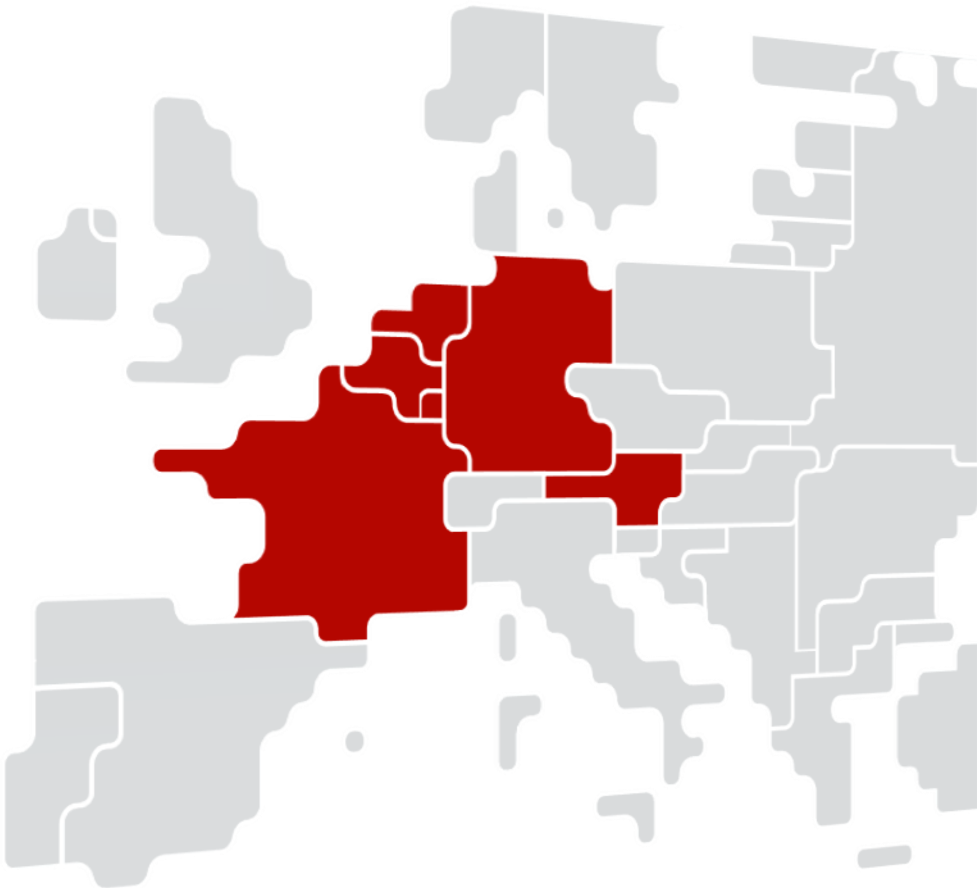
CWE

GSK Monitoring Study



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1. DOCUMENT HISTORY AND STATUS

Date	Summary of Changes	Version	By
20220406	Final version of report for MPs (Due to confidentiality provisions in national legislations, some sensitive information has been blackened.)	1.0	CWE TSOs

Content

2. INTRODUCTION

In May 2015, the day ahead flow-based capacity calculation and market coupling in the Central West European region (CWE) went live. The approval by the CWE National Regulatory Authorities (NRA) was conditional on certain requirements, including post go-live studies. These requirements are described in the NRA Common Position Paper on Flow-based market coupling (published in March 2015, and updated in 2018), and aimed to investigate several main aspects which could lead to an improvement of the flow-based market coupling methodology.

Since May 2015, the CWE Transmission System Operators (TSOs) submitted several high level proposals and action plans to ensure most of the requirements could be delivered according to NRA expectations. This report, hereafter named Generation Shift Key (GSK) monitoring study, focuses on the evaluation of the accuracy of the GSK, one of the main inputs of capacity calculation, used in the CWE region. Due to the study setup also valuable information about the D2CF quality was gained. This report fulfils the NRA condition to perform the GSK monitoring study.

The approach applied in this study is to compare the forecasted power plant schedules obtained by using the GSK with the realized schedules of the power plants.at the nodal level. Assessments are performed on different elements, such as comparing TSOs, fuel types, and violations of the minimum and maximum power infeed of power plants.

The report has the following structure:

- First in section 3, the definition of GSK and the different strategies currently implemented by CWE TSOs is described;
- In section 4, the methodology of this study as well as the inputs and tools that have been developed and used to perform this extensive study are explained;
- In section 5, the results of the analyses performed are given; and
- Last in section 6, general conclusions and an assessment of possibilities for improvements are given.

3. GENERATION SHIFT KEYS

The Generation Shift Key (GSK) defines how a change in net position is mapped to the generating units in a bidding area. Therefore, it contains the relation between the change in net position of the market area and the change in output of every generating unit inside the same market area. The working of the GSK is also included in paragraph 4.1.7 of the CWE FB DA MC approval package.

Flow-Based capacity calculation aims to deliver the best forecast of the impact on Critical Branches of a net position change, taking into account the operational feasibility of the reference production program, projected market impact on units and market/system risk assessment. Due to convexity prerequisite of the Flow Based domain, the GSK must be linear. From this limitation it follows that errors cannot be prevented as real power plants have to keep technical limits e.g. a minimum and maximum generation that are non-linear.

Every TSO determines a GSK for its control area taking into account the characteristics of its network. In general, the GSK includes power plants that are market driven and that are flexible in changing the electrical power output. This includes the following types of power plants: gas/oil, hydro, pumped-storage and hard-coal. TSOs will additionally use fewer flexible units, e.g. nuclear units, if they do not have sufficient flexible generation for matching maximum import or export program or if they want to moderate the impact of flexible units. Redispatch or balancing power are not modelled via GSK. Please note that renewable energy production units sharing nodes with power plants represented in the GSK may cause unforeseen variances. The GSK values can vary for every hour and are given in dimension-less units. (A value of 0.05 for one unit means that 5% of the change of the net position of the bidding zone will be realized by this unit.)

Individual GSKs of control areas are merged if they are in the same bidding zone. The GSKs of the four German TSOs are therefore merged to one German GSK via the usage of Generation Share Keys which are described in chapter 4.3.

It is very important to note that the GSKs influence the results of the capacity calculation in two ways. Firstly, it determines the GSK shift of each individual power plant when the dataset is shifted to another net position. Secondly, the GSKs together with the grid topology determine the PTDFs. This study focuses on the first part. An evaluation of the quality of PTDFs resulting from the GSKs is out of scope for this study.

In the next sections, the GSK approach is described per bidding zone and TSO.

3.1. Austrian GSK (APG)

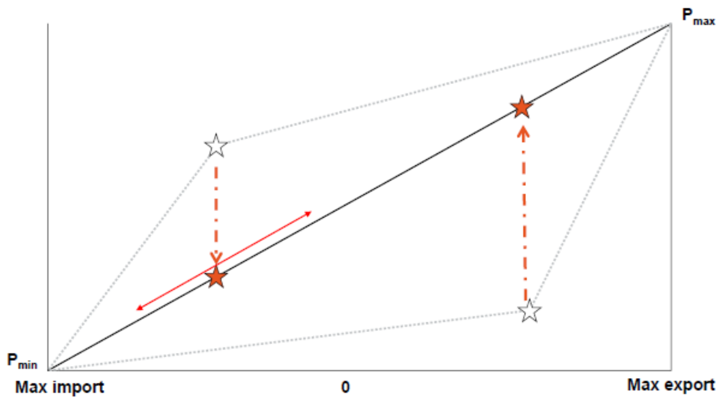
With the split of the German-Austrian bidding zone in October 2018, Austria became an independent bidding zone and the Austrian power plants were no longer part of the German GSK. APG therefore created an independent Austrian GSK, and the German Generation Share Keys were also adapted to take this bidding zone split into account.

APG is considering only market driven power plants in the GSK file. The selection was done with statistical analysis of the market behaviour of the power plants. In this analysis, only pump storage and

thermal units were considered. Power plants which generate base load (run of river power plants) are not considered in the GSK file, except those power plants with the ability of daily water storage.
The individual GSK factor is proportional to the maximum power output of the unit. Due to the nature of the considered power plant units, a distinction between peak and off-peak hours is not foreseen.
Depending on the future developments in the Core CCR, this GSK selection might be changed to a more dynamic approach. The investigation for this approach was started and no conclusion can been drawn so far as this will be done in the course of the Core Day-ahead implementation.
The list of relevant power plants is updated regularly in order to consider maintenance or outages.

3.2. Belgian GSK (Elia)

Elia uses in its GSK all flexible and controllable production units which are available inside the Elia grid (whether they are running or not). Units unavailable due to outage or maintenance are not included.
The GSK is tuned in such a way that for high levels of import into the Belgian hub all units are, at the same time, either at 0 MW or at Pmin (minimum infeed by GSK power plant) (including a margin for reserves) depending on whether the units have to run or not (specifically for instance for delivery of primary or secondary reserves). For high levels of export from the Belgian hub all units are at Pmax (maximum infeed by GSK power plant) (including a margin for reserves) at the same time.
For the Nuclear units Pmin is equal to Pmax. For pumped storage plants Pmin is set equal to – Pmax.
After producing the GSK, Elia will adjust production levels in all 24 hour D2CF to match the linearized level of production to the ex-change programs of the reference day as illustrated in the following figure.



3-1: Belgian GSK

3.3. Dutch GSK (TenneT TSO B.V.):

TenneT B.V. will dispatch the main generators in such a way as to avoid extensive and not realistic under- and overloading of the units for extreme import or export scenarios.
The GSK for the TenneT B.V. control area contains all units with a maximum infeed above 60 MW. Unavailability due to outages are considered in the GSK.
All GSK units (including available GSK units with no production in the D2CF file) are redispatched pro rata on the basis of predefined maximum and minimum production levels for each active unit. The total production level remains the same.

The maximum production level is the contribution of the unit in a predefined extreme maximum production scenario. The minimum production level is the contribution of the unit in a predefined extreme minimum production scenario. Base-load units will have a smaller difference between their maximum and minimum production levels than start-stop units.
With Pi0 being the initial MW dispatch of unit i, and Pi1 being the new dispatch of unit i after the redispatch, then

$$P_{i1} = Pmin_i + (Pmax_i - Pmin_i)\frac{(\sum_k P_{k0} - \sum_k Pmin_k)}{(\sum_k Pmax_k - \sum_k Pmin_k)} \text{ (eq. 1)}$$

The linear GSK method also provides new GSK values for all active GSK units. This is also calculated on the basis of the predefined maximum and minimum production levels:

$$GSK_i = \frac{Pmax_i - Pmin_i}{\sum_k Pmax_k - \sum_k Pmin_k} \text{ (eq. 2)}$$

The 24-hour D2CF is adjusted, as such that the net position of the Netherlands is mapped to the generators in accordance to eq.1.

The GSK is directly adjusted in case of new power plants. TTN includes the outage information of generators daily in the GSK, which is based on the information sent by Market Parties.

3.4. French GSK (RTE)

The French GSK is composed of all the units connected to RTE’s 225 and 400 kV network.
The variation of the generation pattern inside the GSK is the following: all the units which are in operations in the base case will follow the change of the French net position on a pro-rata basis. That means, if for instance one unit is representing n% of the total generation on the French grid, n% of the shift of the French net position will be attributed to this unit.
This is a so-called “Country GSK” or “Proportional GSK”.

3.5. German GSK

The GSK of the German Bidding Zone consists of the individual GSK factors of the four German TSOs that are combined via the Generation Share Key (GShK).

The Generation Share Key differentiates between peak- and off-peak hours as well as weekdays and weekend days. For bank holidays or special days, the weekend values will be used.

Following formula describes the dependencies.

$$GSK_{final,TSO} = GShK_{TSO} * GSKfactor_{TSO}$$

The Generation Share Key for the individual TSOs is calculated according to the reported available market driven power plant potential of each TSO divided by the sum of market driven power plant potential in the bidding zone.

$$GShK_{TSO} = \frac{Available\ power\ in\ control\ area\ of\ TSO}{\sum_{k=1}^{4} Available\ power\ in\ control\ area\ of\ TSO_k}$$

Therefore, any changes of the available market driven power plant potential of each German TSO impact the German Share Key and thus the final GSKs of the other German control areas. For example, the potential can differ for a winter and summer situation. During a certain period, the German Share Keys are considered as constant until the next update.

For German TSOs, only market driven power plants are part of the GSK as they participate actively in the market and change the infeed more sensitively based on market prices. For example, power plants that are not allowed to participate in the market like grid reserve or baseload power plants like nuclear and lignite power plants which are constantly running when technically available don't fulfil this requirement and are not considered as a GSK power plant. Besides that, German TSOs do not include any renewable generation units (wind, photovoltaic or run-of-river power), since their infeed is less controllable and doesn't react on market prices.
Since April 2019 Amprion TTG and TNG use the same formula to calculate the GSK factors of the aforementioned power plants:

$$GSKfactor_i = \frac{P_{max,i} - P_{min,i}}{\sum_1^n (P_{max,i} - P_{min,i})}$$

The character (n) describes the number of all power plants in a TSO´s control area considered as GSK relevant for the dedicated timeframe (peak/off-peak; weekday/weekend).

In the next subsections, the GSK approach is described per German TSO.

3.5.1 Amprion GSK

Amprion established a regular process in order to keep the GSK as close as possible to the reality. In this process Amprion checks for example whether there are new power plants in the grid or whether there is a block out of service. According to these changes in the grid Amprion updates its GSK. In general, Amprion only considers middle and peak load power plants as GSK relevant. With other words, basic load power plants like nuclear and lignite power plants are excluded to be a GSK relevant node. From this it follows that Amprion only takes the following types of power plants: hard coal, gas and hydro power plants. In the view of Amprion only these types of power plants are taking part of changes in the production.

During the timeframe of the study the GSK methodology of Amprion was updated. With the former methodology each power plant considered by Amprion as GSK relevant acquired the same GSK factor. Therefore, changes of the German net position, modelled in the control area of Amprion via GShK, were distributed equally among all relevant power plants within the Amprion control area, independent from the available power of a single power plant. This caused bigger GSK shifts and increased errors in regions where a high number of smaller units were modelled. In addition, the distribution of Netposition shift by an almost static German Share Key over the year was not seen as suitable from operational experience as some power plants become temporary non available during the summer period due to e.g. maintenance.

Therefore, this approach was updated by Amprion in April 2019 to harmonize and to align it with the methodology of the other German TSOs and to improve the quality of the GSK.

To determine the GSK relevance of a single power plant, Amprion performs an ex-post analysis of historical data and considers the latest developments. Only power plants that are frequently in operation and directly connected to the transmission grid are taken into account.

With the update of the GSK, Amprion only considers hard coal and gas-fired power plants as relevant for the GSK. Hydro power plants were removed from Amprion’s GSK.

3.5.2 TransnetBW

Besides the general methods described in the beginning of chapter 3.5 (deciding based on fuel type if a power plant can be included in the GSK) TransnetBW takes into account the power plant availability and the most recent available information at the time when the individual GSK-file is generated to determine GSK relevant generation units.

3.5.3 TenneT Germany

In order to determine the TTG GSK, a statistical analysis on the behaviour of the non-nuclear power plants in the TTG control area has been made with the target to characterize the units.
Only those power plants, which are characterized as market-driven, are put in the GSK. This list is updated regularly.

3.5.4 50Hertz

50Hertz also provides GSK files for the CWE FB market coupling which improves the quality of the German GSK. During the monitored timeframe pumped-storage and black coal power plants of 50 Hertz were part of the GSK. Due to the small number of GSK relevant power plants and the distance to CWE CNECs, the actual impact is smaller than by the other German GSK power plants.

However, as part of the German Sharing Key, the 50Hertz forecast influences the final GSK factors of all German TSOs.

Note: The GSK nodes of 50 Hertz are not always the nodes of the corresponding power plant. This needs to be taken into consideration while analysing the KPIs of this study.

A detailed assessment of 50Hertz` input data is not in scope of this study.

4. METHODOLOGY OF THE GSK MONITORING STUDY

4.1. Input data

With the split of the German-Austrian bidding zone in October 2018, Austria and Germany became separate bidding zones. Therefore, the Austrian power plants are no longer part of the German GSK (which they were before the split), but are since part of an independent Austrian GSK. Also, the Generation Share Keys have been adapted to take the bidding zone split into account. To obtain meaningful results for the future, this study covers a one year timeframe beginning after the DE/AT split. It includes data from 01/10/2018 until 30/09/2019.

Various input data has been collected and analysed with the Logarithmo monitoring tool for this study. It includes:

- Merged GSKs as provided by TSOs as input to the capacity calculation process
- Real GSKs as calculated by the FB system
- Characteristics of power plants (node name, Pmax, Pmin, geo coordinates, fuel type, control area)
- D2CF IGMs and CGMs as used for the capacity calculation process
- DACF IGMs and CGMs used as input for the coordinated Day-ahead security analysis process before application of remedial actions or redispatch
- Snapshot IGMs and CGMs representing the network state in real time
- Reference programs including the net positions of the different hubs in the different grid models

The analysis of data will be performed for all timestamps for which all input data has successfully been retrieved resulting in an adequate data sample of 7951 timestamps.
In this study data for more than 400 grid nodes in the CWE network is analysed. The majority of nodes are GSK nodes. The rest of the nodes is analysed to identify possible modelling problems in the grid models.

4.2. GSK merging process accounting for generator availability

During the FB process, each TSO creates an individual GSK for its control area. All individual GSKs are merged to a single file, the merged GSK.

The merged GSK for a specific business day contains either all individual GSK factors of the bidding zone or the used GSK strategy (e.g. give each power plant included in the grid model an equal share). The GSK values included in the merged GSK are not necessarily the values used during the FB computation. It's a starting point for a pre-processing step resulting in the final GSK values, also called real GSK.

Before the GSK is used for the capacity calculation, the merged GSK is matched with the latest available information of the D-2 grid models including the actual availability of power plants. For example, if a TSO appoints a power plant as GSK relevant with a certain factor, but this power plant cannot be found within the grid model or is not connected to the grid, it is removed from the GSK for the FB calculation and its share is allocated over the remaining power plants of its bidding zone. Hereby, incorrect assumptions will be corrected dynamically, and it is ensured that all GSK factors of each bidding zone sum up to one which is required to perform the shifting. For TSOs using an automatic GSK strategy as e.g. Country GSK, the real GSK contains the computed values for all determined GSK nodes of this strategy.

4.3. German Share Key values during the study period

Due to an update of the GSK relevance of some power plants within the control area of Amprion, the German Share Key was updated during the timeframe of the study.

<u>01.10.2018 - 17.4.2019</u>

	weekdays peak	weekdays off-peak	weekend peak	weekend off-peak
Amprion	53,2%	48,7%	51,3%	46,4%
TransnetBW	17,0%	15,8%	16,5%	16,7%
Tennet Germany	18,9%	20,4%	22,3%	22,6%
50Hertz	10,9%	15,1%	9,9%	14,3%

<u>18.04.2019 - 31.9.2019 (summer period)</u>

	weekdays peak	weekdays off-peak	weekend peak	weekend off-peak
Amprion	39,4%	34,4%	22,0%	20,6%
TransnetBW	20,7%	20,2%	26,4%	24,7%
Tennet Germany	25,3%	26,1%	35,7%	33,5%
50Hertz	14,6%	19,3%	15,9%	21,2%

Furthermore, an adapted winter German share key was applied afterwards, but not part of the scope of this study.

<u>01.10.2019 – 1.4.2020 (winter period)</u>

	weekdays peak	weekdays off-peak	weekend peak	weekend off-peak
Amprion	41,3%	36,2%	41,0%	31,0%
TransnetBW	20,0%	19,6%	20,0%	21,5%
Tennet Germany	24,5%	25,4%	27,0%	29,1%
50Hertz	14,2%	18,8%	12,0%	18,4%

The changed German Share Key impacts the distribution of possible net position shifts within the German bidding zone. The pattern for a weekday peak GSK of Germany before and after the update can be found below:

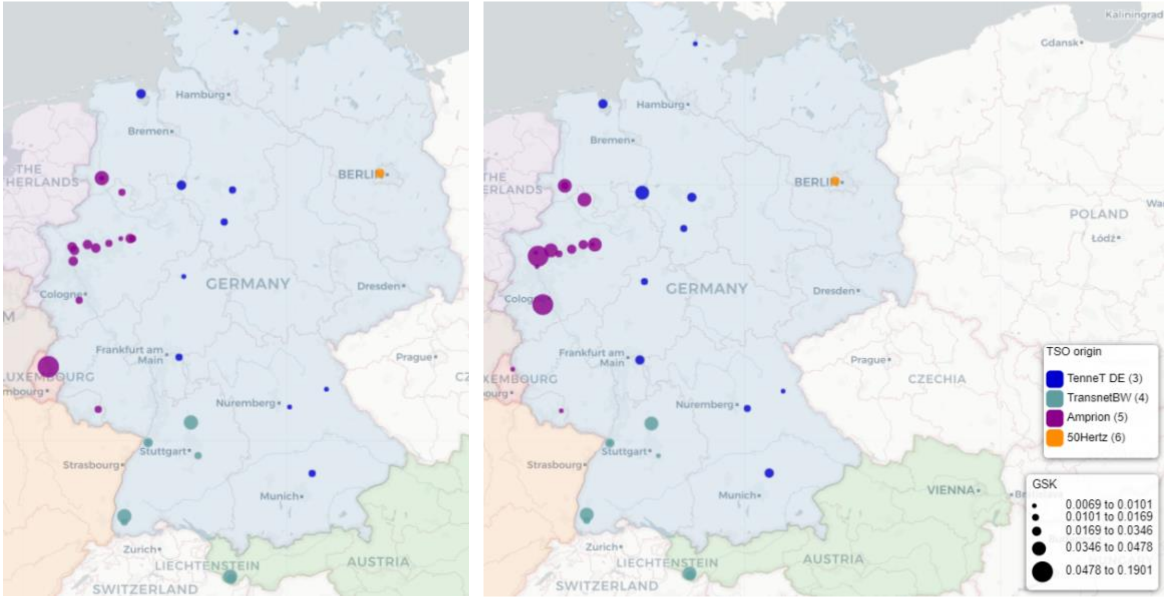


Figure 1: On the left peak GSK of 17/04/2019 and on the right peak GSK of 18/04/2019 after adaptation of the Sharing Keys and new Amprion GSK methodology.

The update was triggered by operational feedback as some power plants of the GSK are not running during the summer months due to a temporary decommissioning or less activity. For some power plants, there is no added benefit for being available when prices are lower (lower load in summer). Some are in maintenance. Therefore, German TSOs decided to update Share Key more frequently.

The effect of this change for the capacity calculation was investigated during a SPAIC analysis published on JAO. An increased volume of FB domain by 5% on average was shown as well as a small impact on max/min net positions for BE and AT while having increased theoretical import capability for Germany (less export) and NL as well as a little less import for FR. The direct Impact on Market Coupling was not investigated due to the problems performing SPAICs after DE/AT split (the historical order books could not be matched on the investigated time period due to the difference in bidding zone configuration).

4.4. CWE Flow-Based Analytics Tool

During this study the power infeed at more than 400 nodes has been analysed in different grid models and exchange situations in nearly 8000 hours resulting in more than 16 million analysed data points. To handle this amount of data efficiently CWE TSOs developed together with Logarithmo the CWE Flow-Based Analytics Tool.
All described input data have been collected in the tool`s database. The tool itself allows a performant access to the data creating predefined graphs and indicators.

Figure 2: Overview of the CWE Flow-Based Analytics Tool

The tool allows to easily identify the nodes with the highest infeed deviations between D-2, DA and Real-time. Afterwards a detailed look at the infeed time series of those nodes can be taken in the second module of the tool.

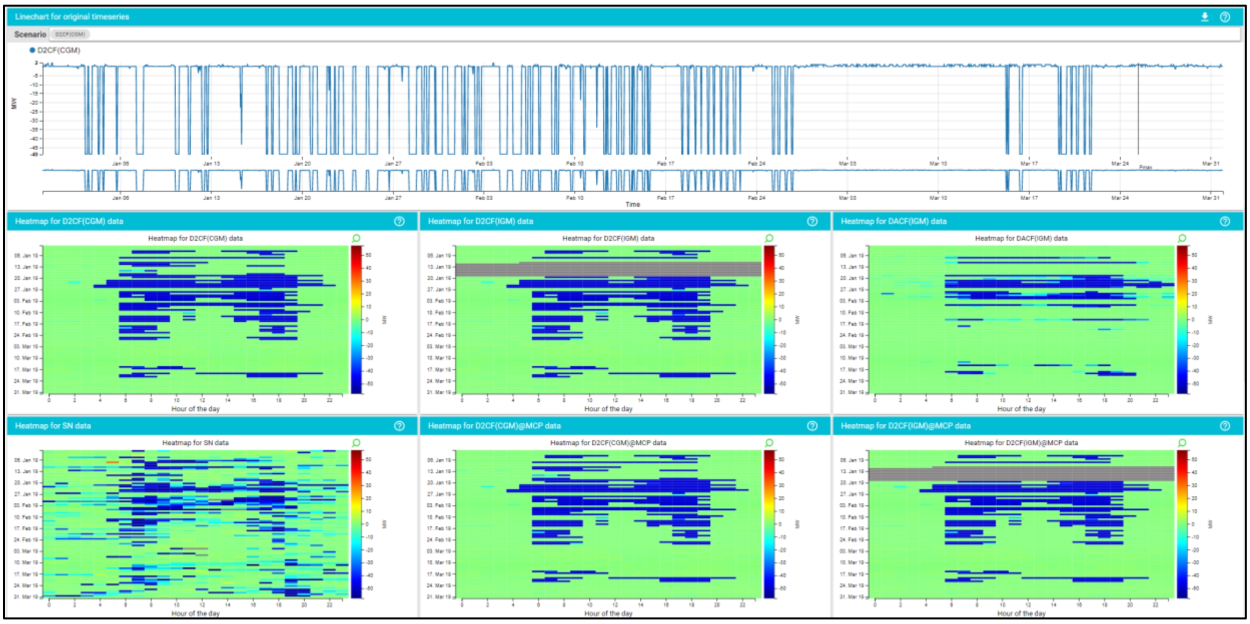


Figure 3: Node specific analysis of infeed time series for several datasets

4.5. Investigated grid models

A good forecast of the grid situation and the Day-ahead market behaviour is crucial for the Day-ahead capacity calculation.

The D2CF grid model has to be as accurate as possible. Two points of the D2CF building process are important as they determine the “starting point” of the generation infeed of each power plant from where the shift via GSK is performed:

- the best forecast of the production of generating units[1]
- the best estimation for the outages of generating units

The D2CF creation can be classified into two categories among TSOs:

1. Best forecast approach for IGM D2CF creation (DE TSOs, APG, TenneT NL)
    a. General principle
    The general principle for the creation of the individual grid models is using the best possible forecast of the system state at D-2. This includes the latest available topology including planned outages for the dedicated business day, the best forecast of renewables and power plant schedules as well as a load forecast.

    b. Specificities for APG, TransnetBW and TenneT DE
    Power plant schedule forecasts directly coming from the power plant operators are used.

    c. Specificities for Amprion
    Amprion uses the results of a market approximation which is also used for the Week Ahead Process Planning (WAPP), a process which determines the grid reserve in Germany.

2. RefProg approach for IGM D2CF creation (Elia, RTE)
    a. General principle
    The general principle is to have a good approximation directly at RefProg as this set of Net Position will be used for the CGM merging.
    b. Specificities for Elia
    Since the quality of the RefProg is, from time to time,poor and it impacts the generation pattern in the CGM, Elia tries to minimize this impact by using a GSK-driven approach. This approach starts by making a proper Best Forecast of the target NP . Therefore, the load forecast, the RES forecast and the non-coordinatable generators are combined to create an individual grid model at a a (local) best forecast Net Position.
    Since this NP is different from the one used for the merging (i.e. RefProg), the NP of the IGM needs to be adapted towards the Reference Day schedule.
    To do so, the GSK is applied to shift the newly created IGM to zero-balance cancelling the forecasted Net positions and then shifting back to the RefProg Net positions.
    Using this approach, during the merging the CGM is shifted to zero-balance with the RefProg, the error of the RefProg is countered. This approach in the end leads to the setpoints of loads, RES and generation not included in the Elia GSK to be at best forecast setpoints, while the setpoints of the generation of nodes defined in the GSK ensure an overall NP of the BE IGM that is equal to the Reference Day Schedule.

For CWE TSOs except Elia, the quality of the D2CF forecast can be derived from the comparison of the D2CF IGM@OriginalNP which includes the best forecast of TSOs with the DACF IGM@OriginalNP

[1] For Elia, a best forecast is created for the assumed Net Position based on the RefProg.

which includes the real Day-ahead power plant schedules. This comparison can deliver valuable insights for TSOs how good their D2CF forecast is and where it can be improved. For Elia, the IGM is created with the reference day net position (RefProg) in order to have the CGM at zero-balance as representative as possible. [2]

For the study the following grid models are investigated and used to create the KPIs as listed in chapter 0:

- **D2CF IGM@OriginalNP:** Individual D2CF grid model as created by TSOs as input for the D2CF merging. D2CF IGMs can include the best forecast (TenneT NL, TenneT DE, TransnetBW, Amprion[3], and APG) or reference day (Elia, RTE) net position depending on the TSO strategy.
- **D2CF IGM@MCP:** Individual D2CF grid model as created by TSOs as input for the D2CF merging but shifted via GSK to the DA MCP.
- **D2CF IGM@realized NP:** Individual D2CF grid model as created by TSOs as input for the D2CF merging but shifted via GSK to the realized NP (NP of the snapshot).
- **D2CF CGM@OriginalNP:** Merged or common D2CF grid model includes the reference day net positions except for hours when base case improvement (BCI[4]) was applied.
- **D2CF CGM@MCP**: Merged or common D2CF grid model shifted to the DA MCP.
- **DACF IGM@OriginalNP:** Individual DACF grid model before application of remedial actions including the DA MCP.
- **SN CGM@OriginalNP:** Real-time snapshot (common-) grid model including the realized net position.

Remark: OriginalNP do not refer to the same Net Positions at any timeframes. It refers to the fact that these Net Positions come from the Grid Model creation process and are not result of a GSK shift. For the D2CF the OriginalNP is the Net Position as provided by the TSO in its grid model. For the DACF (D-1), the MCP and the orginalNP of the DA are identical. For the snapshots the common grid model are used. Here the OrginalNP also includes possible ID trading or balancing.

The KPIs will be further explained in the subsequent chapter.

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[3] Used the best forecast but preshifted to a reference NP of Amprion (not CWE) in the past. The process is not in operation anymore, but could have influenced the results of the study.

[4] BCI is used in hours where a shift of one or more D2CF IGMs from their NP to the RefProg is not possible, as the maximum shifting capacity of the TSOs is exceeded by the difference between D2CF IGM NP and RefProg. This can for instance be the case in situations where there is a high difference between the RES infeed of the Reference Day and the modelled BD (Business Day). In such situations, the RefProg gets adapted by a special mechanism to meet the necessity of a balanced grid.

5. RESULTS OF THE ANALYSES

5.1. Analysis of pre-defined KPIs

For all graphs in this chapters, codes instead of the full TSO Name where used to keep the graphs clear (AT = APG, BE = Elia, D2 = TennetDE, D4 = TransnetBW, D7 = Amprion, D8 = 50Hertz, FR = RTE, NL = TennetNL).

As a general remark for all quantification of the errors, the shift to be done by the GSKs compared to the loading of the BZ will impact the results of this study. The more the NP is comparable to the loading of the BZ, the more significant errors can be expected.

5.1.1 Compare D-2 IGMs with the Day-Ahead power plant schedules

This KPI compares TSOs' individual D2CF schedules to the DACF schedules (i.e. the actual outcomes of the Day-ahead market). Therefore, the errors do not focus on the quality of the GSK, but rather the quality of the forecasts of D2CF and DACF for the TSOs using best forecast as an input of the merging.

In Figure 4, the ten nodes of each TSO can be seen, which have the highest mean absolute error / deviation regarding their infeed in two models (in this case the D2CF IGM@OriginalNP - DACF IGM@OriginalNP). The relative error is calculated by dividing the difference of the nodal NP between D-2 and Day Ahead IGM by the Pmax of this node. A high bar in this graph can be the result of a high deviation of the nodal NP in the D-2 and the Day Ahead model, or the result of a small Pmax value of the node, or the combination of both.
This applies to each graph of the following chapters, which represent the top ten nodes with the highest deviations for each TSO - the deviation of the models varies depending on the KPI respectively the compared models.

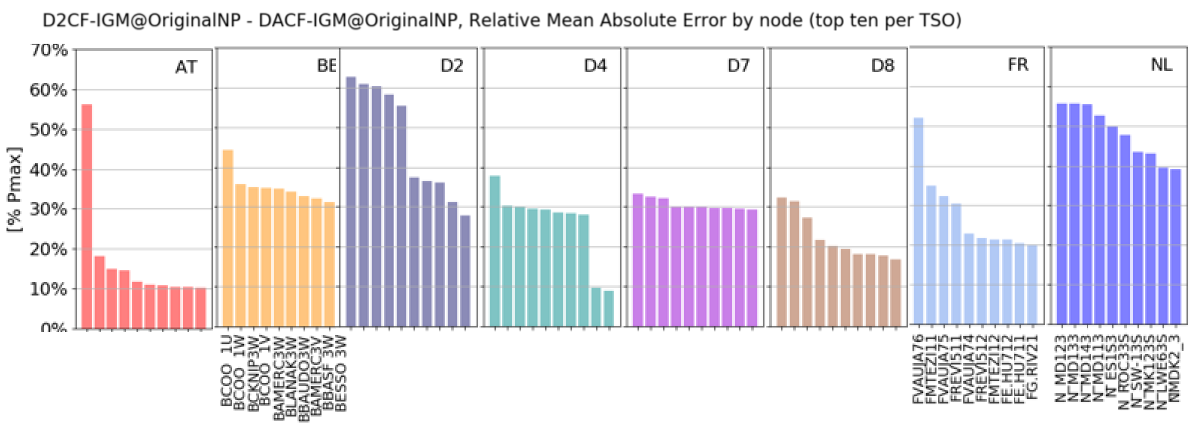


Figure 4: nodal deviation between D2CF IGM-original NP and DACF IGM- original NP, relative mean absolute error by node (top ten per TSO)

Analysis per TSO

APG

- The high value for the node in [redacted] is due to the fact that at this node there are not only GSK relevant power plants feeding in but also a lot of renewables (~ 1000 MW). As the infeed of all GSK power plants on this node adds up to ~100 MW, the relative mean absolute error of about 55% is mostly due to changes of wind forecast between D2CF and DACF. At current state, the IGM is not provided on a granularity which reflects each power plant infeed in its respective node. This might change in the future
- For the nodes with pumped storage infeed, the mean relative errors are somewhere between 10% and 20%, the forecasting quality is therefore quite good. As the used forecasts are from the power plant operators, APGs has no influence on the quality or a special tool to increase the level of accuracy.

Elia

- As already described in section 4.5, the error displayed in the graphs will also include the error regarding the RefProg compared with a proper forecast.

Tennet Germany

[redacted]

- The results are the consequence of the datasets creating method and of the inputs: DACF creation of datasets uses the power plant schedules and a more accurate forecast of the load and of the renewables infeed, whilst the D2CF are created two days prior to the business day, and not all the power plants have a fixed schedule yet and the forecasts such as load and renewables infeed are not as accurate as for the DACF.

TransnetBW

- The highest forecast errors are observed for pumped storage power plants which are harder to predict since they are very flexible units. Additionally, the infeed can vary between maximum infeed and maximum consumption (pumping) and not only between Pmin and Pmax like for thermal units. The maximum error per timestamp is therefore not limited to Pmax but to Pmax_turbin – Pmax-pump. This is also visible in the graph per fuel type. The highest median error is reached by pumped storage power plants.
- The first thermal unit in the top ten is [redacted]. [redacted] the forecast has a good quality. This is the case for the majority of the units in the TransnetBW control area.

Amprion:

- [redacted] as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.
- High errors for [redacted] also caused by the fact that Amprion performed a preshift with a GSK before providing the grid model to the merging entity. No real comparison of the best forecast possible.
- [redacted] Removing this big cluster of generators from the Amprion GSK improved the results.

RTE :

- On the Top 10, 7 nodes are with pumped-storage infeed and 3 with gas unit infeed (Grand Riviere & Emile Huchet 1 & 2), those are the most flexible unit possible in the grid, therefore the planning of production is highly variable. This reflects the unavoidable difference of forecast between the D2CF and the DACF.
- The Node with highest deviation is FVAUJA76 (above 50%), it's a node with pumped-storage infeed (Grand-Maison dam), therefore regarding to the nature of the unit, it's not a surprise to notice high deviation. In addition, the units on this node had a common mode of operation with the other units connected to the 5 other node of this substation (to start a pump in the other unit of Grand Maison, you need to activate the turbine connected to node FVAUJA76 first) leading to even higher difference on that particular node.

TenneT Netherlands

- The Netherlands have a relatively homogenous set of generators, dominated by gas-fired plants. This may explain why no clear "outliers" or "jumps" are observed in the values for this KPI, but rather a fairly smooth descending distribution. Coal-fired plants do not appear in the top-10 as they tend to show less volatile market behaviour.

Figure 5 shows the distribution of the mean absolute error / nodal deviation of infeed between two models for all examined nodes of a TSO (in this case of D2CF IGM@OriginalNP - DACF IGM@OriginalNP). This box-plot graph obeys to a Tukey representation with outliers. Every data point is displayed. This logic is used for every following box-plot graph of this chapter comparing TSOs. With this plot, a better overview of the performance of each TSO regarding this KPI can be provided.

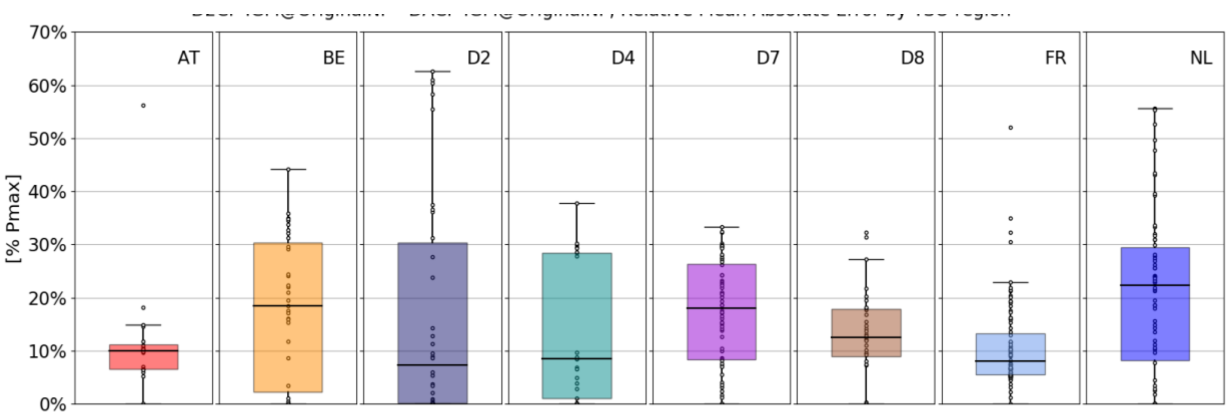


Figure 5: deviation between D-2 IGM-original NP and DACF IGM-original NP, relative mean absolute error by TSO region

In Figure 6, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF IGM@OriginalNP and DACF IGM@OriginalNP when all observed CWE nodes are clustered regarding their fuel type.

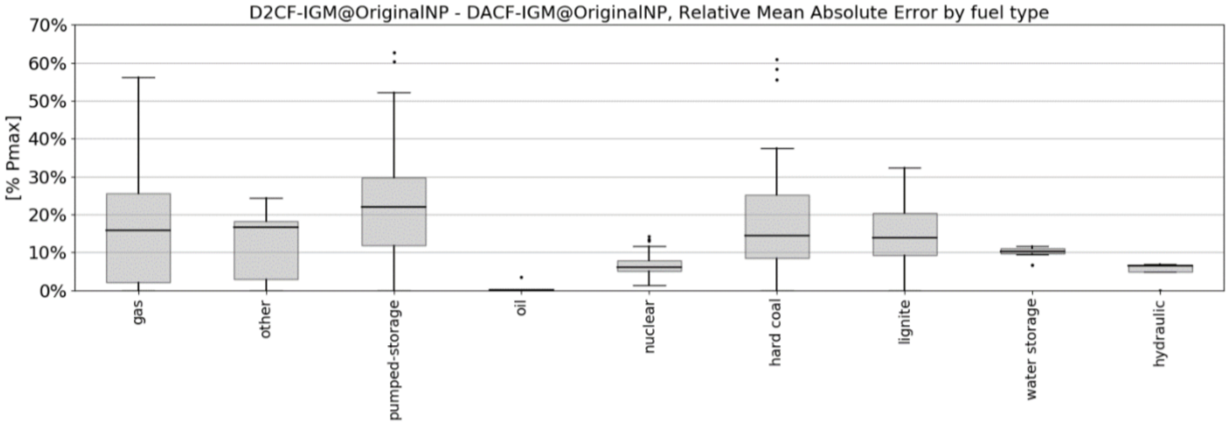


Figure 6: deviation between D-2 IGM-original NP and DACF IGM-original NP, relative mean absolute error by fuel type

<u>General conclusion</u>

Nodes with pumped-storage infeed, gas power infeed and hard coal infeed seem to be more volatile as nodes with nuclear power infeed.

No other CWE TSO, except Amprion [redacted], has a high amount of generators connected to one node while at the same time applying a proportional GSK approach. Therefore the conclusion that removing [redacted] improves GSK quality in general cannot be drawn for other TSOs.

5.1.2 Compare D-2 CGM-shifted to the MCP with the Day-Ahead power plant schedules

This KPI compares the merged D2CF grid model shifted, according to the GSK values, to the Market Coupling Point of the Day Ahead time frame to the DACF schedules (i.e. the actual outcomes of the Day-ahead market). The relative mean absolute error (D2CF CGM@MCP – DACF IGM@OriginalNP) can be found in Figure 7.

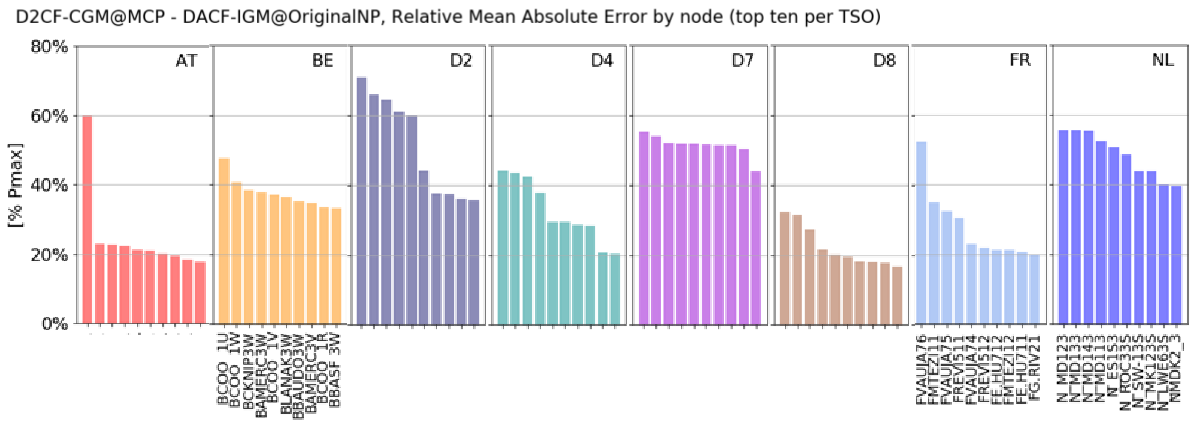


Figure 7: nodal deviation between D2CF CGM@MCP and DACF IGM@Original NP, relative mean absolute error by node (top ten per TSO)

<u>Analysis per TSO</u>

APG:

- Besides the node in [redacted], which has a small amount of GSK power plant infeed and high infeed of renewable energy which results in high relative absolute errors (see chapter 5.1.1), mainly nodes with pumped storage power plant infeed like [redacted] see a rise of their relative mean absolute error compared to the first KPI (see chapter 5.1.1). This is due the fact, that these nodes have the lion-share of the Austrian GSK and therefore their error gets significantly bigger after merging and shifting to MCP. Besides that, it must be stated that Austria has many non-CWE borders and for merging the IGMs, many adjustments have to be done.

Elia:

- The biggest errors come from the pumped storage which are less predictable and are big GSKs nodes for Belgium as it is a significant source of flexibility.

TenneT Germany:

[redacted]

- The results are similar to the ones presented in the section 5.1.1 (D2CF-IGM@OriginalNP - DACF-IGM@OriginalNP ≈ D2CF-CGM@MCP – DACF IGM@OriginalNP)
- In this case for TenneT Germany GSK nodes there is not such a high difference between D2CF-IGM@OriginalNP and D2CF-CGM@MCP. This highlights the fact that shifting the power plants schedule to the market clearing point in the common grid model of D2CF does not generate high errors (so D2CF-IGM@OriginalNP is not that different in comparison with D2CF-CGM@MCP), which

means that the present method of creating the D2CF is very accurate and leads to solid flow based results.

TransnetBW:

- Comparing the indicators from chapters 5.1.2 and 5.1.3 one can observe that the merging has a slight negative impact on the forecast accuracy. If the merging is performed at a common net position forecast (instead of the RefProg NP) like it is designed in the Core CC project this error is expected to decrease.

Amprion:

- [redacted] as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.

RTE:

- Similar comments as section 5.1.1

TenneT Netherlands

- The list of generators is mostly the same as in 5.1.1 (KPI D2CF IGM@OriginalNP – DACF IGM@Original NP). Observations from that KPI also apply to this KPI.

Figure 8 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF CGM@MCP and DACF IGM@OriginalNP for each TSO.

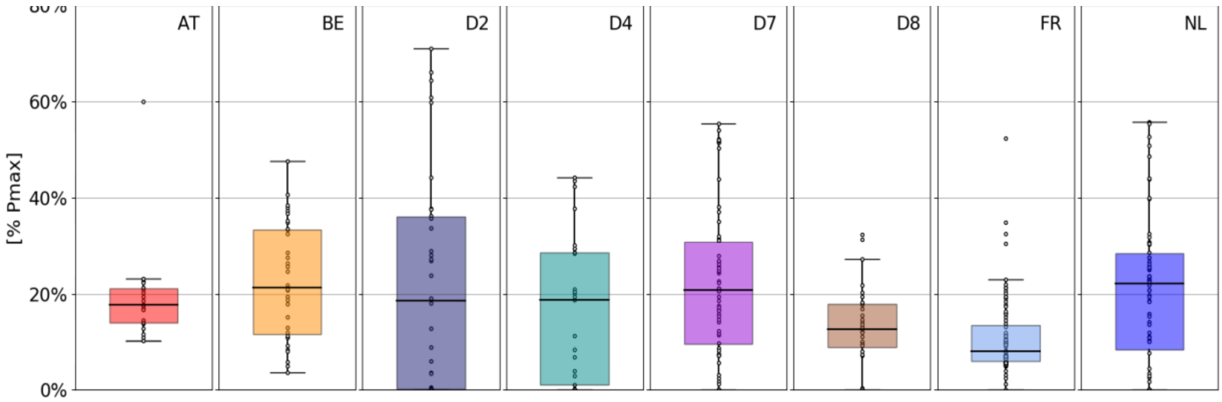


Figure 8: deviation between D2CF CGM- MCP and DACF IGM, relative mean absolute error by TSO region

In Figure 9, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF CGM@MCP and DACF IGM@OriginalNP when all observed CWE nodes are clustered regarding their fuel type.

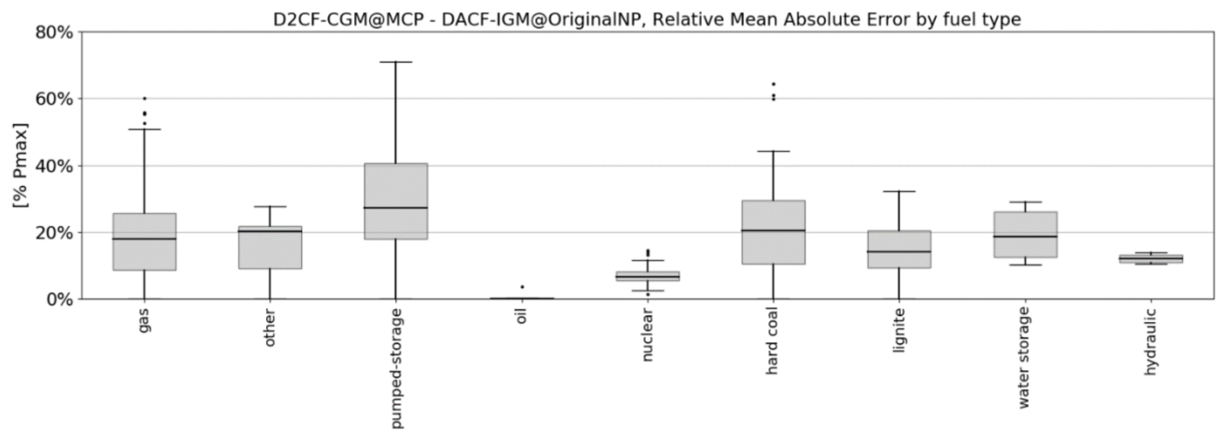


Figure 9: deviation between D2CF CGM- MCP and DACF IGM, relative mean absolute error by fuel type

<u>General conclusion</u>

For most TSOs, the relative mean absolute error between D2CF CGM@MCP and DACF IGM@OriginalNP (taking all nodes of the TSO region into account) increases compared to the KPI of the previous chapter. Besides that, a slight increase of the error of pumped storage and hard coal power plants can be observed compared to the previous chapter.

5.1.3 Compare D-2 IGMs-shifted to the MCP with the Day-Ahead power plant schedules

This KPI compares TSOs' individual D2CF schedules-shifted to the MCP to the DACF schedules (i.e. the actual outcomes of the Day-ahead market). The relative mean absolute error per node (D2CF IGM@MCP – DACF IGM@OriginalNP) can be found in

Figure 10. For TSOs who attempt to model only Day-ahead (not intra-day) trade with their GSK, this is an indicator – though not a perfect one – of GSK performance.

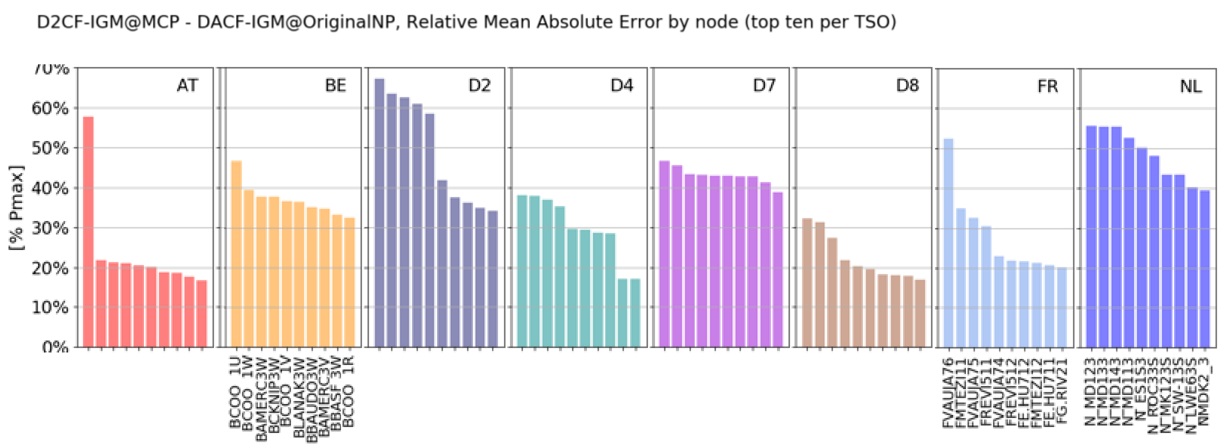


Figure 10: nodal deviation between D2CF IGMs-shifted to the MCP and DACF IGM, relative mean absolute error by node (top ten per TSO)

Analysis per TSO:

APG

- It can be observed, that leaving out the step of merging the D2CF-IGMs to a CGM and only shifting the IGM NP to the MCP, does not really affect the KPI since the order of nodes and their values do not really change compared to the KPI of chapter 5.1.2.
- The direct comparison with the KPI of chapter 5.1.1 (D2CF-IGM@OriginalNP – DACF-IGM@OriginalNP) shows, that the shift of the D2CF IGM to MCP mainly leads to higher relative mean absolute errors for nodes with pumped storage power plant infeed as they have a high share in the Austrian GSK.

Elia

- The biggest errors come from the pumped storage which are less predictable and are big GSKs nodes for Belgium as it is a significant source of flexibility.

TenneT Germany

[redacted]

TransnetBW

- The relative forecast errors increase compared to the D2CF IGM@OriginalNP which has not been shifted by the GSK. We attribute this observation to the reasons explained in chapter 5.2.

Amprion:

- [redacted]: as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.

RTE

- Similar comment as section 5.1.1

TenneT Netherlands

- The list of generators is mostly the same as in 5.1.1 (KPI D2CF IGM@OriginalNP – DACF IGM@Original NP). Observations from that KPI also apply to this KPI.

Figure 11 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF IGM@MCP and DACF IGM@OriginalNP for each TSO.

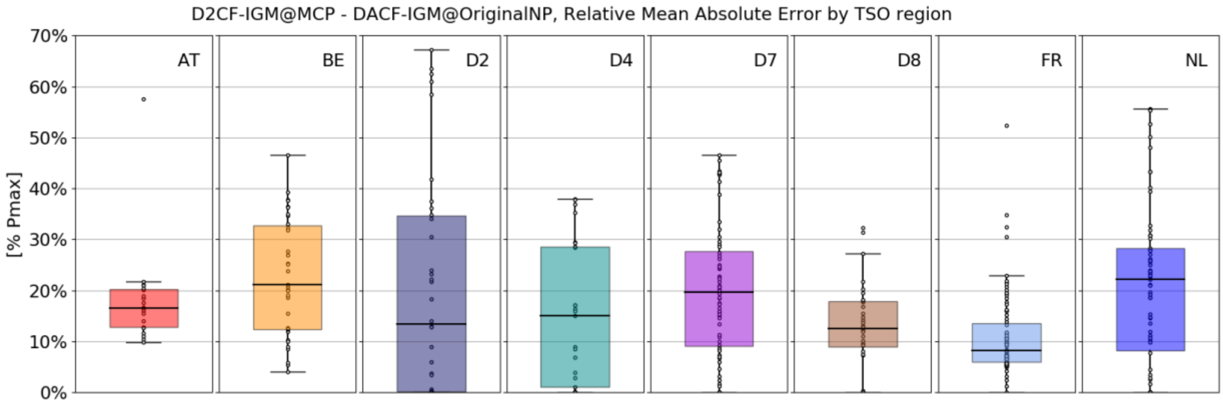


Figure 11: deviation between D2CF IGMs-shifted to the MCP and DACF IGM, relative mean absolute error by TSO region

In Figure 12, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF CGM@MCP and DACF IGM@OriginalNP when all observed CWE nodes are clustered regarding their fuel type.

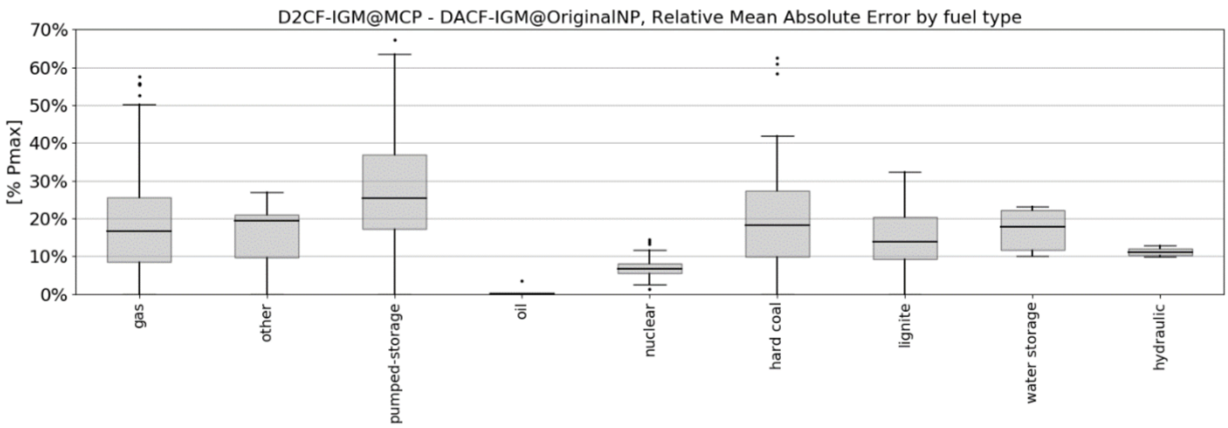


Figure 12: deviation between D-2 IGMs-shifted to the MCP and Day Ahead IGM, relative mean absolute error by fuel type

<u>General conclusion</u>

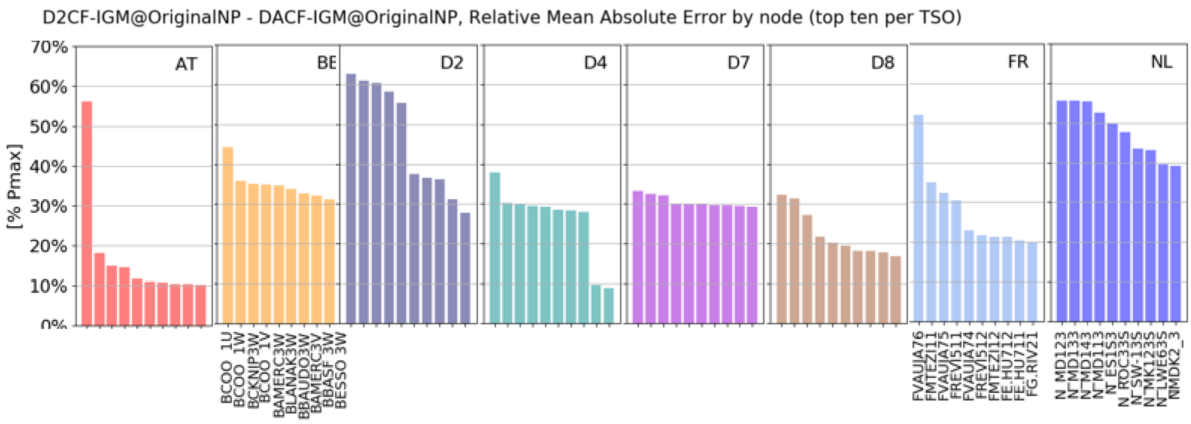
The results are almost identical to the ones presented in the section 5.1.2 (D2CF-CGM@MCP – DACF IGM@OriginalNP ≈ D2CF-IGM@MCP - DACF – IGM@OriginalNP). This leads to the conclusion that during the process of D2CF merging, the power plant outputs do not undergo significant changes (D2CF-CGM@MCP and D2CF-IGM@MCP).

5.1.4 But when comparing the results to section 5.1.1

This KPI compares TSOs' individual D2CF schedules to the DACF schedules (i.e. the actual outcomes of the Day-ahead market). Therefore, the errors do not focus on the quality of the GSK, but rather the quality of the forecasts of D2CF and DACF for the TSOs using best forecast as an input of the merging.

In Figure 4, the ten nodes of each TSO can be seen, which have the highest mean absolute error / deviation regarding their infeed in two models (in this case the D2CF IGM@OriginalNP - DACF

IGM@OriginalNP). The relative error is calculated by dividing the difference of the nodal NP between D-2 and Day Ahead IGM by the Pmax of this node. A high bar in this graph can be the result of a high deviation of the nodal NP in the D-2 and the Day Ahead model, or the result of a small Pmax value of the node, or the combination of both.
This applies to each graph of the following chapters, which represent the top ten nodes with the highest deviations for each TSO - the deviation of the models varies depending on the KPI respectively the compared models.



it can be observed that the forecast error of the D2CF increases when it is shifted to the DA MCP. At first glance, this is surprising since the forecasted market direction in the D2CF@OriginalNP is replaced by the correct DA MCP when shifting it to D2CF@MCP. Possible explanations for this behaviour can be found in chapter 5.3.

As Figure 12 shows, the behaviour of nuclear power plants is by far the easiest to map with the GSK (the "oil" category includes only a handful of units so there are likely other effects at play there). Pumped-storage facilities are notably more volatile, often showing up as the worst-predicted node for a given control area, e.g. Coo (BE), [redacted] and Grand Maison (FR). The fact that pumped storage power plants have a statistical disadvantage in this investigation plays a role here and is explained in detail in chapter 5.3.

5.1.5 Compare D-2 IGMs with the real-time power plant schedules (Snapshot)

This KPI compares individual D2CF created by TSO as an input of the merging, to the snapshot dispatch (i.e. the actual dispatch seen in real time). It is important to note that there is by definition still a delta between these resulting from intra-day shifts, redispatch activations and balancing activations, so this indicator should not be used as an indicator of GSK performance. The relative mean absolute error per node (D2CF IGM@OriginalNP – SN-CGM@OriginalNP) can be found in Figure 13.

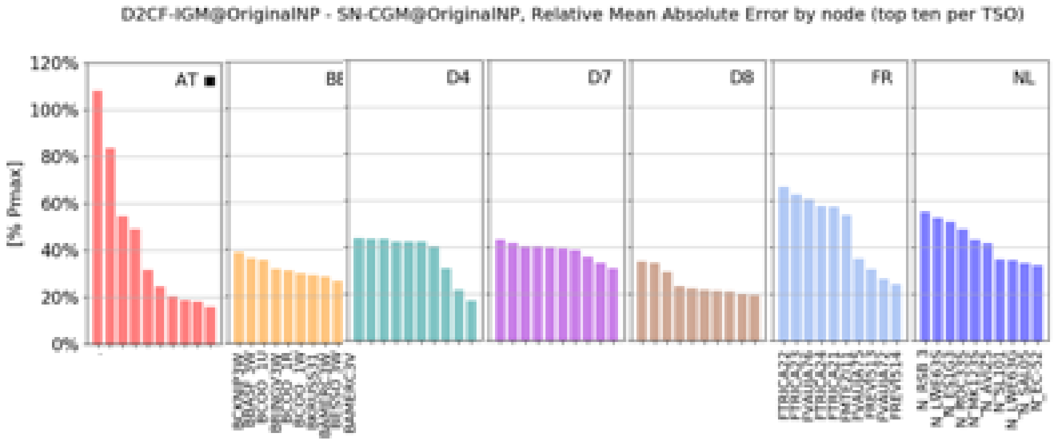


Figure 13: nodal deviation between D2CF IGMs and the real time power plant schedules (Snapshot), relative mean absolute error by node (top ten per TSO)

<u>Analysis per TSO</u>

APG:

- ■) The graph “Relative Mean Absolute Error by node” shows APGs highest KPIs beginning with the 3rd highest and ending with the 12th highest node. This was done to keep the graphs for the different TSOs comparable since APGs nodes with highest KPI are [redacted] with 343% Pmax and [redacted] with 166% Pmax.
- For five of the six APG nodes with the highest error the reasons for the extreme values can be explained by the definition of the KPI and the different modelling of nodes in snapshots compared to grid models, i.e. the forecast / modelling process in D2CF and DACF and the actual real-time network situation. In the D2CF and DACF on the one hand, the infeed from (renewable) power plants in nodes of the distribution network (which are not represented in the D2CF or DACF models) are assigned to the associated nodes of the transmission network (like [redacted]) as schedules. The snapshot, on the other hand, provides the real-time Netposition of the node (sum of infeed and load). For hours where the NP shows that the node acts as a load, the infeed in the snapshot is set to zero. This is the case for almost all hours for nodes like [redacted]. Hence, when calculating the relative mean absolute errors, the infeed values of the (merged) D2CF or DACF models (with or without shifting) are most of the time compared to a zero value (of the snapshot), leading to high error values.
- For example: As the maximum market driven infeed “Pmax“ at the node [redacted] is 100 MW and the maximum wind power infeed on this node is ~ 1 GW, the scheduled infeed in D2CF and DACF (P_{Gen_IGM}) can become > than 1 GW. Compared to the Snapshot infeed (P_{Gen_SN}), which is due to the load most of the time zero, the relative absolute error therefore can become up to ~ 1000 %. As a formula: $\frac{P_{Gen\_IGM} - P_{Gen\_SN}}{p_{max}} = \frac{1000\ MW - 0\ MW}{100\ MW} = 10 \triangleq 1000\ \%$
- The same explanation regarding the difference between D2CF / DACF and Snapshot applies for the nodes [redacted]. In these cases, the error is (slightly) smaller, as the ratio of maximal infeed in D2CF and DACF (schedules) to maximum market driven infeed “Pmax” is smaller.
- For the node [redacted] and other pumped storage or water storage nodes like [redacted], the deviations can be explained with intraday exchanges, redispatch and balancing.

Elia

- On top of the additional discrepancies mentioned in the general text (Intraday, Redispatch and balancing), the error regarding the RefProg mentioned in section 4.5 is still present.

TenneT Germany

- The power plants which appear in this Top 10 are the same ones as in the previous charts, only the hierarchy changes and the differences are significantly lower than before. The high errors that appear for the Top 10 power plants are the consequence of the Re-Dispatch and intraday processes, which occur after the creation of the D2CF finished.

TransnetBW

- Indicators making a comparison to the snapshots are not as relevant as the comparisons to the DACF for TransnetBW as the real time power plant schedules in the snapshots include the ID market results, balancing and redispatching actions. As the D2CF and the GSK model the Day-ahead market it can be justified to have differences to the infeed in the snapshot.

Amprion:

- [redacted]: as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.
- High errors for [redacted] also caused by the fact that Amprion performed a preshift with a GSK before providing the grid model to the merging entity. No real comparison of the best forecast possible.

RTE :

- On the Top 10 Node comparison with Snapshot, for RTE, one thing is obvious: 4 nuclear plant (FTRICA2X) are displayed, with more than 50% error. This out of ordinary results can be explained by the process to produce Snapshot, and not because of a particular forecast error on those 4 plants. The Snapshot chosen for this comparison, relevant for most of the TSO, did not adopt a good convention naming for the node TRICA (Nuclear plant of Tricastin), some deviations are observed, and the Node 1 has to be considered with the Node 4 (same for Node 2 and 3). This convention mistake corrected, the Relative Mean Absolute Error for FTRICA21 & FTRICA24 is 7%, FTRICA22 & FTRICA23 is 11%. Those values are within the range of the error of other nuclear plant within this study.
- According to this previous comment, the 4 outliers of nuclear fuel type in Figure 15 are the generation unit of Tricastin in south France.

TenneT Netherlands

- As is the case for the KPIs shown in sections 5.1.1-5.1.3, there are no clear jumps or outliers observed in the graph but rather a smoothly descending line. This is probably caused by the homogeneity of the Dutch generator fleet (dominated by gas-fired power plants). Relative to previous KPIs the specific generators in the top-10 have changed somewhat, with Sita, RoCa and Merwedekanaal units taking the place of WKC Moerdijk. Likely these are more active on the intra-day market.

Figure 14 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF IGM@OriginalNP and SN CGM@OriginalNP (Snapshot) for each TSO.

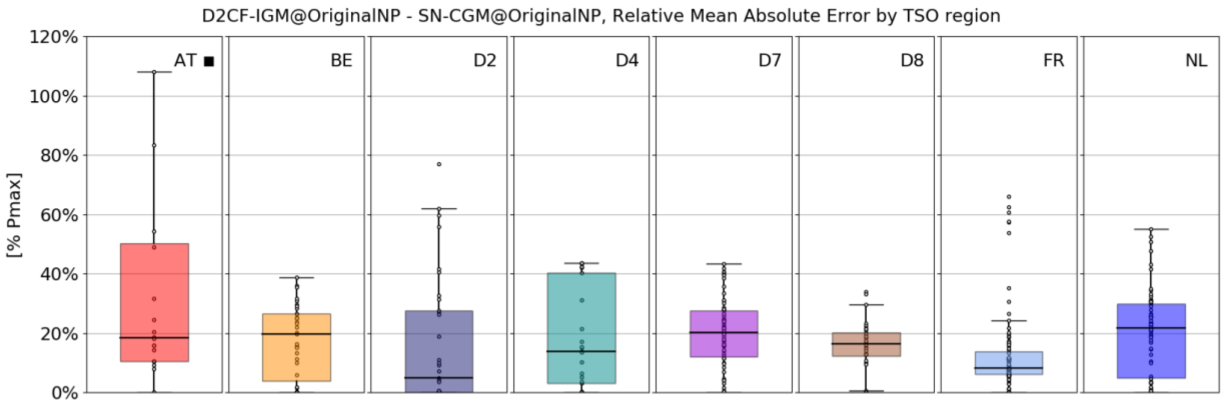


Figure 14: deviation between D2CF IGMs and the real time power plant schedules (Snapshot), relative mean absolute error by TSO region

In Figure 15, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF IGM@OriginalNP and SN CGM@OriginalNP (Snapshot), when all observed CWE nodes are clustered regarding their fuel type.

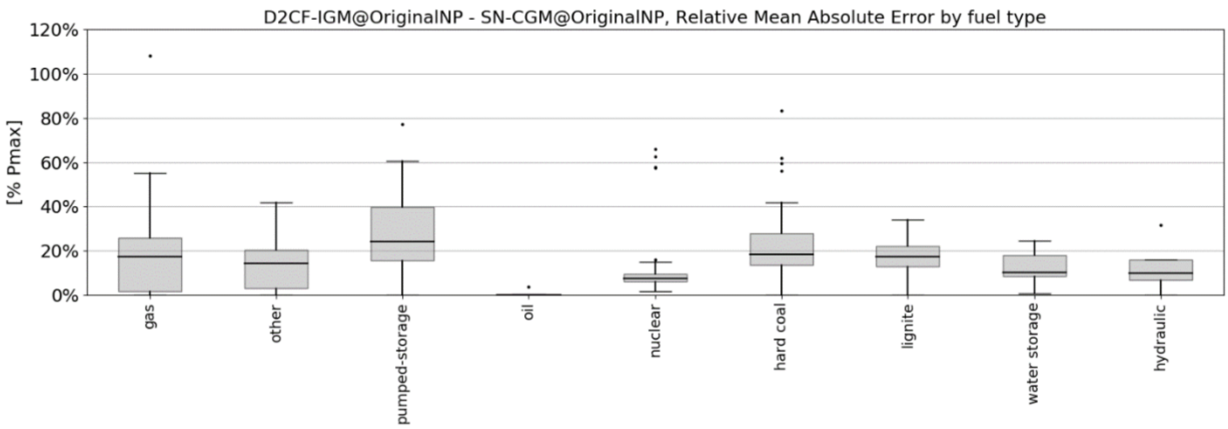


Figure 15: deviation between D2CF IGMs and the real time power plant schedules (Snapshot), relative mean absolute error by fuel type

<u>General conclusion</u>

This graph confirms the fact that nuclear generation unit are the most easy to predict, due to their low volatility, the 4 outliers are only caused by a wrong convention naming (this remarks on the 4 generation units of Tricastin applies for all KPIs involving a comparison with Snapshot). In addition, there is by definition still a delta between these resulting from intra-day shifts, redispatch activations and balancing activations, so this indicator should not be used as an indicator of GSK performance.

5.1.6 Compare D-2 IGMs-shifted to MCP with the real-time power plant schedules (Snapshot)

This KPI compares TSOs' individual D2CF schedules, shifted to the market-clearing point of the Day-ahead market with the GSK, to the snapshot dispatch (i.e. the actual dispatch seen in real time). There is by definition still a delta between these resulting from intra-day shifts, redispatch activations and balancing activations, so this indicator should not be used as an indicator of GSK performance. The relative mean absolute error per node (D2CF IGM@MCP – SN-CGM@OriginalNP) can be found in Figure 16.

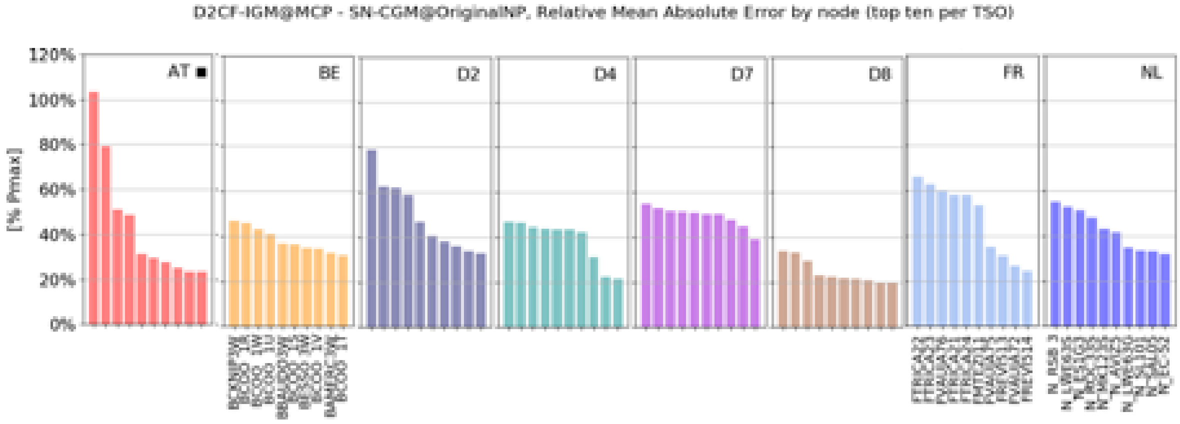


Figure 16: nodal deviation between D2CF IGMs-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by node (top ten per TSO)

<u>Analysis per TSO</u>

APG:

- [redacted]) The graph “Relative Mean Absolute Error by node” shows APGs highest KPIs beginning with the 3rd highest and ending with the 12th highest node. This was done to keep the graphs for the different TSOs comparable since APGs nodes with highest KPI are [redacted] with 340% Pmax and [redacted] with 161% Pmax.
- The high relative mean absolute error of some nodes is explained in chapter 5.1.4

TenneT Germany:

- The high errors that appear for the Top 10 power plants may occur as the consequence of the Re-dispatch and intraday processes, which takes place after the creation of the D2CF finished. Even though the D2CF is shifted to the market clearing point, in this case it does not include the Re-Dispatch amounts and the Intra-Day results.

TransnetBW:

- Indicators making a comparison to the snapshots are not as relevant as the comparisons to the DACF for TransnetBW as the real time power plant schedules in the snapshots include the ID market results, balancing and redispatching actions. As the D2CF and the GSK model the Day-ahead market it can be justified to have differences to the infeed in the snapshot.

Amprion:

- [redacted] as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.

TenneT Netherlands:

- The list of generators is mostly the same as in 5.1.4 (KPI D2CF IGM@OriginalNP – SN CGM@OriginalNP). Observations from that KPI also apply to this KPI.

RTE

- Similar comment as section 5.1.4

Figure 17 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF IGM@MCP and SN CGM@OriginalNP (Snapshot) for each TSO.

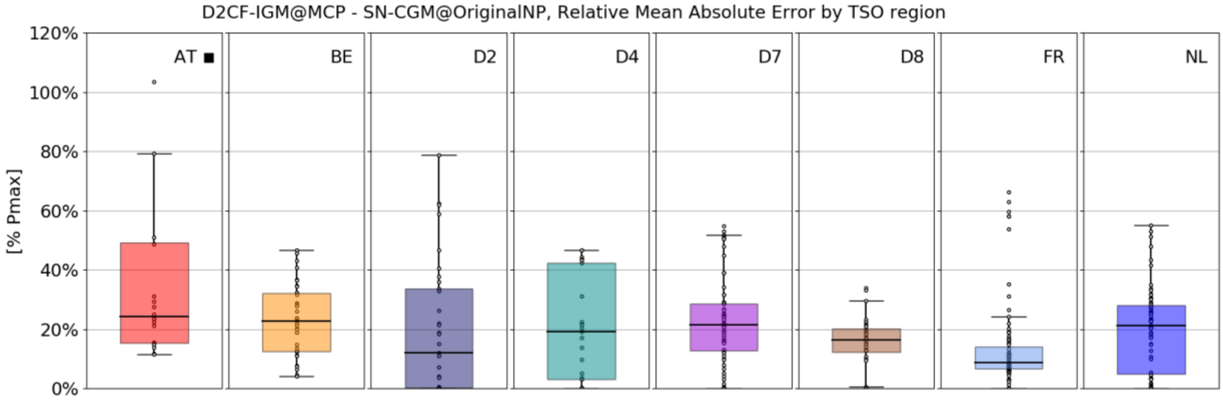


Figure 17: deviation between D2CF IGMs-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by TSO region

In Figure 18, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF IGM@MCP and SN CGM@OriginalNP (Snapshot), when all observed CWE nodes are clustered regarding their fuel type.

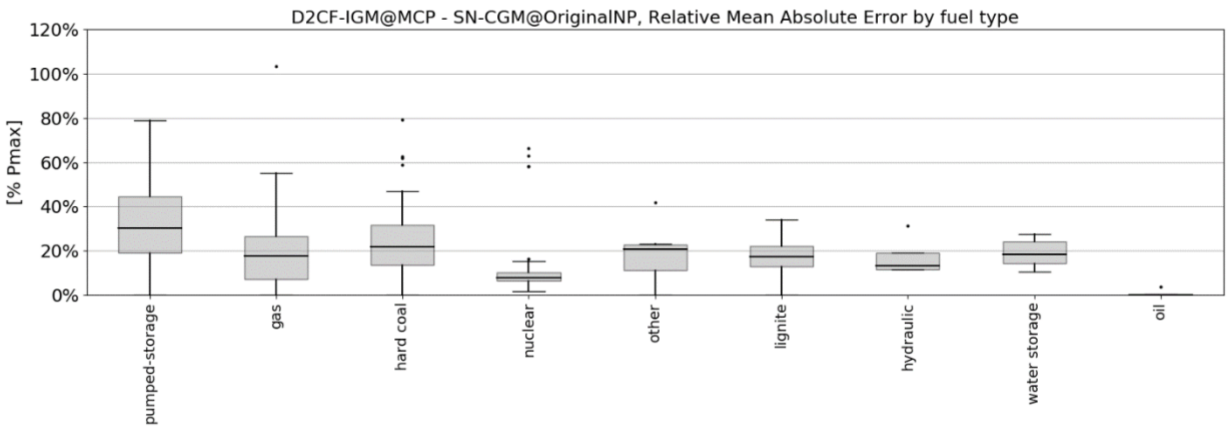


Figure 18: deviation between D-2 IGMs-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by fuel type

<u>General conclusion</u>

Similar to 5.1.4, this graph confirms the fact that nuclear generation unit are the most easy to predict, due to their low volatility. A comparison to snapshot is difficult due to the influence of balancing and redispatch.

5.1.7 Compare D-2 CGM-shifted to MCP with the real-time power plant schedules (Snapshot)

This KPI compares common D2CF, to the snapshot dispatch (i.e. the actual dispatch seen in real time). There is by definition still a delta between these resulting from intra-day shifts, redispatch activations and balancing activations, so this indicator should not be used as an indicator of GSK performance. The relative mean absolute error per node (D2CF CGM@MCP – SN-CGM@OriginalNP) can be found in Figure 19.

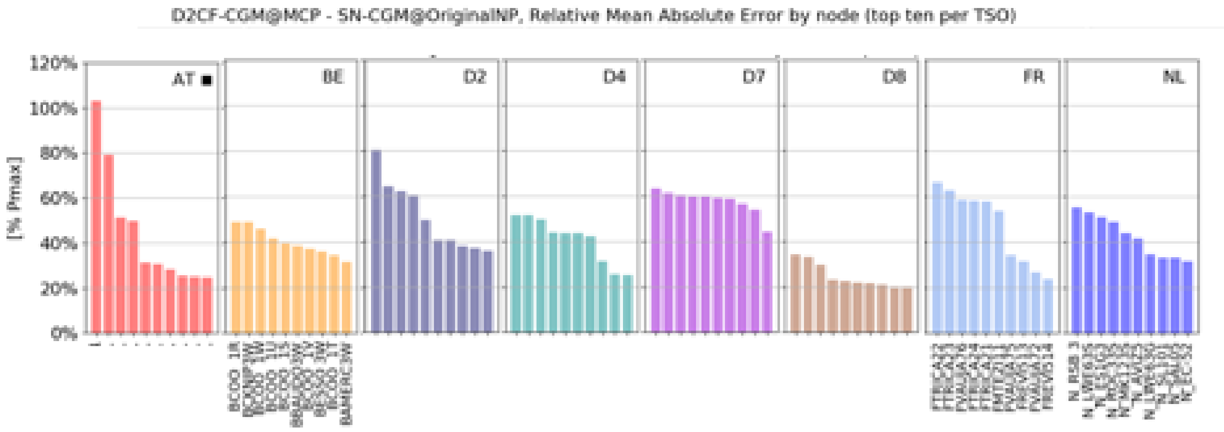


Figure 19: nodal deviation between D2CF CGM-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by node (top ten per TSO)

<u>Analysis per TSO</u>

APG:

- ■) The graph "Relative Mean Absolute Error by node" shows APGs highest KPIs beginning with the 3rd highest and ending with the 12th highest node. This was done to keep the graphs for the different TSOs comparable since APGs nodes with highest KPI are [redacted] with 341% Pmax and [redacted] with 161% Pmax.
- The high relative mean absolute error of some nodes is explained in chapter 5.1.4

TenneT Germany:

- In this chart the values coming from similar types of grid models are compared (meaning from two **common** grid models)
- The differences may occur as the consequence of the Re-dispatch and intraday processes, which takes place after the creation of the D2CF finished. Even though the D2CF is shifted to the market clearing point, in this case it does not include the Re-Dispatch amounts and the Intra-Day results.

TransnetBW:

- Indicators making a comparison to the snapshots are not as relevant as the comparisons to the DACF for TransnetBW as the real time power plant schedules in the snapshots include the ID market results, balancing and redispatching actions. As the D2CF and the GSK model the Day-ahead market it can be justified to have differences to the infeed in the snapshot.

Amprion:

- [redacted] as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.

TenneT Netherlands:

- The list of generators is mostly the same as in 5.1.4 (KPI D2CF IGM@OriginalNP – SN CGM@OriginalNP). Observations from that KPI also apply to this KPI.

Figure 20 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF CGM@MCP and SN CGM@OriginalNP (Snapshot) for each TSO.

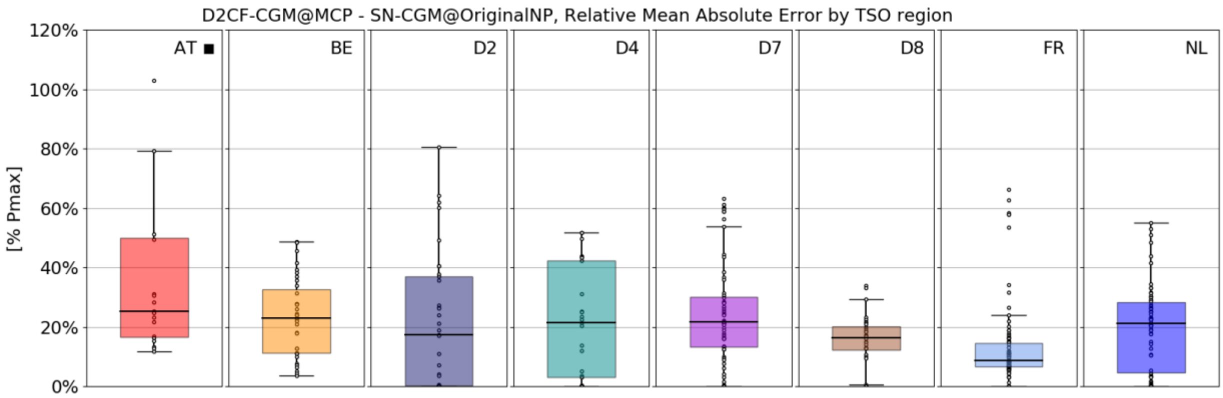


Figure 20: deviation between D2CF CGM-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by TSO region

In Figure 21, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF CGM@MCP and SN CGM@OriginalNP (Snapshot), when all observed CWE nodes are clustered regarding their fuel type.

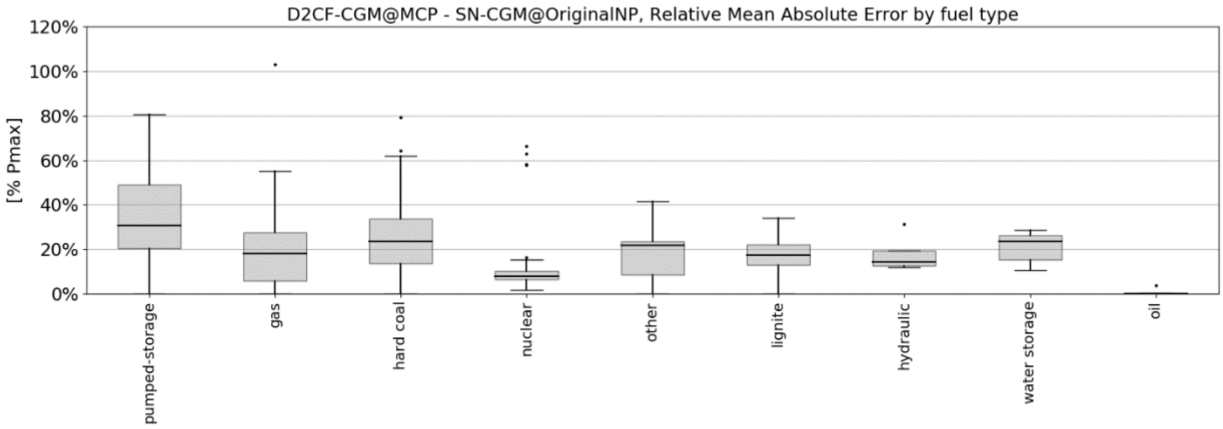


Figure 21: deviation between D2CF CGM-shifted to MCP and the real time power plant schedules (Snapshot), relative mean absolute error by fuel type

General conclusion

Same as for the previous two KPIs.

5.1.8 Compare D-2 IGMs-shifted to realised NP with the real-time power plant schedules (Snapshot)

This KPI compares TSOs' individual D2CF schedules, shifted to the real-time realised net positions with the GSK, to the snapshot dispatch (i.e. the actual dispatch seen in real time). For TSOs who attempt to model Day-ahead *and* intra-day trade with their GSK, this is an indicator – though not a perfect one – of GSK performance. A particular source of error that must be kept in mind are intra-day processes that are not part of the regular ID market, such as redispatch and balancing actions, so this indicator should not be used as an indicator of GSK performance. These influence the snapshot dispatch but are not modelled by the GSK. The relative mean absolute error per node (D2CF IGM@Realised NP – SN-CGM@OriginalNP) can be found in Figure 22.

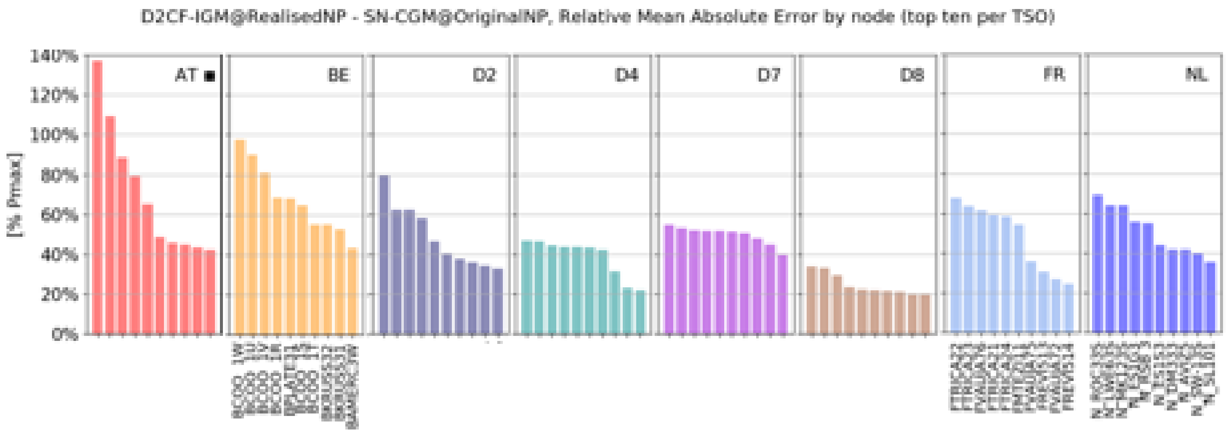


Figure 22: nodal deviation between D2CF IGM-shifted to realised NP and the real time power plant schedules (Snapshot), relative mean absolute error by node (top ten per TSO)

Analysis per TSO

APG:

- [redacted]) The graph “Relative Mean Absolute Error by node” shows APGs highest KPIs beginning with the 3rd highest and ending with the 12th highest node. This was done to keep the graphs for the different TSOs comparable since APGs nodes with highest KPI are [redacted] with 374% Pmax and [redacted] with 191% Pmax.
- The high relative mean absolute error of some nodes is explained in chapter 5.1.4

Elia:

- The consideration of the realized Net Position on the D2CF does not make sense as it includes intraday, redispatch and balancing. A GSK shift does not intend to represent these other markets.

TransnetBW:

- Indicators making a comparison to the snapshots are not as relevant as the comparisons to the DACF for TransnetBW as the real time power plant schedules in the snapshots include the ID market results, balancing and redispatching actions. As the D2CF and the GSK model the Day-ahead market it can be justified to have differences to the infeed in the snapshot.

Amprion:

- [redacted] as huge shifts were performed with relatively small power plants and equal GSK factors for each power plant. The removal of [redacted] with the GSK update of Amprion was already performed to mitigate this issue.

Figure 23 shows the distribution of the relative mean absolute error / nodal deviation of infeed between the models D2CF IGM@RealisedNP and SN CGM@OriginalNP (Snapshot) for each TSO.

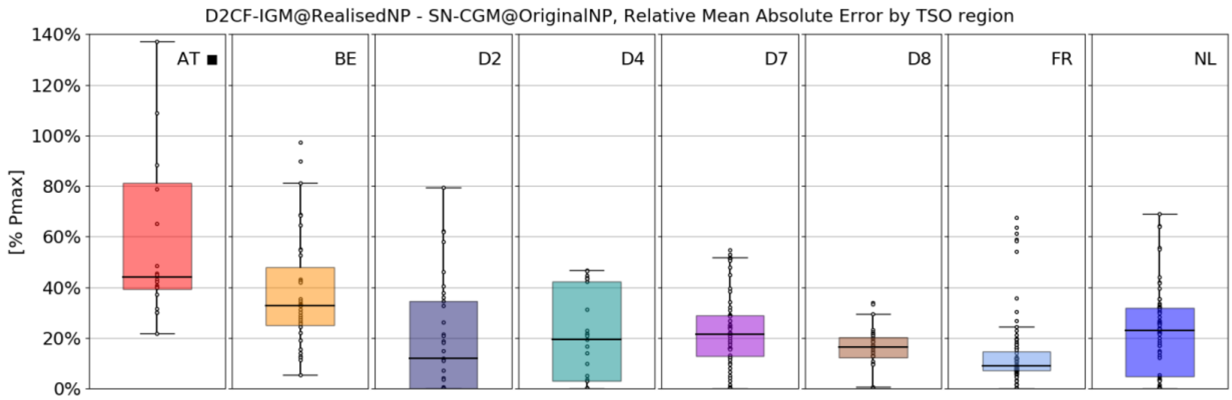


Figure 23: deviation between D2CF IGM-shifted to realised NP and the real time power plant schedules (Snapshot), relative mean absolute error by TSO region

In Figure 24, a similar graph shows the distribution of relative mean absolute errors / nodal deviation of infeed between D2CF IGM@RealisedNP and SN CGM@OriginalNP (Snapshot), when all observed CWE nodes are clustered regarding their fuel type.

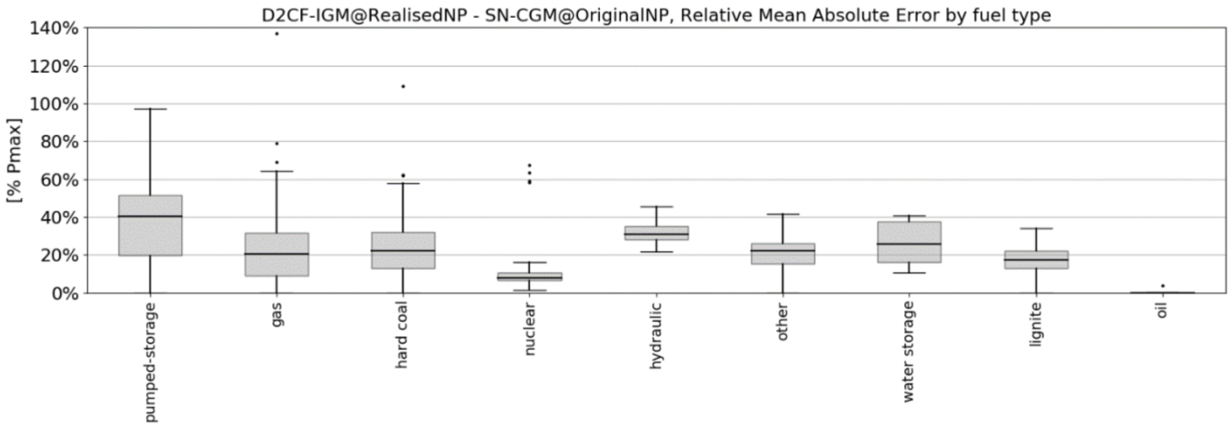


Figure 24: deviation between D2CF IGM-shifted to realised NP and the real time power plant schedules (Snapshot), relative mean absolute error by fuel type

General conclusion:

Nuclear still shows the smallest deviations (oil also has small deviations, but a to small sample size of power plants to be representative); what is interesting is the much less predictable behaviour of hydraulic power plants, compared to what was observed when only the Day-ahead market was considered.

5.1.9 Violations of minimum and maximum infeed of power plants

One way to discover a lack of quality in grid models and the inaccuracy caused by the linear GSK shift is to look at the violations of technical limits (Pmin/Pmax) of power plants. For example a coal power plant with a rated power of 500 MW might not be able to feed in with a power between 0 MW and 100 MW due to technical restrictions. 100 MW is then called Pmin and if an infeed larger than 0 MW and smaller than 100 MW is detected in a grid model then this is counted as a Pmin violation. An infeed above the rated power of 500 MW would be a Pmax violation.

The following graphs show the Pmin and Pmax violations for the ten nodes per TSO with the highest number of timestamps with violations. For Elia and Tennet NL no Pmin violations are visible as the Pmin value used for this study is equal to zero for all power plants.

Figure 25 shows the Pmax violations of the D2CF IGM@OriginalNP. The grid model is not shifted by the GSK, so all violations are modelling errors by the TSOs in their D2CF (unless renewable energy or load is connected to the same node, as is the case for APG, leading to Pmin and Pmax violations. The amount of violations also depends on the value of the Pmax itself).

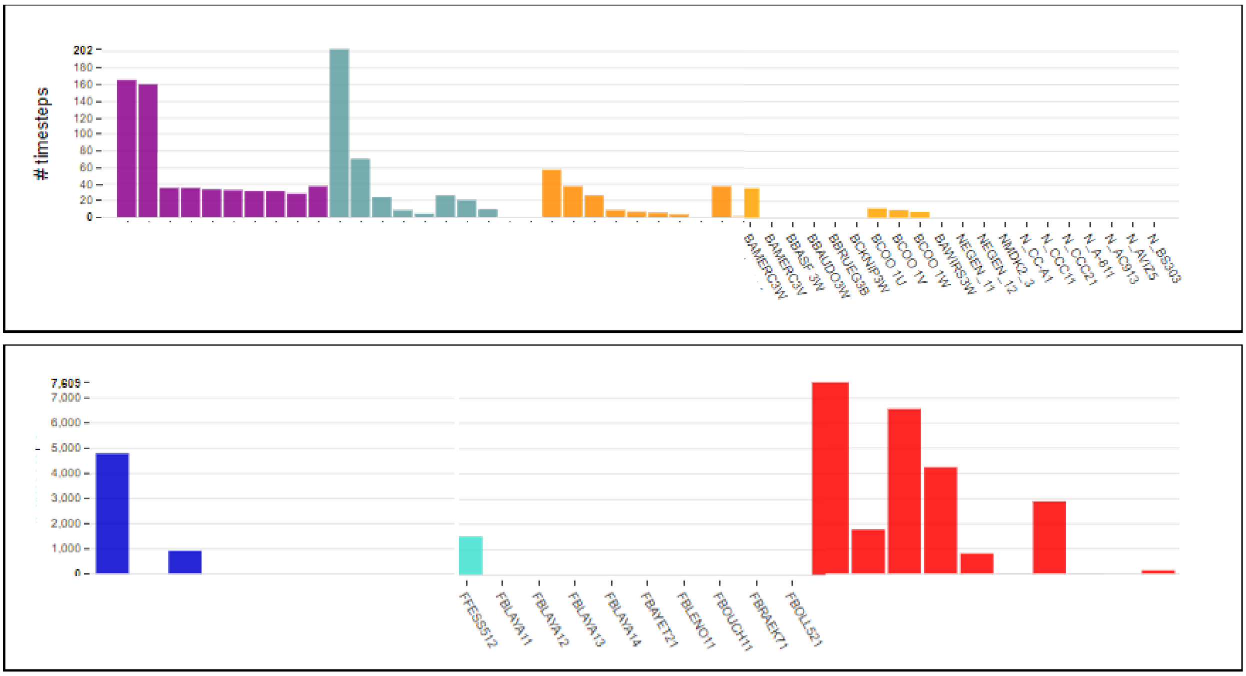


Figure 25: Number of timestamps with Pmax violation larger than 3% in the D2CF IGM@OriginalNP

Figure 26 shows the Pmax violations of the D2CF IGM@MCP (the grid individual D-2 model after shifting to the MCP by the GSK). Besides modelling errors by the TSOs, violations also occur due to shifting the D2CF.

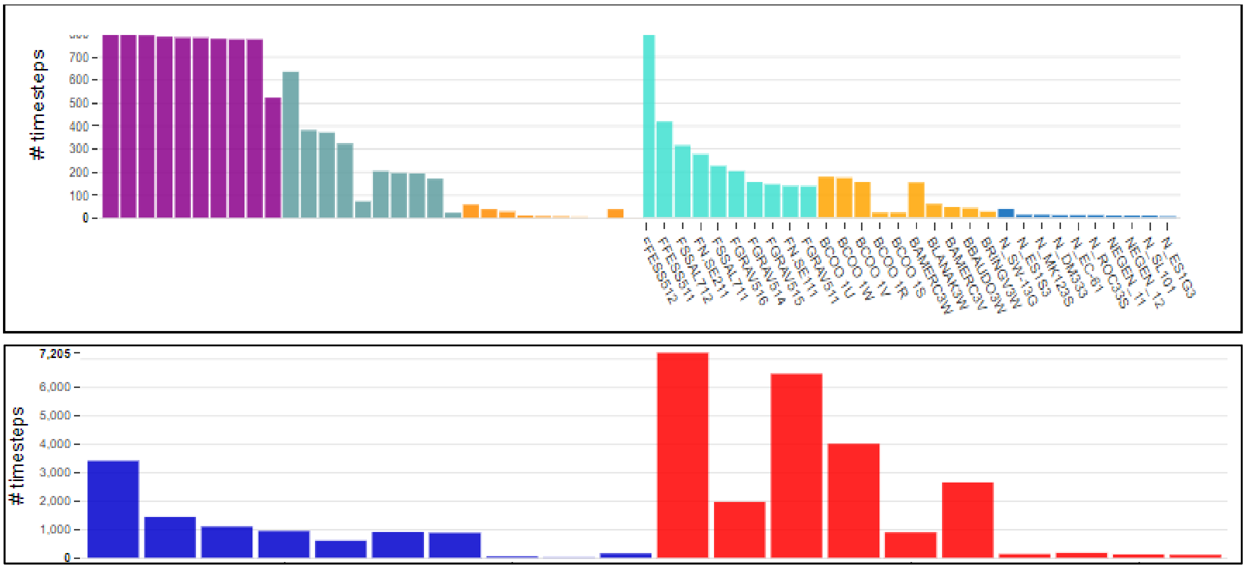


Figure 26: Number of timestamps with Pmax violation larger than 3% in the D2CF IGM@MCP

Figure 27 and Figure 28 show the Pmin violations of the D2CF IGM@OriginalNP (TSO modelling errors) and D2CF IGM@MCP (TSO modelling errors and errors due to shifting with the GSK), similar to the graphs before for Pmax.

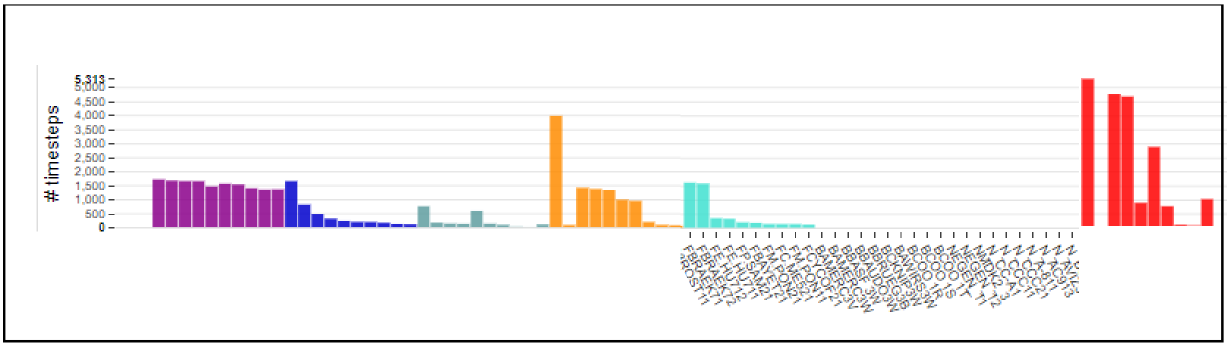


Figure 27: Number of timestamps with Pmin violation larger than 3% in the D2CF IGM@OriginalNP

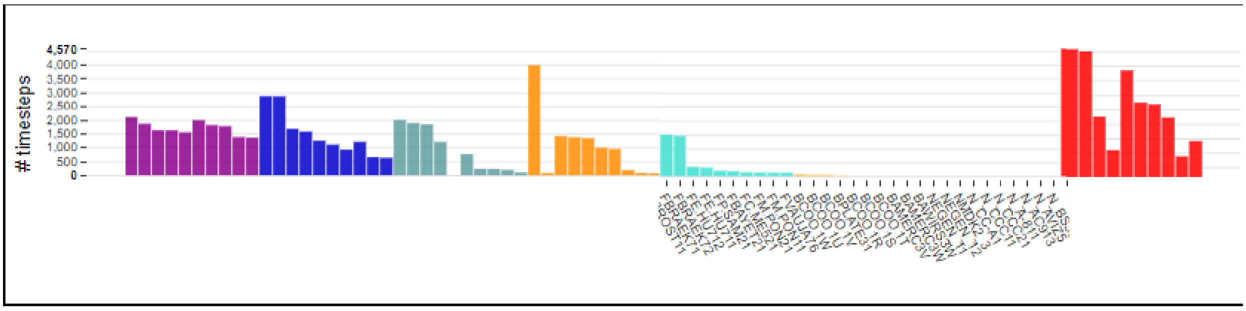


Figure 28: Number of timestamps with Pmin violation larger than 3% in the D2CF IGM@MCP

The following graphs present the Pmax and Pmin violations per TSO.

For the graphs in Figure 30, Figure 32, Figure 34 and Figure 36 which show average numbers, the average is calculated over all power plants in the control area of the respective TSO.

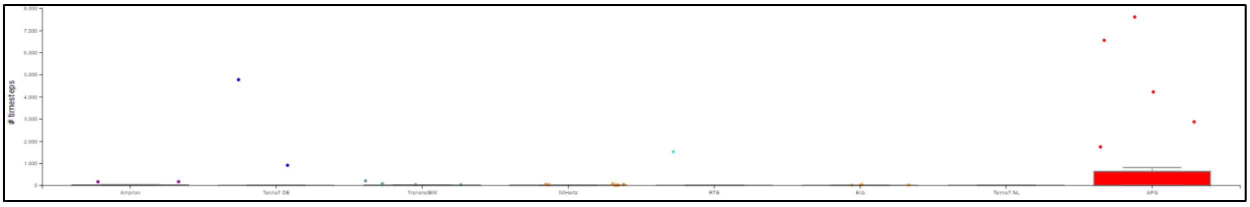


Figure 29: Statistical distribution of the number of Pmax violations larger than 3% for individual nodes in the D2CF IGM@OriginalNP

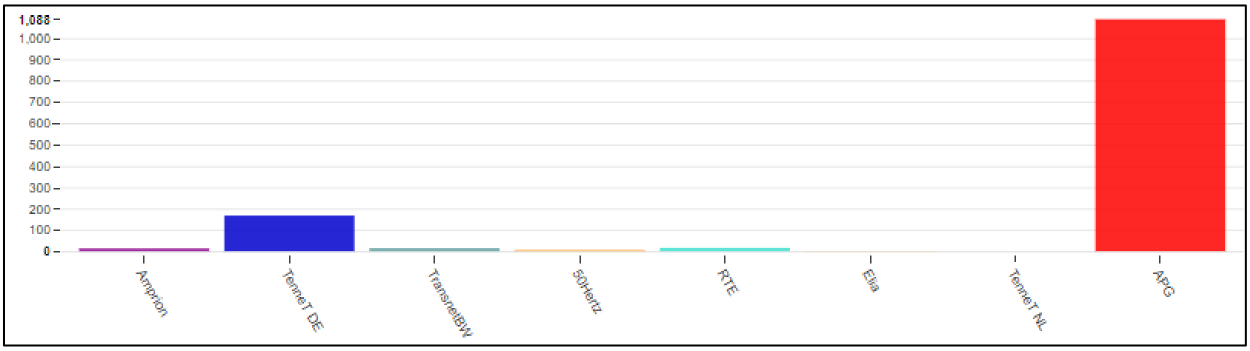


Figure 30: Average number of Pmax violations larger than 3% per TSO in the D2CF IGM@OriginalNP

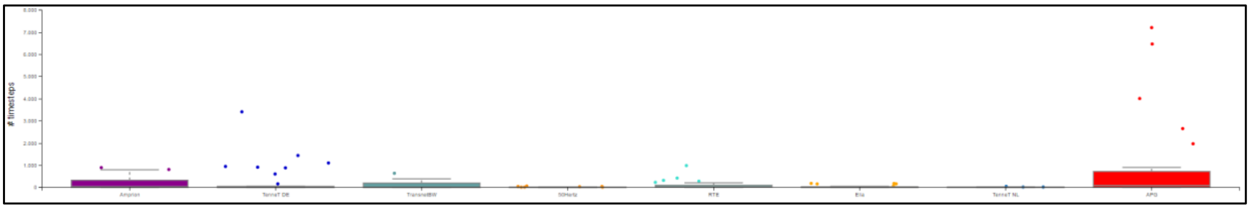


Figure 31: Statistical distribution of the number of Pmax violations larger than 3% for individual nodes in the D2CF IGM@MCP

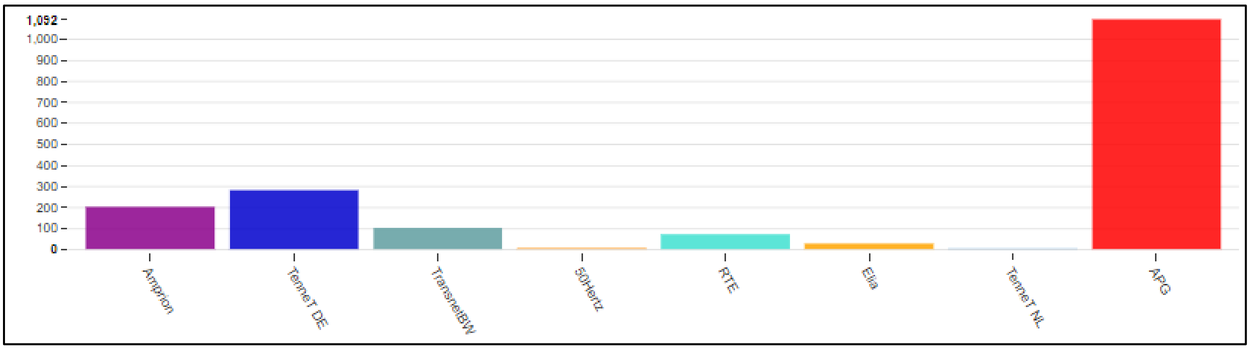


Figure 32: Average number of Pmax violations larger than 3% per TSO in the D2CF IGM@MCP

As expected, significantly more Pmax violations are observed for nodes included in the GSK after shifting the individual D2CF@OriginalNP to the DA MCP, since GSKs are linear and do not respect Pmin and Pmax. If power plants are expected to feed in at Pmax, Pmin or are expected not to run, already a small shift via GSKs suffices to violate Pmax or Pmin respectively.

There are several options how Pmin and Pmax violations could be reduced in GSK shifted grid models but all of them come with a downside.

- Model power plants in the D2CF differently. Instead of modelling them with an infeed of Pmax or Pmin leave a margin X for a potential GSK shift. So a power plant is for example modelled with an infeed of Pmax – X instead of Pmax. As long as the shift via GSK is smaller than X no Pmax violation will occur. The downside is, that the D2CF forecast itself is negatively influenced by the margin X. So a better Pmin/Pmax violation indicator is paid with a potentially worse “Compare D-2 IGMs with the Day-Ahead power plant schedules” indicator.

- Exclude power plants which feed in with Pmin or Pmax from the GSK to avoid a shift beyond the limit. The problem here is that a GSK shift is always needed either in upwards or downwards direction but it is not known in advance in which of the both. Therefore if e.g. all power plants feeding in at Pmax are excluded from the GSK but a downwards shift is performed the inclusion was superfluous in the end as anyways no Pmax violation would have occurred. If just all generators feeding in at Pmin or Pmax are excluded from the GSK this also increases the GSK factors of the remaining generators. In this study it has been observed that the accuracy indicators usually get worse with an increased GSK factor.

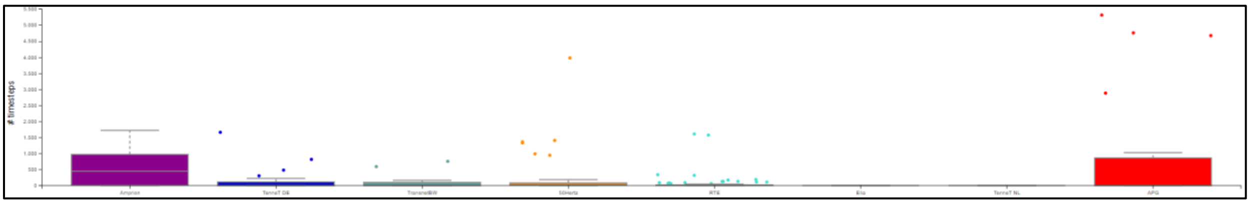


Figure 33: Statistical distribution of the number of Pmin violations larger than 3% for individual nodes in the D2CF IGM@OriginalNP

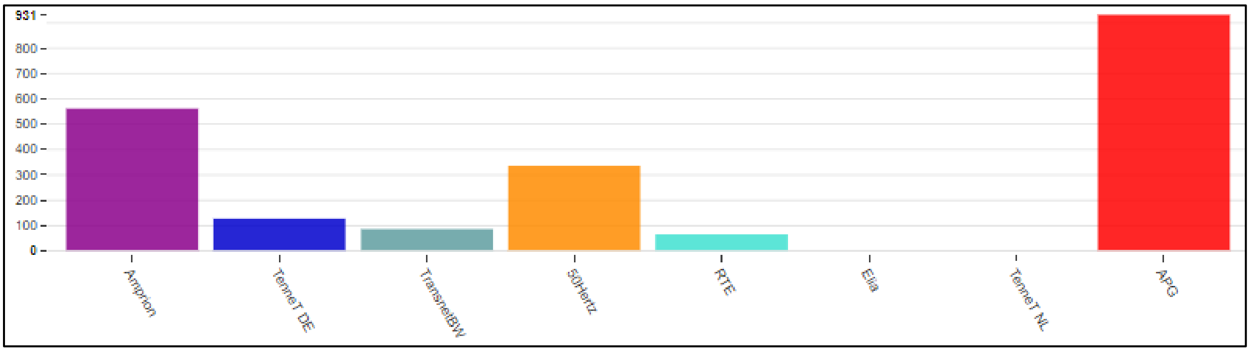


Figure 34: Average number of Pmin violations larger than 3% per TSO in the D2CF IGM@OriginalNP

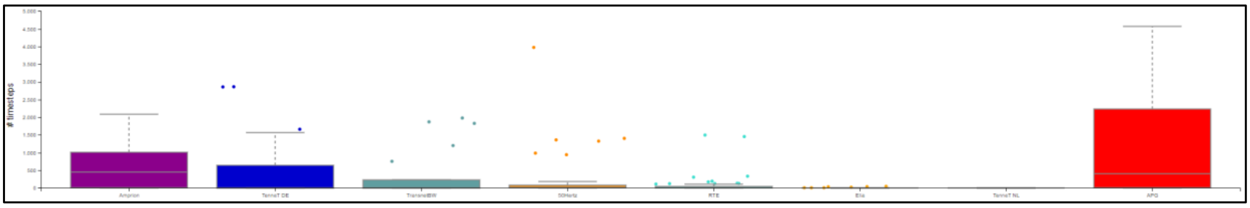


Figure 35: Statistical distribution of the number of Pmin violations larger than 3% for individual nodes in the D2CF IGM@MCP

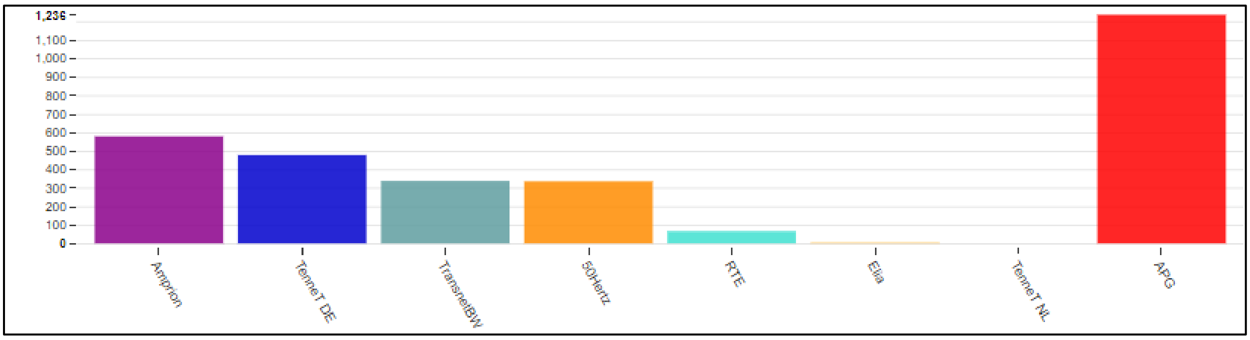


Figure 36: Average number of Pmin violations larger than 3% per TSO in the D2CF IGM@MCP

Analysis per TSO

APG:

- Pmax violations:
  As already explained, the nodes [redacted] do have little GSK relevant power infeed and relative high infeed of renewable energy, leading to high numbers of Pmax violations larger than 3% for the nodes and therefore to a high average number of Pmax violations larger than 3% for the TSO APG. For Example: the node [redacted] has ~1000 MW wind power and about 100 MW of GSK relevant power infeed connected. As we want to monitor the GSK performance in this study, the Pmax of this node is not 1100 MW but 100 MW (only the Pmax of the GSK relevant power plant is considered). In any model, where the infeed of this node is higher than 103 MW, this hour is monitored as a Pmax violation, leading to misleading high numbers of violations. APG is going to investigate, if the future grid models should be more detailed so that for instance in node [redacted] there will be no infeed anymore, as the underlying nodes with their infeed are modelled then (the one with the wind park and the one with the GSK power plant connected).
- Pmin violations:
  The Pmin violations will be investigated but are most likely linked to inconsistent Pmin values, and thus less related to GSK performance.

TransnetBW:

- The Pmax violations of [redacted] can be explained by a missing input file which lead to an erroneous D2CF creation of TransnetBW for some days. Pmax was violated by several hundred MW on those days. The error has been fixed in summer 2019. For all other nodes the violations in the D2CF IGM@OriginalNP are very small which is very important for TransnetBW. The ones that exist can be attributed to seldom errors in the data delivered by the power plant operators.
- To reduce the violations in grid models shifted via GSK measures would have to be implemented that negatively impact other KPIs. In TransnetBW´s view those negative impacts would outweigh the gain.

Amprion:

- Overall, a low level of Pmax violations can be seen. Pmax and Pmin violations mainly caused by shifts in [redacted]. In addition, additional Pmin violations occur for hard coal and gas power plants due to shifting beyond technical limitations that could cause by ramping up power plants originally not feeding in and the performed comparison with a static Pmin value for the whole timeframe.

5.2. Why a GSK shift often increases forecast error

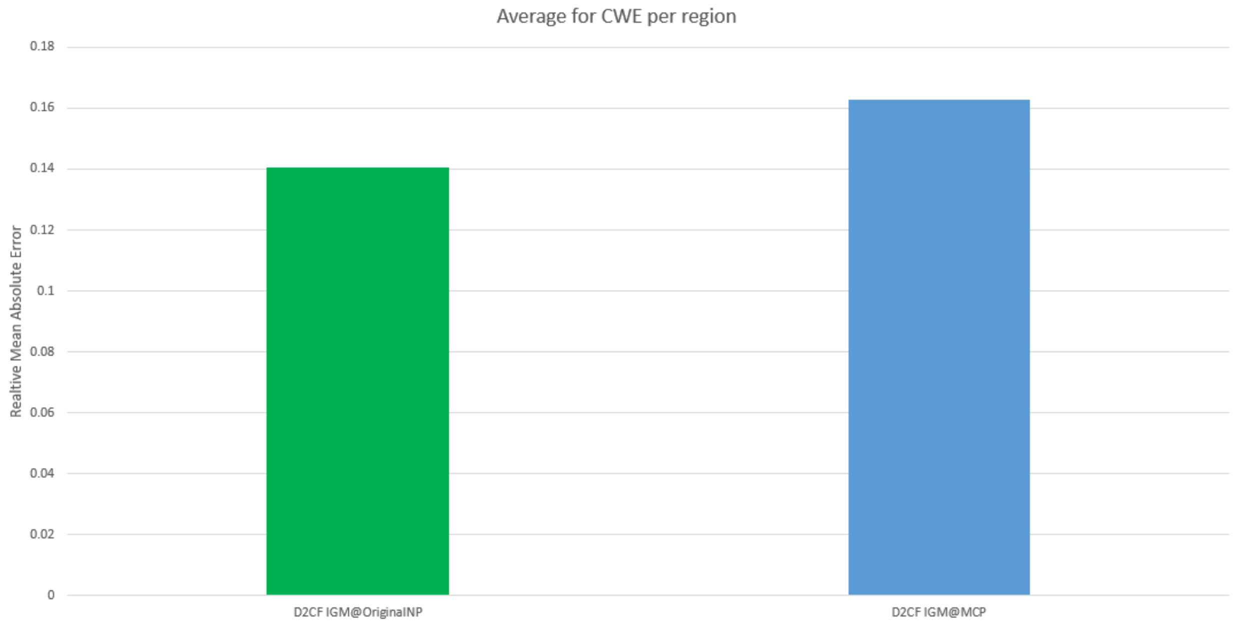


Figure 37: Comparison of different grid models to the DACF

In this chapter, it is explained why a shift in the grid model via the GSK often increases forecast error. One reason for this is that TSOs respect the technical limitations of power plants when creating the D2CF IGM@OriginalNP. Power plants will usually not feed in with

- generation below 0 MW (act as consumer, unless they are pumped storage power plants)
- generation between 0 MW and Pmin (technically not possible)
- Generation above Pmax

which reduces the maximal forecast error.

In contrast, after the shift via GSK it is possible that the power infeed is in those restricted intervals which are technically not possible. The following graph shows this behaviour exemplary. Often the power infeed in the D2CF@OriginalNP (dark blue) and in the DACF (orange) is zero. Forecasting that the power plant is not running, is often a perfect forecast. In the shifted D2CF@MCP (light blue) a deviation of several hundred megawatts is frequently observed due to the linear GSK shift.

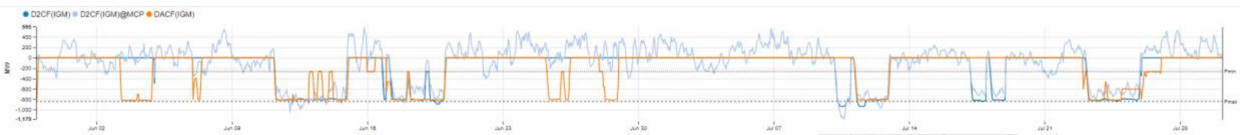


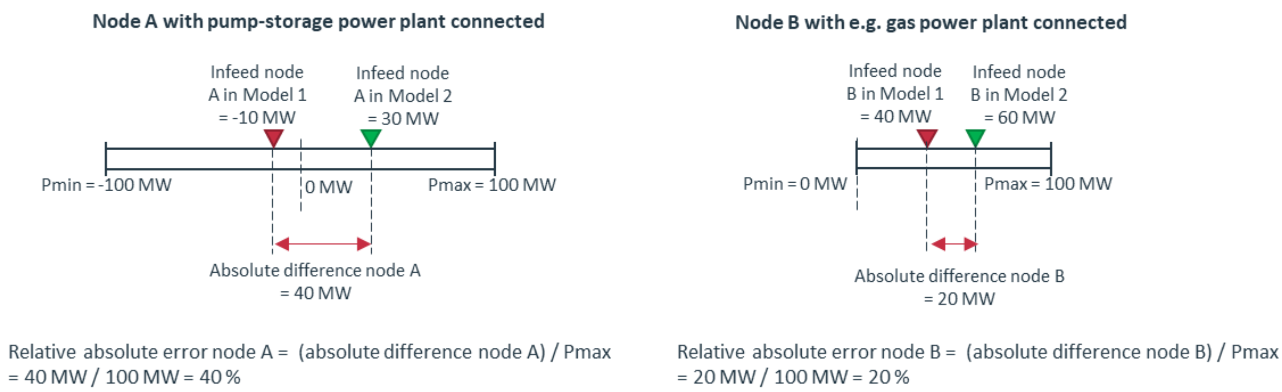
Figure 38: Infeed of a coal power plant in the D2CF IGM@OriginalNP, D2CF IGM@MCP and DACF

5.3. Impact of KPI calculation method on different node types / reason for high relative mean absolute error of pump-storage power plants.

Each of the KPIs in chapter 5.1.1. to 5.1.7. compares two models on a nodal granularity and provides either information about forecast accuracy, GSK quality or other aspects of e.g. the merging process. Since the difference in nodal infeed between two models can either be positive or negative, always the absolute value has been considered as a measure for the mismatch. Besides that, e.g. 10 MW difference can be much or little mismatch, depending on the power unit(s) connected to this node. That´s why all KPIs are calculated as relative mean absolute errors (RMAE, see formula below). For their calculation, the mean absolute infeed difference over all hours of the covered time period is divided by the maximum GSK power plant infeed of a certain node (Pmax).

$$RMAE\ of\ node\ A = \frac{\sum_i^{hours} |Infeed\ node\ A\ in\ model\ 1 - Infeed\ node\ A\ in\ model\ 2|}{Pmax\ node\ A \cdot Number\ of\ hours}$$

The higher RMAE for nodes with pump storage infeed can be explained by this formula too. Pmax reflects the maximum infeed from all GSK relevant power plants for a certain node. The infeed of pumped storage power plants can vary between maximum infeed and maximum consumption (pumping) and not only between Pmax and zero like for thermal units. The maximum error per timestamp is therefore not limited to Pmax but to Pmax_turbin – Pmin (for pumped storage power plants Pmin is the maximum power consumption of the pumps, Pmax is the maximum power generation). As for this type of node the infeed in the model can either be positive or negative (pumping or generation), the ratio of infeed difference to Pmax tends to be higher in comparison to nodes with generation units only. This effect is shown in the figure below:



As can be seen in the figure, node A has a higher relative absolute error than node B. In case of considering that the range of possible infeed from node A is -100 MW to + 100 MW, the relative absolute error would be equal to the one of node B. The higher relative mean absolute error for nodes with this type of power plant connected can therefore also be linked to the calculation method for the KPIs.

During the study the question occurred why APG can, based on the information of the power plant operators, predict the infeed of pumped storage power plants with a smaller RMAE than for example TransnetBW. As no methodological differences are observed (both TSOs use the forecasted schedules of power plant operators) a deeper look is taken at the particularities of both control areas. As explained above the RMAE depends on the maximum possible relative error that can be made when forecasting the infeed of pumped storage power plants. If the power of the turbines is as high as the power of the pumps of a power plant then the maximum possible relative error is 200% (predicted as full pumping while generating power or vice versa). In the example above the power plant would be predicted to pump with -100 MW but is actually generating 100 MW then the RMAE is:

$$\text{RMAE} = \frac{\left|(P_{predicted} - P_{actual})\right|}{P_{max}} = \frac{|(-100\text{MW} - 100\text{ MW})|}{100\ MW} = 200\%$$

The maximum RMAE as calculated in the example above for the pumped storage power plants in APG`s and TransnetBW`s control areas are on average at ~135% and ~175%. So if the power plant operators in the two control areas predict their infeed the complete opposite of the realised schedule then the relative error would be at 135% for APG and 175% for TransnetBW. This is due to the fact, that maximum pumping (maximum load) and maximum infeed of pumped storage power plants in the area of TNG are more symmetrical than those in the area of APG, leading to a higher RMAE due to a bigger span of deviation (numerator in the above equation).

5.4. Assessment of the potential to improve the overall forecast quality in D-2 by improving the GSK methodology

In this section, the results of an assessment of potential benefits of improving the GSK methodology while focusing on the D-2 and D-1 timeframe, are given.

Ideally, the GSK models the DA market behaviour in comparison to the assumption made in the individual grid models while minimizing the prediction error between forecasts. In general, a better forecast of net positions and power plant forecasts lead to less shifting via GSK and thus less importance of GSK accuracy. On the other hand, in case of high deviations between forecast and final market results, huge GSK shifts might be required to model the foreseen power plant schedules which increases the chances of errors.

To compare the current GSK performance with a benchmark, a “perfect GSK” can be created based on historical data. The application of this GSK would minimize the average error for the monitored bidding zone.
Such a GSK cannot be used in operation as potential errors are not known beforehand. Moreover, if the errors were known, an improvement could be implemented by updating the forecast in the D2CF.

However, this analysis can give more insights about the current performance and possible potential of improvements.

Creation of “theoretically optimal GSK”

To create the “theoretically optimal GSK” a constrained linear least-squares problem was solved which minimizes the distance between the needed shift by a GSK for each power plant considering the net position changes between D-1 and D-2 of the dedicated bidding zone and the generation forecast deviation from DACF to D2CF for each power plant.

See formula below:

$$\min_{GSK} \frac{1}{2} \|-(NP_{D-1} - NP_{D-2}) \cdot GSK - \ (P_{D-1} - P_{D-2})\|_2^2$$

$$such\ that \begin{cases} \sum GSK = 1\ for\ each\ bidding\ zone \\ 0 \leq GSK \leq 1\ for\ each\ powerplant\ of\ a\ bidding\ zone \\ NP_{D-1} - NP_{D-2}\ difference\ netposition\ from\ D-1\ to\ D-2 \\ P_{D-1} - P_{D-2}\ difference\ generation\ per\ powerplant\ from\ D-1\ to\ D-2 \end{cases}$$

Ideally, a GSK could be found that leads to the same power plant injection in D-2 as D-1 under the consideration that all GSK nodes are shifted by the delta net position of the D-2 IGM and the market clearing point in DA.

Overall, this is hard to realise as the equality constraint for each bidding zone requires that the delta net position needs to be allocated to all GSK nodes. Furthermore, ramping up and down of power plants is dependent on the difference of the net position forecast in D-2 and the final market clearing point. For example, the GSK cannot increase the power infeed of the power plants within a bidding zone in case the original forecast refers to a higher net position than the final market outcome. Shifting via GSK would result in lower generation for all GSK nodes which increases the error.

In addition, although the shift via GSK removes the forecast uncertainty of the net position it poses the risk to worsen the forecast accuracy of certain power plants due to the linearization (e.g. ignoring minimum and maximum infeed restrictions of power plants) at the same time.

The following figure shows the results of the average relative mean absolute error of the analysis for the optimised GSK ("perfect GSK") in comparison to today's GSK methodology (IGM@MCP) and the original individual D-2 grid model that was created by TSOs:

- "IGM@MCP" compares the D2CF IGM shifted by the GSK used during the FB computation to the DA MCP with the DACF
- "IGM@original" compares the un-shifted D2CF IGM as provided by TSOs for the FB computation with the DACF
- "Perfect GSK" compares the D2CF IGM shifted by the "perfect" GSK calculated as described above to the DA MCP with the DACF

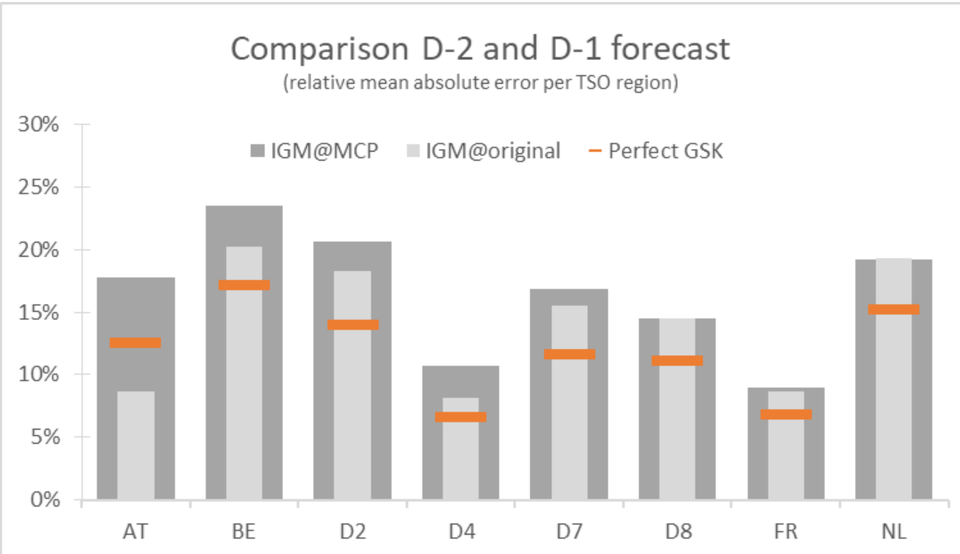


Figure 39: Potential improvements due to "perfect GSK" strategy

As explained above the GSK, the net position forecast and the power plant schedule forecast impact the forecast errors as shown in the figure above. It can be seen that even with a perfect GSK strategy, it is not possible to eliminate forecasting errors. Therefore, a better forecast of the power plant schedules and net positions is the key factor to improve overall quality as the additional improvement by a better GSK is limited to the remaining error after applying a "perfect GSK".

In addition, it is shown in chapter 5.2 that for most TSOs shifting via GSK increases the errors compared to the original forecast. This theoretically optimal GSK could only improve the current one between 2,1% and 6,5% compared to today's strategy (IGM@MCP).

For Austria, it is evident that the shift of power plants leads to an increase of the forecasting errors for the monitored nodes. Even with a "perfect GSK" the error increases by 3,9% compared with the error of the original D-2 forecast, which implies a good D-2 forecast in the first place.

For Germany it is observed that the original D-2 forecast contains smaller errors than the shifted grid models with the current GSK. The consideration of "Load Shift Keys" could help to improve the overall forecast of power plant injections. However, it could impact the quality of load nodes that are out of scope in this study.

For Belgium, the IGM@Original NP is not the best forecast (as detailed in section 4.5). Therefore, the results from the analysis above cannot be taken into account.

As France uses a country GSK strategy, possible deviations are shifted equally among all power plants within the country. This leads, together with a good original forecast, in particular due to large percentage of nuclear power plants, to small errors. Improving the GSK methodology has almost no benefits.

As seen above, the introduction of "Load Shift Keys" could help some TSOs to reduce the individual forecast error of each power plant. First of all, because adjustment on load nodes is a possibility on the grid, therefore the addition of load shift could better fit the reality. Secondly, as the "unavoidable error" due to the needed Netposition shifts, as long as the Netposition forecast does not match the later Day-ahead market clearing point, would be better distributed within the bidding zone. Indeed the error will be distributed to more nodes, leading to less deviation on each single node (to be compared with the French strategy of proportional GSK to distribute error on all nodes leading to lower relative deviations)In particular, for TSOs where the error largely increases from the IGM@orginalNP to the shifted grid model (IGM@MCP) an improved performance could be reached.

All conclusions should be viewed with the knowledge that the presented "theoretically optimal GSK" is only perfect in minimizing the deviation between the D2CF@MCP and the DACF power plant infeed. But the purpose of the GSK is not to minimize the forecast error included in the D2CF compared to the DA market result. This should be achieved by a good D2CF forecast.

General impact of modelling a "theoretically optimal GSK"

There are several reasons why an almost "perfect GSK" matters. Improved GSK methodologies can help to minimize deviations between D-2 and later forecasts and thus support minimizing reliability margins used for the capacity calculation. This could increase remaining available margins of CNECs and consequently the offered capacity for the market coupling. This could be an indirect benefit of a better GSK. Nevertheless, a better GSK strategy does not necessarily lead to more capacities and higher social welfare gains as this is not the primary objective of the GSK. However, good quality GSKs help to define the final flow based domain in a more accurate way. This in turn reduces the risk that the market clears in an area/corner, which might be available in case of a non-accurate GSK, which could lead to e.g. a higher need for redispatch. Therefore, good quality GSKs contribute to an efficient market coupling since they can also reduce the need for redispatching after the Day-ahead market coupling.

In general, quality matters to forecast expected load flows on critical lines which could cause operational issues during the later security analyses. The actual forecast of a single power plant -benchmark for this study- is less important than the general sensitivity of each line towards cross border exchanges. A good forecast allows TSOs to provide the market with save capacities unless LTA or MinRAM inclusion are triggered. The GSKs directly influence the PTDFs and indirectly the RAMs, which are the two parts of the FB parameters. RAMs are calculated at zero balance. The shift from best forecast to zero balance is performed by the GSKs. This means that the preloading of the grid before calculating the capacities is highly impacted by the GSK. Inaccurate GSKs can lead to inaccurate PTDFs and RAMs and therefore to an inaccurate FB domain. Possible consequences are that in case of a too small domain the market is more constraint than necessary from a grid security perspective or that in case of a too big domain costly remedial actions have to be activated to safeguard the given capacities.

The purpose of the GSK is to model a cross-border exchange as accurately as possible and to describe its physical implications on the grid. This means that a GSK with higher quality can lead to more or less capacities depending on the original error created by the lower quality GSK.

5.5. Impact of the update of Amprion's GSK in April 2019

In April 2019, Amprion updated its GSK methodology to improve the quality of its GSK. As this change was performed in the middle of the timeframe of this study, it's possible to show the impact of the update on overall forecast quality, in particular for Amprion's power plants.

Therefore, the monitored timeframe can be split into two timeframes:

- Before GSK update (until 17.04.2019)
- After GSK update (starting 18.04.2019)

As seasonal effects could influence the key performance indicators, the KPIs of other TSO are shown in comparison for the same timeframes.

The following figure shows the development for the relative mean absolute error per TSO region before and after the application of the updated GSK methodology on the original IGM and IGM shifted to the market clearing point in Day-ahead.

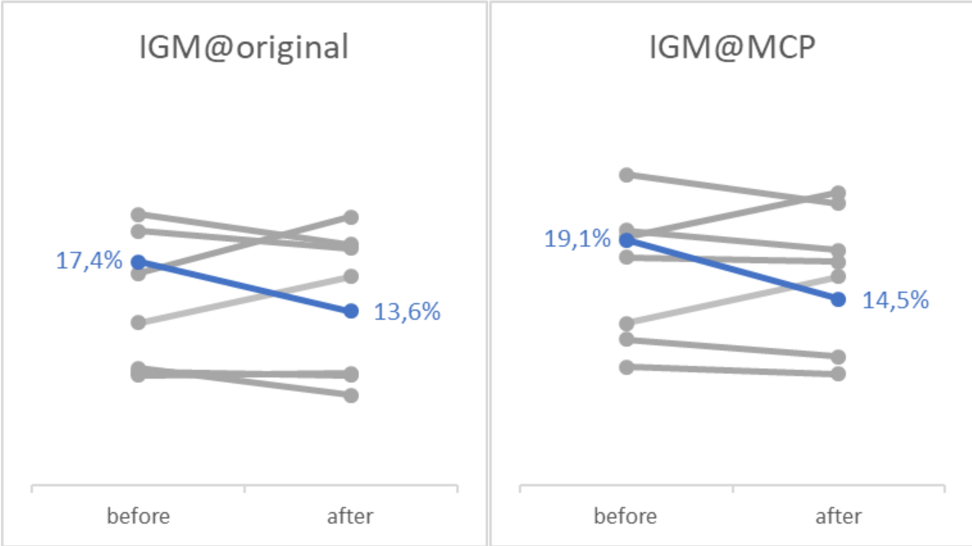


Figure 40: KPI: relative mean absolute error for the base case of D-2 (IGM@original) as well as shifted D-2 forecast (IGM@MCP) with the Day-Ahead power plant schedules (blue line: Amprion)

It shows an overall improvement for the KPIs of 3,8% for the original IGM and 4,6% for the shifted one. As Amprion preshifted the original grid models for the scope of this study, the benefits of an improved GSK can be seen here as well. It is observed that seasonal effects are small for non-German TSOs (0,4% up to 2,2%). Therefore, it can be concluded that the improvement of Amprion's GSK methodology is sustainable and not caused by seasonal effects.

The next KPI that was investigated was the number of violations of the Pmax and Pmin of the monitored power plants per TSO. The following figure shows an positive impact for Amprion’s power plants.

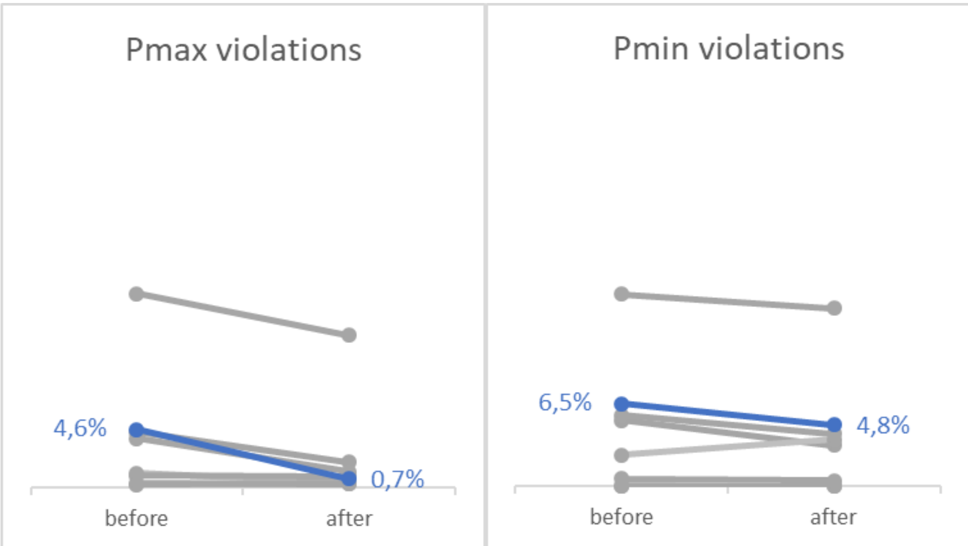


Figure 41: : KPI: relative Pmax and Pmin violations for the shifted D-2 forecast (IGM@MCP) with the Day-Ahead power plant schedules (blue line: Amprion)

To compare the number of Pmax or Pmin violations for two different timeframes, the amount of violations was divided by the absolute number of timestamps during the dedicated timeframe “The relative Pmax and Pmin violations per timestamp are shown for the timeframe “before” and “after” introducing the new methodology.

The number of Pmax violations decreases by almost 4% ending up below 1% overall. Also the Pmin violation indicator could be improved by 1,6%. It seems that the Pmax violation indicator is more dependent on seasonal effects as a general improvement could be observed for almost all TSOs.

Overall, the analysis shows the positive effects of the GSK update. The updated selection of GSK power plants and scaling the GSK factor with Pmax and Pmin values seems to enhance the overall quality for power plants within the control area of Amprion. A main driver for the improvements could be caused by the removal of the [redacted] of the GSK and adaption of the German Share Key which considers dedicated values for summer and winter situations since the update.

6. CONCLUSION

CWE TSOs have analysed their GSKs as applied in the period of 01/10/2018 – 01/10/2019. This one year period since the DE-AT BZB allowed taking most of the GSK evolutions (splitting of shared Austrian-German sharing key into a separate Austrian and German GSK) into account. The CWE Flow-Based Analytics Tool was used to study the agreed KPIs.
All KPIs agreed upfront between TSOs and NRAs have been calculated and included in this report. However, TSOs conclude that not all KPIs seem to be appropriate to measure GSK performance (e.g. comparisons with snapshots).

In general, it was concluded that the highest relative forecast errors are observed for pumped storage power plants which to a certain extend is caused by the normalization of forecast errors to Pmax. On the other hand, for nuclear power plants the smallest deviations were observed. As expected, significantly more Pmax and Pmin violations are observed for nodes included in the GSK after shifting the D2CF to the DA MCP since GSKs are linear and do not respect Pmin and Pmax.

The knowledge gained from the analysis of the KPIs, was applied to investigate what is needed to create a "perfect" GSK in terms of reducing the deviation between D2CF@MCP and the DACF. It is demonstrated that it is not possible to eliminate forecasting errors even with a "perfect" GSK strategy. Moreover, it can be concluded that a good forecast of the power plant schedules in the D2CF is the key factor to reduce this deviation. In addition, it is shown that for most of the CWE TSOs shifting via GSK increases the errors compared to the original forecast. However, a theoretical improvement could be reached between 2,1% and 6,5% compared to today's strategy. Nevertheless, the "perfect" GSK can only be produced ex-post as the error is dependent on the quality of the original TSO forecast.

In addition, the GSK monitoring study confirmed an overall positive impact of the updated GSK methodology, introduced by Amprion in April 2019, for its power plants.

CWE TSOs concluded that possible improvement could be realized by adding more power plants to the GSK, or the consideration of "Load Shift Keys" for some CWE TSOs as the unavoidable error as seen in the "Perfect GSK" section could be better distributed within the bidding zone and thus be reduced for each individual node.

As highlighted in section 4.5, the creation of IGM is done in two different ways (RefProg or Best forecast). In order to improve further the representativeness of the CGM, it could be assessed, in the Core framework, how the IGM creation shall be done and what is the impact on the CGM. For the moment, the two ways of creating the IGMs are kept and will in the future be harmonized by the Common Grid Model Alignment[5].

[5] All TSOs' Common Grid Model Alignment Methodology in accordance with Article 24(3)(c) of the Common Grid Model Methodology (entsoe.eu)

6.1 Lessons learned from the GSK Monitoring study and potential for harmonizing GSK methodologies

The aim of the study was to provide an initial overview of the influence of the GSK on the capacity calculation in CWE. For this purpose, different models were compared at the nodal level. In addition to real models that are used in the capacity calculation, synthetic models were also created in order to be able to consider different influencing variables in isolation. The results of this study are very complex and are dealt with in the individual subsections of Chapter 5. Due to the different GSK methods of the individual TSOs and the different circumstances for each TSO, no final "one fits all" conclusion can be drawn from the study.

The analysis that most closely allows an isolated statement about the GSK can be found in subsection 5.1.3., as this study compares the individual D2CF models shifted to the NP coming from the day ahead market clearing (resulting in the D2CF IGM@MCP) with the Individual DACF models (DACF IGM@OriginalNP, where the “OriginalNP” is also the NP coming from the market clearing). In a perfect scenario, the shifted D2CF model has the same nodal injections as the DACF IGM@OriginalNP, as the GSK perfectly mapped the change of NP (from D2CF IGM@OriginalNP to D2CF IGM@MCP) on all nodes in the model. This way, one can estimate how good the GSK works by looking at the nodal deviations in both models.

In addition to the results of the study, conclusions for a more detailed investigation were drawn during the evaluation, which might find use in a similar analysis in Core CCR:

- It would be advisable to calculate the relative mean absolute errors (KPIs in chapter 5.1.1 to 5.1.7.) for nodes with pumped storage power plants in respect to Pmax-Pmin instead of Pmax. This would lead to an equal treatment of nodes with pump-storage power plants connected.

- It would be advisable for TSOs to have more detailed IGMs where different types of power plants (e.g. GSK relevant and non GSK relevant power plants) are not modelled in one node, as this can lead to misleading high errors (see APG explanation in chapter 5.1.1.)

- A broader distribution of GSK factors to more nodes, possibly also nodes with only load and/or renewable energies connected helps to reduce the relative error created at the current GSK nodes due to the GSK shift. Of course this could lead to a decrease in forecast accuracy at the nodes newly included in the GSK. Although from a theoretical point of view, it is not advisable to add non-price sensitive nodes in the GSK a solution has to be found for the ongoing decrease of nodes with conventional power plants due to the energy transition.

- The “theoretically optimal GSK” could be used for further GSK harmonization processes as a theoretical benchmark. When different GSK strategies are analysed the “theoretically optimal GSK“could serve as a theoretical optimum for comparison.

7. ANNEX – LIST OF NODES WITH ASSOCIATED POWER PLANTS INCLUDED IN THE GSKS

Human readable name of the power plant or the generator unit	Fuel type	TSO	UCTE node
[redacted]	water storage	APG	[redacted]
[redacted]	water storage	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	hydraulic	APG	[redacted]
[redacted]	hydraulic	APG	[redacted]
[redacted]	hydraulic	APG	[redacted]
[redacted]	water storage	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	hard coal	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	pumped-storage	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	hard coal	APG	[redacted]
[redacted]	hydraulic	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	Gas	APG	[redacted]
[redacted]	Gas	APG	[redacted]
Amercoeur 3V	gas	BE	BAMERC3V
Amercoeur 3W	gas	BE	BAMERC3W
Awirs 3W	other	BE	BAWIRS3W
BASF 3W	gas	BE	BBASF 3W
Saint ghislain 3W	gas	BE	BBAUDO3W
Brueg 3B	gas	BE	BBRUEG3B
Knippegroen 3W	gas	BE	BCKNIP3W
Coo 1R	pumped-storage	BE	BCOO 1R
Coo 1S	pumped-storage	BE	BCOO 1S
Coo 1T	pumped-storage	BE	BCOO 1T
Coo 1U	pumped-storage	BE	BCOO 1U
Coo 1V	pumped-storage	BE	BCOO 1V
Coo 1W	pumped-storage	BE	BCOO 1W
Zwijndrecht Inesco 3U	other	BE	BCZWIJ3U
Zwijndrecht Inesco 3V	other	BE	BCZWIJ3V
Zwijndrecht Inesco 3W	other	BE	BCZWIJ3W

Drogenbos 3U	gas	BE	BDROGE3U
Drogenbos 3V	gas	BE	BDROGE3V
Scheldelaan 3W	gas	BE	BESSO 3W
Ham 3R	gas	BE	BHAM 3R
Herdersbrug 3U	gas	BE	BHBRUG3U
Herdersbrug 3V	gas	BE	BHBRUG3V
Wilmarsdonk 31	gas	BE	BKRUSS31
Wilmarsdonk 32	gas	BE	BKRUSS32
Lanaken 3W	gas	BE	BLANAK3W
Seraing Leval 2W	gas	BE	BLEVAL2W
Lillo 32	gas	BE	BLILLO32
Plate-Taille	pumped-storage	BE	BPLATE31
Ringvaart 3W	gas	BE	BRINGV3W
Rodenhuizen 3W	other	BE	BRODEN3W
Schaerbeek	other	BE	BSCARB32
Seraing	gas	BE	BSERAI21
Tergnée	gas	BE	BTERGN31
Vilvoorde	gas	BE	BVERBR3A
Zwijn 31	other	BE	BZWIJN31
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MORANDES 1	gas	FR	FBAYET21
BLAYAIS 1	nuclear	FR	FBLAYA11
BLAYAIS 2	nuclear	FR	FBLAYA12
BLAYAIS 3	nuclear	FR	FBLAYA13
BLAYAIS 4	nuclear	FR	FBLAYA14
BLENOD 5	gas	FR	FBLENO11
BOLLENE 1-6	water storage	FR	FBOLL521
BOUCHAIN 1	gas	FR	FBOUCH11
DK6 1	gas	FR	FBRAEK71
DK6 2	gas	FR	FBRAEK72
BUGEY 2	nuclear	FR	FBUGEY11
BUGEY 3	nuclear	FR	FBUGEY12
BUGEY 4	nuclear	FR	FBUGEY13
BUGEY 5	nuclear	FR	FBUGEY14
BELLEVILLE 1	nuclear	FR	FBVIL711
BELLEVILLE 2	nuclear	FR	FBVILX11
CROIX-DE-METZ 1	gas	FR	FC.ME521
CATTENOM 1	nuclear	FR	FCATG111
CATTENOM 2	nuclear	FR	FCATG211
CATTENOM 3	nuclear	FR	FCATG311
CATTENOM 4	nuclear	FR	FCATG411
CHINON 1	nuclear	FR	FCHIN211

CHINON 2	nuclear	FR	FCHIN212
CHINON 3	nuclear	FR	FCHINX11
CHINON 4	nuclear	FR	FCHINX12
CHOOZ 1	nuclear	FR	FCHOO111
CHOOZ 2	nuclear	FR	FCHOO211
CIVAUX 1	nuclear	FR	FCIVAU11
CIVAUX 2	nuclear	FR	FCIVAU12
CORDEMAIS 3	oil	FR	FCORD511
CORDEMAIS 5	hard coal	FR	FCORD521
CORDEMAIS 4	hard coal	FR	FCORD522
CRUAS 1	nuclear	FR	FCRUA511
CRUAS 3	nuclear	FR	FCRUA512
CRUAS 4	nuclear	FR	FCRUA513
CRUAS 2	nuclear	FR	FCRUA514
CYCOFOS 1	gas	FR	FCYCOF21
DAMPIERRE-EN-BURLY 1	nuclear	FR	FD.BUR11
DAMPIERRE-EN-BURLY 2	nuclear	FR	FD.BUR12
DAMPIERRE-EN-BURLY 3	nuclear	FR	FD.BUX11
DAMPIERRE-EN-BURLY 4	nuclear	FR	FD.BUX12
EMILE-HUCHET 7	gas	FR	FE.HU711
EMILE-HUCHET 8	gas	FR	FE.HU712
EMILE-HUCHET 6	hard coal	FR	FE.HUC22
FESSENHEIM 1	nuclear	FR	FFESS511
FESSENHEIM 2	nuclear	FR	FFESS512
FLAMMANVILLE 1	nuclear	FR	FFLAMA12
FLAMMANVILLE 2	nuclear	FR	FFLAMA13
GRANDES RIVIERES 1	gas	FR	FG.RIV21
GOLFECH 2	nuclear	FR	FGOLF511
GOLFECH 1	nuclear	FR	FGOLF512
LA GRACIEUSE 1	gas	FR	FGRACI21
GRAVELINES 1	nuclear	FR	FGRAV511
GRAVELINES 2	nuclear	FR	FGRAV512
GRAVELINES 3	nuclear	FR	FGRAV513
GRAVELINES 4	nuclear	FR	FGRAV514
GRAVELINES 5	nuclear	FR	FGRAV515
GRAVELINES 6	nuclear	FR	FGRAV516
HAVRE 4	hard coal	FR	FHAVRE21
MARTIGUES-PONTEAU 6	gas	FR	FM.PON11
MARTIGUES-PONTEAU 5	gas	FR	FM.PON21
MONTEZIC 1&2	pumped-storage	FR	FMTEZI11
MONTEZIC 3&4	pumped-storage	FR	FMTEZI12
NOGENT-SUR-SEINE 1	nuclear	FR	FN.SE111
NOGENT-SUR-SEINE 2	nuclear	FR	FN.SE211
PONT-SUR-SAMBRE 1	gas	FR	FP.SAM21

PONT-SUR-SAMBRE 1	gas	FR	FP.SAM23
PALUEL 3	nuclear	FR	FPALUE11
PALUEL 2	nuclear	FR	FPALUE12
PALUEL 1	nuclear	FR	FPALUE13
PALUEL 4	nuclear	FR	FPALUE14
PENLY 1	nuclear	FR	FPENLY11
PENLY 2	nuclear	FR	FPENLY12
PROVENCE 5	hard coal	FR	FPROV522
REVIN 1	pumped-storage	FR	FREVI511
REVIN 2	pumped-storage	FR	FREVI512
REVIN 3	pumped-storage	FR	FREVI513
REVIN 4	pumped-storage	FR	FREVI514
ST-ALBAN-ST-MAURICE 1	nuclear	FR	FSSAL711
ST-ALBAN-ST-MAURICE 2	nuclear	FR	FSSAL712
ST-LAURENT-DES-EAUX 1	nuclear	FR	FSSEA211
ST-LAURENT-DES-EAUX 2	nuclear	FR	FSSEA212
TRICASTIN 4	nuclear	FR	FTRIC621
TRICASTIN 3	nuclear	FR	FTRIC622
TRICASTIN 2	nuclear	FR	FTRIC623
TRICASTIN 1	nuclear	FR	FTRIC624
TRICASTIN 4	nuclear	FR	FTRICA21
TRICASTIN 3	nuclear	FR	FTRICA22
TRICASTIN 2	nuclear	FR	FTRICA23
TRICASTIN 1	nuclear	FR	FTRICA24
GRAND MAISON 7&8	pumped-storage	FR	FVAUJA71
GRAND MAISON 5&6	pumped-storage	FR	FVAUJA72
GRAND MAISON 11&12	pumped-storage	FR	FVAUJA73
GRAND MAISON 9&10	pumped-storage	FR	FVAUJA74
GRAND MAISON 3&4	pumped-storage	FR	FVAUJA75
GRAND MAISON 1&2	pumped-storage	FR	FVAUJA76
Amer 8	hard coal	NL	N_A-811
Amer 9	other	NL	N_AC913
AVI Hengelo	other	NL	N_AVIZ5
Borssele 30	nuclear	NL	N_BS303
Claus A	gas	NL	N_CC-A1
Claus C1	gas	NL	N_CCC11
Claus C2	gas	NL	N_CCC21
Claus C3	gas	NL	N_CCC31
Claus C4	gas	NL	N_CCC43
Centrale Rotterdam	hard coal	NL	N_CR101
Delesto	gas	NL	N_DES15
Diemen 33	gas	NL	N_DM333
Diemen 34	gas	NL	N_DM341
Eems 20 G	gas	NL	N_EC202G

Eems 20 S	gas	NL	N_EC202S
EC-30	hard coal	NL	N_EC301
EC-31	hard coal	NL	N_EC311
EC-3	gas	NL	N_EC-32
EC-5	gas	NL	N_EC-52
EC-6	gas	NL	N_EC-61
EC-7	gas	NL	N_EC-71
Eemshaven 10	gas	NL	N_EH-11
Eemshaven 20	gas	NL	N_EH-21
Eemshaven 30	gas	NL	N_EH-31
Elsta G	gas	NL	N_ES1G3
Elsta S	gas	NL	N_ES1S3
EVI Coevorden	gas	NL	N_EVIC5
Flevo 4	gas	NL	N_FL-41
Flevo 5	gas	NL	N_FL-53
IJsselcentrale 1	gas	NL	N_HC615
IJsselcentrale 2	gas	NL	N_HC625
Hemweg 8	hard coal	NL	N_HW-83
Hemweg 9	gas	NL	N_HW-93
IJmond	gas	NL	N_IJM 3
Lage Weide 6 G	gas	NL	N_LWE63G
Lage Weide 6 S	gas	NL	N_LWE63S
WKC Moerdijk 1	gas	NL	N_MD113
WKC Moerdijk 2	gas	NL	N_MD123
WKC Moerdijk 3	gas	NL	N_MD133
WKC Moerdijk 4	gas	NL	N_MD143
Merwedekanaal 12 G	gas	NL	N_MK123G
Merwedekanaal 12 S	gas	NL	N_MK123S
Maasstroom	gas	NL	N_MSEC1
Maasvlakte 3	hard coal	NL	N_MV-31
PerGen 1	gas	NL	N_PG013
PerGen 2	gas	NL	N_PG023
Rijnmond Energie A	gas	NL	N_RECA3
Rijnmond Energie B	gas	NL	N_RECB3
Rijnmond Energie X	gas	NL	N_RECX3
RoCa G	gas	NL	N_ROC33G
RoCa S	gas	NL	N_ROC33S
Sita	gas	NL	N_RSB 3
Salinco	gas	NL	N_SAL05
Scaldia (Eerbeek)	gas	NL	N_SCE 3
Sloe 10	gas	NL	N_SL101
Sloe 20	gas	NL	N_SL201
NAM Schoonebeek	gas	NL	N_SNBV5
Swentibold G	gas	NL	N_SW-13G

Swentibold S	gas	NL	N_SW-13S
Velsen 24	gas	NL	N_VN243
Velsen 25	gas	NL	N_VN253
WKC Helmond 1	gas	NL	N_WKC13
WKC Helmond 2	gas	NL	N_WKC23
Enecogen 10	gas	NL	NEGEN_11
Enecogen 20	gas	NL	NEGEN_12
Moerdijk 2	gas	NL	NMDK2_3