across the electricity markets MGP, MI and MSD.
Eventually, I decided to restrict the domain of the analyses to the three-year period 2017 to 2019, **focusing on Northern Italy**, where the greatest portion of energy exchanges happen. The principal target variable of my work will be the specific service denoted as *"Gradino 1"* (**GR1**) on MSD ex-ante, which translates to "First Step" and it is associated to a request from the Production Unit to increase (OFF type) or decrease (BID type) the amount of energy to be produced.
The Italian market for ancillary services was previously analysed in [1], [2] and [3], each time with a specific focus on one single topic, such as the event denoted *opposite call* in [1] or the prediction of the acceptance of bids by the TSO Terna in [3]. This work has the purpose to built on the existing literature, providing the **first *wide-ranging* analysis** of the Italian electricity markets to our knowledge, posing a particular attention to the offer profiles submitted on MSD by the PUs operating in Northern Italy.

2. Data collection process

The first achievement of this work was the construction of a set of massive datasets, accounting for all the relevant features to our analyses. This was done with the active support of RSE and eng. Filippo Bovera, who helped me defining five macro-classes of variables. All the data are publicly available, and were mainly retrieved from [5] and [6].
The main areas of interest are addressed below:

- **Baseline Data**:
  A set of calendar variables and other useful features, such as the day and hour of each bid, the day of the week and a Boolean variable to flag each festivity.
- **Markets' Data**:
  Comprise all the bids submitted on the electricity markets MGP, MI and MSD in the years 2017 to 2019, across all Italian zones.
- **Production Units' Data**:
  A dataset containing information on 117 selected PUs, comprehending their technology, operator, installed capacity and voltage level of the connection to the Power Grid. The units were chosen from all the available ones, by filtering for those active in the bidding zone `NORD` during the three years under consideration.
- **Structural Data**:
  Data describing characteristics of the structure of the energy system, including the forecasted load and generation, the cumulative water reservoir in basins used by hydroelectric plants and the scheduled commercial exchanges, both with foreign countries and between Italian zones.
- **Exogenous Data**:
  I have grouped here data extraneous to the electricity markets, but possibly correlated to it. This group comprehends weather data (including average temperature in the day, wind speed and pressure), together with the spot price of natural gas on the respective Day-Ahead market.

3. Clustering the Production Units in Northern Italy

As anticipated in the introduction, this work has the primary scope to provide a **wide-ranging analysis** of the **Ancillary Services Market**, with the final aim being that of **interpreting** and **predicting** the bids on MSD GR1. To this extent, an initial **visual analysis** of the offer curves presented by the 117 PUs in our dataset highlighted major differences between the various power plants. Indeed, some units presented **extremely variable bids**, trying to adapt their offers to the price of electricity on the Day-Ahead Market, while other units submitted **constant bids for extended periods of time**. This quite evident difference in behaviour suggests that not all the units eligible to take part in MSD are equally interested to place competitive bids in it, at least at every hour. As a consequence, I decided to perform a **clustering analysis** of the units in the dataset, segmenting the power plants on the basis of their ***macro-behaviour*** across all the electricity markets.
To do that, I tracked the following variables:

- **Equivalent Operating Hours of Production**, in the years 2017 to 2019;
- **Total Net Income** on the three-year period, across the markets MGP, MI and

MSD. Data were weighted by dividing for the Installed Capacity of the PU, thus measured in €/MW;

- **Earnings from Day-Ahead Market (MGP)**, considering only OFF bids and dividing this value by the Installed Capacity of the PU [€/MW];
- **Intra-Day Market Total Expenses from BID bids**, divided by the Installed Capacity of the PU [€/MW];
- **Intra-Day Market Total Earnings from OFF bids**, divided by the Installed Capacity of the PU [€/MW];
- **Expenses from Ancillary Services Market - BID bids**, divided by the Installed Capacity of the PU [€/MW];
- **Earnings from Ancillary Services Market - OFF bids**, divided by the Installed Capacity of the PU [€/MW].

To perform the analysis, I decided to use the **algorithm K-Means**[1], which is one of the most established tools in unsupervised machine learning. This said, since the underlying setting is quite complex, it was necessary to **refine** and further interpret the results of the algorithm, by looking at the **offer profiles on MSD** of the units in each identified cluster, as well as their technology and operator.

After the refinement of the K-Means results, I managed to identify **eight** different **well-defined clusters** of Production Units, each characterized by a unique behaviour on the electricity markets and having units placing similar bids on MSD. The identified clusters are briefly presented below, posing particular attention to their strategies on the market MSD[2], which is the main purpose of this work.

3.1. Cluster of thermoelectric PUs from Enipower

It is a set of **nine CCGT power plants** from the operator **Enipower**, which have extremely **high values** for the **Equivalent Operating Hours** of Production, and report **great revenues** from MSD OFF bids. Analysing the offer curves from this cluster, I found that these PUs present bid profiles on MSD that are extremely close one another. Furthermore, the bids from this cluster have a really **high variability** and are updated almost on a hourly basis, **following** the trend of the zonal price of electricity on the **Day-Ahead Market** (MGP).

This makes this cluster one of the most interesting to be analysed in greater details, and I have fit with incredibly accurate results a Random Forest model to predict its MSD GR1 bids, of both upward and downward type.

3.2. Cluster of dispatchable hydroelectric PUs from ENEL

This group comprehends a set of **17 hydroelectric power plants** of *dispatchable* type, a production technology that indicates units operating with water basins and dams, excluding all the Pumped-Storage hydroelectric ones. These units belong to the operator ENEL, report **almost no revenues** from the **Ancillary Services Market** (MSD) and present quite low values of Equivalent Operating Hours of production. However, they appear to have a lot of accepted bids on the Intra-Day market (MI).

Looking more in detail at their offers on MSD, we notice that these units seem to be **not-interested** in taking part to this market, since they all submit constant BID offers at the value 0 €/MWh, for almost the entirety of our time span. Regarding OFF offers, they present more variability than BID ones, but still remain constant for many consecutive weeks.

Indeed, my analysis identified that the **operator ENEL** adopts the **same pricing strategy** across most of its units, with a common baseline value from which the units deviate only on the basis of some **auto-regressive variables** that are unit-specific, such as the programmed production after the market MI or the amount of water stored in their basin.

3.3. Cluster of "ENEL to Alperia" hydroelectric PUs

This cluster comprehends a set of 4 units that **switched management** from the operator **ENEL** to the operator **Alperia**, during the period of our analysis, precisely in March 2019.

[1] This was not the first considered approach, since initially we tried to perform the clustering directly on the offer curves of the Production Units, in a functional way. However, the results of this procedure were quite unsatisfactory, due to the difficulty to define a powerful notion of distance in the space of MSD GR1 bids.

[2] I refer to the relative part of the thesis to their complete analysis, as well as a graphical visualisation of their bids on MSD, necessary to fully appreciate the presented topics but omitted in this summary for space constraints.

All the units in this group are geographically located in *Val d'Ultimo*, in South Tyrol. Looking at the bids of these units on MSD, we can see a **profound difference** between those submitted under the management of ENEL, which are quite close to the ones presented for the previous cluster, and those under the management of **Alperia**. In particular, under Alperia **BID bids** are **more variable** and are on average at a higher price than those from ENEL, effectively implying **better price competitiveness**.

3.4. Cluster of thermoelectric PUs from ENEL

This cluster comprehends a group of 11 PUs that belong to a total of **4 power plants** controlled by ENEL (*La Casella*, *Fusina*, *Porto Corsini* and *La Spezia*), including all the thermoelectric PUs by ENEL in our dataset. All the selected units have in common a very **high activity** in the **Intra-Day Market**, especially for bids of BID type, in an analogue way to what was already observed for hydroelectric units of this operator. Regarding MSD bids, those of **BID type** present **less variability** than OFF ones, and are generally constant for many months. On the opposite, OFF bids seem to adapt to the seasonal oscillations of the MGP price, even if they are not updated on a hourly basis.
Furthermore, by looking more in depth at the offers from this cluster, I discovered how the operator ENEL places **MSD GR1 bids** that are usually **constant on a daily basis**, from midnight to 11 P.M. of almost every day, **regardless** the **hourly oscillation** of the zonal price on MGP or the forecasted load and generation. This behaviour is quite a surprising one and differs significantly from that of ENEL's competitors. It also **appears** to be somehow "**sub-optimal**", due to the fact that at certain hours the upward bids on MSD result being quite close to the price of energy on the Day-Ahead Market. Furthermore, focusing only on **OFF bids**, I found that about 80% of them have **values that are multiple of 5**. This indicates with great likelihood a **human involvement in the process of bid definition**, with offer prices that are often rounded to the closest multiple of 5.

3.5. Cluster of thermoelectric PUs active on MSD-BID

This cluster comprehends six **thermoelectric plants of CCGT production technology**, belonging to various operators and including all the units that were most active in **MSD** for **BID types of offers**, according to the algorithm K-Means. The units selected by the clustering are those of *Leini*, *Livorno Ferraris*, *Torviscosa*, *Vado Ligure*, *Voghera* and *Tavazzano*, and reported the highest amount of money exchanged with the TSO Terna for MSD bids of BID type, in the period of our analysis. Geographically, the units are located in different parts of Northern Italy, but still present a **similar behaviour** on the electricity markets.
I decided to pose particular attention to this cluster, due to the peculiarity of MSD offers of BID type. Indeed, those offers are associated to a request made by the PU to "buy back" energy from Terna, and this is generally associated to the definition of **more complicated tactics** also on **prior markets**, that should take into account the possibility to reduce the working range on MSD. To address this issue, I fit a Random Forest model to predict and interpret downward bids on MSD, from the units in this cluster.

3.6. Cluster of thermoelectric PUs active on MSD-OFF

This cluster comprehends a set of six different Production Units (*Azotati*, *Cassano*, *Piacenza*, *Sermide*, *Turano Lodigiano* and *Turbigo*) that earned the greatest amount of money on MSD through bids of OFF type, according to the K-Means algorithm. All the units in this group are of **thermoelectric technology** and belong to various operators, with A2A being the most represented in the cluster.
In my analyses, I focused on the units from the **operator A2A** and conducted an in depth study of their offers on MSD. What I found is that these units present significant differences between OFF and BID types of bids, with the latter ones that are **mostly constant** throughout the whole time span of this analysis, fixed at a price that is about 33 €/MWh. This value is quite interesting for two reasons: on one side it implies a lack of interest from A2A to adjust its downward offers according to the MGP price. On the other side, though, the offered price is

quite high (especially if compared to the value 0 €/MWh of hydroelectric units from ENEL), therefore these offers end up being very competitive in certain periods of the year, when the zonal price on MGP is low.
Regarding **upward MSD OFF bids** from A2A's thermoelectric units, these seem to present a **much greater variability than BID ones**. The variability, however, is given by sudden "jumps" to extremely high values, which are usually set to 500€/MWh, and thus indicate a general will not to be accepted on MSD. This said, looking more closely at the OFF bids, we can notice that they are generally characterized by a **constant baseline during the majority of the days**, to which the bids deviate only for the "extreme" offers at very high prices. Moreover, similarly to the operator ENEL, this baseline is usually updated at midnight.

3.7. Cluster of pumped-storage hydro PUs from ENEL

This cluster concerns a group of 8 **pumped-storage hydroelectric power plants from ENEL**, that present similar behaviour for MSD bids, especially those of BID type.
It was originally identified by the K-Means algorithm, which grouped together a set of 5 units with the same technology and operator, to which I then decided to add also the units of *Bargi Centrale*, *Entracque Rovina* and *Fadalto*, in order to include all the pumped-storage hydroelectric units from the operator ENEL in a single group. This decision was taken after a manual analysis of the offers on MSD from these PUs, which identified how both BID and OFF bids presented common traits, such as the same variability and similar price values. Furthermore, all the units present a very **peculiar behaviour** around the month of **October 2018**, when they all change the **minimal value** of their BID offers from zero to the value 35 €/MWh, once again confirming that the operator ENEL shares his knowledge across all his units of the same technology.

3.8. Cluster of hydroelectric PUs from CVA

The operator **CVA - *Compagnia Valdostana delle Acque*** is a minor company that produces **renewable energy** through hydroelectric power stations, in the localized region of *Valle d'Aosta*. This operator does not have a particular economic relevance and only owns 4 power plants eligible on MSD, however, I believe that it is quite interesting to conclude this analysis by studying the **behaviour of a smaller company**. A graphical visualisation of MSD bids, identified that CVA adopts very *naive* strategies, with offers that are slightly different among the PUs, but often **constant in both directions** for many weeks, or even months. This said, there seems to be a **seasonal pattern** in the offer curves on MSD from CVA's units, related to the presence of "hollows" in the bids of BID type. These happens in correspondence to the **summer months** and we could possibly interpret this fact by considering that all the units in the cluster are of hydroelectric type and located in the Alps. This fact implies that these four PUs will have **lots of primary resources** available when the summer heat melts the surrounding glaciers, increasing considerably the amount of water in the rivers of *Valle d'Aosta*, thus explaining the identified tendency.

4. Random Forest analysis of MSD GR1 bids

The last part of my work was dedicated to the **creation of prediction models** for some of the identified clusters. In particular, I chose to focus on the units from **Enipower**, as well the cluster of **thermoelectric PUs active with MSD bids of BID type**, since they are the most interesting ones to be analysed for the specific GR1 service on the Ancillary Services Market. The algorithm adopted for this analysis is called **Random Forests**, and was chosen because it combines great predictive performances and a high degree of interpretability. The algorithm was tuned mainly with the help of [4] and managed to achieve incredible accuracy results in all the models fitted.
The **target variable** is the price of the MSD GR1 offer for a specific hour in the time span 2017-2019. Regarding the predictors, they are chosen among the variables collected at the beginning of the analyses, and are all related to the same hour as the target variable. Every predictor is publicly **available** to all the operators of electricity markets **before** the actual observation of the **MSD GR1 prices**, to ensure meaningful results. Some variables are referred to the

specific Production Unit that is placing the bid on MSD, such as the programmed production profile after MI (`MI_PROFILE`) and in that case they are always normalized by the installed capacity of the PU, in order to obtain comparable values among different units in the same cluster.

4.1. Cluster of Enipower, prediction of MSD bids of BID type

I will begin with the study of **BID offers on MSD GR1** from the cluster of thermoelectric units of Enipower. To analyse them, I fit a Random Forest Random Input model, with a total of 50 trees. For this model, the Out Of Bag cross-validation error is steadily decreasing after the first few iterations, eventually reaching the extremely low value of 0.51 $(€/\text{MWh})^2$. Furthermore, the **percentage of variability** explained by the model is more than acceptable, being equal to 99.31, meaning that the model is performing extremely well on the available data.

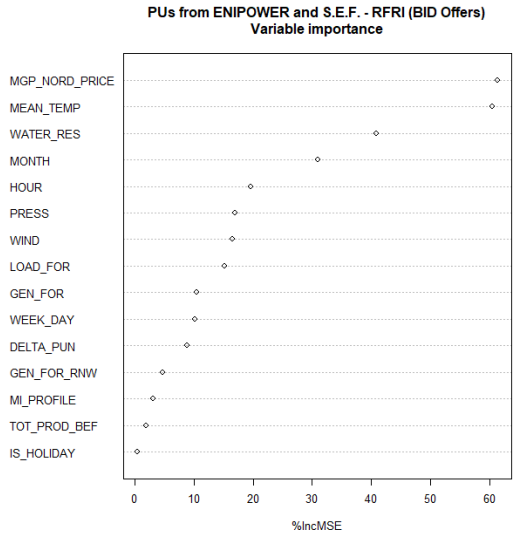

Figure 1: Cluster of Thermoelectric PUs from Enipower, Random Forest algorithm for MSD GR1 **BID Offers**: Variable Importance.

Moving on to the interpretation of the results of the algorithm, we can observe the **ranking of the importance** of the variables composing the model from Figure 1. This picture shows how the units within this cluster place their downward bids on MSD considering mainly the **price of electricity** on the **Day-Ahead Market**, adapting their bids by looking at many indicators of seasonality. Among those, we find the **Mean Temperature**, the variable indicating the **Water Reservoir** in artificial basins used by hydroelectric power plants, and the two variables for the **hour and month** of the considered bid. Moreover, it is also quite interesting to notice that the units in this cluster **do not seem to adapt their BID offers** according to their **percentage of work after MI**, since the variable `MI_PROFILE` has low importance. This is for sure a peculiarity of this cluster of units, and it is a direct consequence of the decision from the operator Enipower to place **almost identical bids** for all his units. This said, the units in the cluster are characterized by the **highest values for Equivalent Operating Hours**, meaning that they will almost always be active as a result of the markets MGP and MI.
Furthermore, it is interesting to notice how the two variables **Load Forecast** and **Generation Forecast** do not appear to be much useful in the definition of the final price of MSD GR1 bids of BID type.

Focusing on the two most important variables in the model, I have reported a visualization of their **marginal effects**, via Partial Dependence Plots, in Figure 2. From the graph on the left side of the picture, we can notice that the the **price of the bids tend to increase** with the **zonal price of electricity on MGP**, meaning that the operator Enipower tends to increase the prices of its BID offers, when the zonal price of electricity on the Day-Ahead Market grows. This is effectively a direct consequence of the fact that the operator tends to keep a **somewhat constant price delta** between the price of electricity on MGP and its downward bids, effectively encouraging the TSO Terna to accept its BID bids when the price of electricity is high. Moreover, from the plot reported on the rightmost part of Figure 2, we can see that the price of bids presented by Enipower seems to **decrease with the mean temperature**. This fact is particularly true if we consider the colder days in our time span, when we know that the price of electricity is generally higher, due to an expected increase in demand. Quite interestingly, though, we do not observe a similar pattern for the hottest days of the observed three-years period.

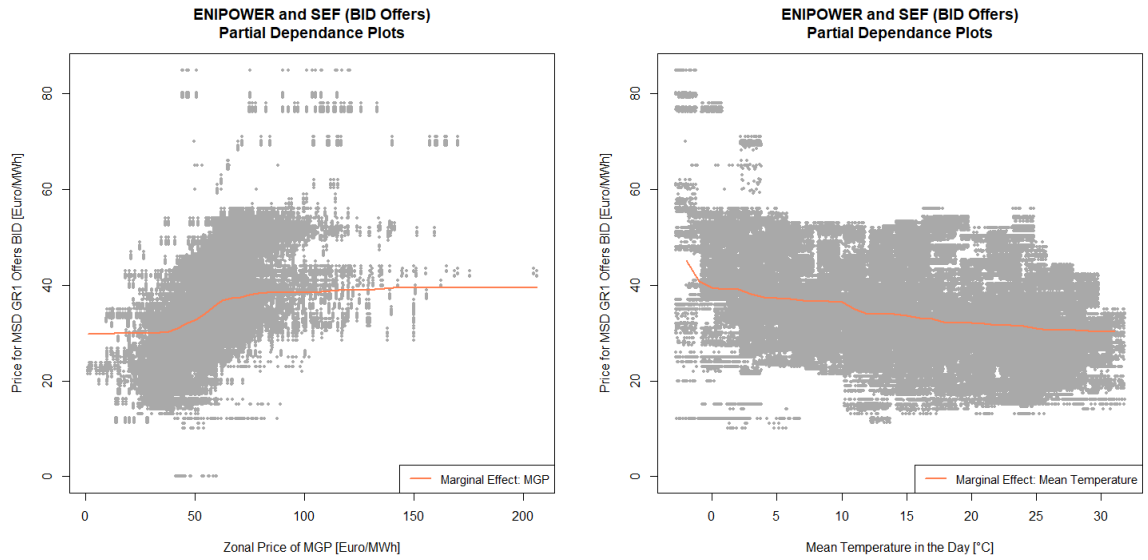

Figure 2: Cluster of Thermoelectric PUs from Enipower, prediction of MSD **BID bids**: visualization of marginal effects via Partial Dependence Plots for the variables **Zonal Price on MGP** (left) and **Mean Temperature** (right).

4.2. Cluster of Enipower, prediction of MSD bids of OFF type

Keeping the attention on the cluster of thermoelectric units of Enipower, I found **analogue results** for MSD bids of OFF type. Even in this case, I have decided to fit a Random Forest Random Input model, with a total of 50 trees. The OOB Mean Squared Error is decreasing with the number of trees, eventually levelling after the first 35 iterations. The final model presents a value for the **OOB cross-validation error** of 14.73 $(€/\text{MWh})^2$, together with a **percentage of variability explained by the model** equal to 97.61%. These values are slightly worse than those of the model for BID offers, but this is mostly due to the fact that **OFF bids have a wider range than BID ones**, and thus we can consider the model to be highly accurate even in this second case.

Looking at variable importance for the model with OFF offers as a target, reported in Figure 3, we can observe that the highest ranked variables are the same as in the previous case, meaning that the operator is somewhat consistent for both types of bids.

To conclude this section, in Figure 4 I have reported the visualization of the **marginal effects for the two most important variables** in the model. From it, we can observe how the **Mean Temperature** influences the bids in quite a similar way than the previous case, since it is appears to be particularly relevant in the coldest days of the time span. Moreover, the price of upward MSD GR1 bids tends to increase with the **MGP zonal price**, in an analogue way to the BID case, meaning that the operator tends to keep his offers within a defined range from the price of energy on the Day-Ahead Market.

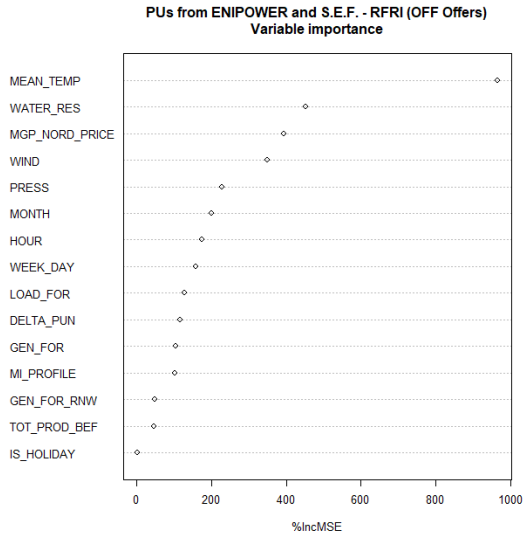

Figure 3: Cluster of Thermoelectric PUs from Enipower, Random Forest algorithm for MSD GR1 **OFF Offers**: Variable Importance.

Figure 4: Cluster of Thermoelectric PUs from Enipower, prediction of MSD **OFF bids**: visualization of marginal effects via Partial Dependence Plots for the variables **Zonal Price on MGP** (left) and **Mean Temperature** (right).

4.3. Cluster of "Thermoelectric PUs active on MSD - BID", prediction of MSD bids of BID type

In the conclusion of my work, I predict and interpret the bids from the cluster of **Thermoelectric Production Units active with BID offers on MSD GR1**. Eventually, I have decided to only fit the model for the **prediction of BID offers** for this cluster, focusing on the five Production Units of *Leini*, *Livorno Ferraris*, *Torviscosa*, *Voghera* and *Tavazzano*.
I proceeded to fit the Random Forest Random Input algorithm for this specific case, setting the number of trees in the forest to 70. In Figure 5 I have reported the **Out Of Bag error** as a function of the number of trees in the forest. From the graph, we can observe that the OOB error is decreasing in a smooth way, eventually reaching the value of 16.80 $(€/\text{MWh})^2$. Regarding the **percentage of variance explained by the model**, we find that it is equal to 90.5%, a value that is lower than previous cases, but still incredibly good, considering that we are dealing with units from three different operators.
Moving on to the **study of Variable Importance** for the model under consideration, we find that the **highest ranked variables are similar to those of the cluster of Enipower**, with the addition of the one indicating the **Equivalent Hours of Production**

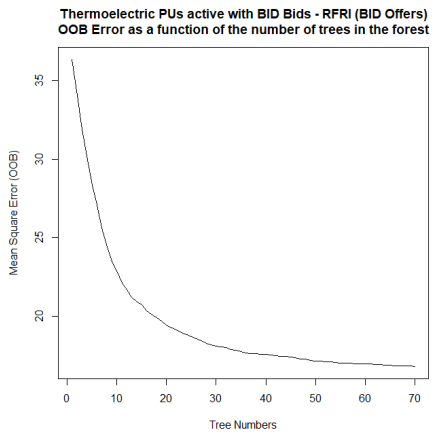

Figure 5: Cluster of Thermoelectric PUs active with BID bids, learning curve of the Random Forest algorithm for MSD GR1 **BID Offers** (OOB error as a function of trees in the forest).

on the previous day (`TOT_PROD_BEF`). Indeed, the Equivalent Hours of Production end up being the most important variable in the cluster, causing a worsening of the error of about 100%, when it is permuted within the observations in the OOB sample. Soon after we find the two variables that dominated the previous models, namely the **Zonal Price of electricity** on MGP and the **Mean Temperature**.
Moreover, in this case it is quite important also the variable `MI_PROFILE`, related to the production percentage of the units as a result of the

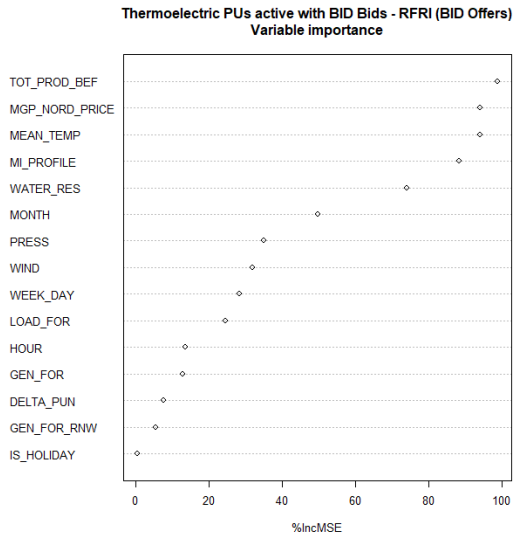

Figure 6: Cluster of Thermoelectric PUs active with BID bids, Random Forest algorithm for MSD GR1 **BID Offers**: Variable Importance.

Intra-Day Market (MI).
Regarding Partial Dependence Plots, they show how the bid price tend to increase with the **zonal price on MGP**, exactly as for the operator Enipower. Furthermore, even in this case, we can observe a prominent effect of the variable **Mean Temperature**, with offer prices on MSD GR1 - BID that decrease, on average, as the climate gets hotter, even though in this case there are no particular peaks in colder days.

5. Future Analyses

The conducted work lays the basis for a set of additional interesting analyses. Indeed, many straightforward extensions are possible, starting from the consideration of also other Italian bidding zones in the clustering.
Moreover, it would be quite interesting to **expand the temporal horizon of these analyses**, both to the **Covid-19 pandemic** months (which sharply decreased the demand of energy in Italy) and to the month of October 2021, when the price of electricity abruptly increased.
Another possible extension of my work on MSD, would be the **definition of more complex models, accounting for other ancillary services** rather than only the GR1. In fact, a more refined model would comprehend also the service denoted as "AS" - *Accensione/Spegnimento* in our dataset, which stands for Switch On/Off[3].
Finally, one last interesting topic to study would be the **acceptance of bids on MSD by the TSO Terna**, since during my research work I have found two interesting facts in this direction and since I believe it has **crucial importance for future analyses**. This subject was already partly studied in [3], and I decided to dedicate a separate section to this topic in my work. The first issue is the apparent existence of a **merit-order** procedure for the acceptation of bids on MSD in each specific **Grid Supply Point**. Indeed, if this hypothesis was confirmed, it would imply the existence of **segments of units** that are effectively in **close competition** to produce on the **highly remunerative market MSD**.
The second discovery is related to a **sudden change** in the acceptance mechanics by Terna for **hydroelectric units**, which **stopped being accepted on MSD** after February 13^{th}, 2019, even if they left unchanged their bids from previous months. Unfortunately, our analysis only consider the years 2017 to 2019 and the identified tendency should be studied more in depth in recent times, assessing if it is still in place nowadays. Nevertheless, this appears to be an evident change in behaviour by Terna.

6. Conclusions

The liberalization of electricity markets gave birth to extremely competitive environments, where **operators** can **bid** in **strategic ways**, in order to maximise their revenues from *all* the units they control.
Indeed, during my work I found out that the great majority of Production Units powered by **Renewable Energy Sources**, especially those with **limited** installed capacity, tend to submit non-competitive bids on MSD. In fact, they generally offer at constant prices for many weeks, or even months and seem effectively **uninterested in taking part in MSD**. On the opposite, **thermoelectric power plants are more "ac-**

[3]Indeed, the units from the operator Enipower, which seem to place the best possible GR1 bids, have almost no accepted offers of the AS type. In contrast, the units from ENEL and A2A seem to begin their production only on MSD quite often, as a result of accepted upward AS bids. If confirmed, this hypothesis may indicate a profound difference in the approach of the units to the market MSD, possibly driven by the specific technological characteristics of each power plant.

tive" on the market, and consider MSD as a **potential** way to cope with their limited revenues from the markets that are based on a merit order, where the price of electrical energy is lower. In general, though, the **units eligible for MSD** place their bids only **considering few variables**, that are generally limited to the price of electrical energy on MGP, seasonal variables, and some **unit-specific conditions**, such as the production profile after the market MI and, for hydroelectric Production Units, the amount of water in their basin.
Focusing on **thermoelectric units**, I found major differences among the analysed operators. For instance, the **company Enipower** places the **same bids** across **all the units** it controls, with a high degree of **variability** and bids that change on a hourly basis, but without taking too much care of the working range after the Intra-Day Market of its Production Units. In contrast, the **operators A2A and ENEL** seem to differentiate more their bids across the units they control, but they update them less often than the cluster from Enipower. Specifically, the operator **ENEL places its bids on a daily basis** (i.e. constant prices for 24 hours straight), thus disregarding completely the forecasted load/generation and the consequent fluctuations of the MGP and MI prices. For two of the identified clusters, I was able to **predict with incredible accuracy** the submitted bids, thanks to the algorithm **Random Forest**.

To conclude, most of the offer curves for the **service GR1 on MSD** appear to be **somewhat perfectible**, with many plants that do not care to bid at competitive prices at every hour. This is probably due to the **difficulty** of the operators to **predict** when there will be an **effective need** for their service on MSD. Thereby, I suggest that future research should focus on the prediction of the need for each ancillary service at every hour, also **explaining the acceptation dynamics** on MSD from the Transmission System Operator Terna.

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