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Integrated dynamic energy management for steel production

(DYNERGYSteel)

FINAL REPORT

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Integrated dynamic energy management for steel production

(DYNERGYSteel)

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Final report

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1 Final summary

WP 1 Power market characterization: tariffs, negotiation, fluctuations, events

The aim of this work package is the determination of the power market and network characteristics influencing monitoring, forecasting and management of the power engagement in the steel plants.

There are several Electricity markets depending on when the energy is booked with respect of when is utilized. In Figure 1 the Electrical Energy Market models is shown highlighting the markets depending on the energy demand forecasting time..

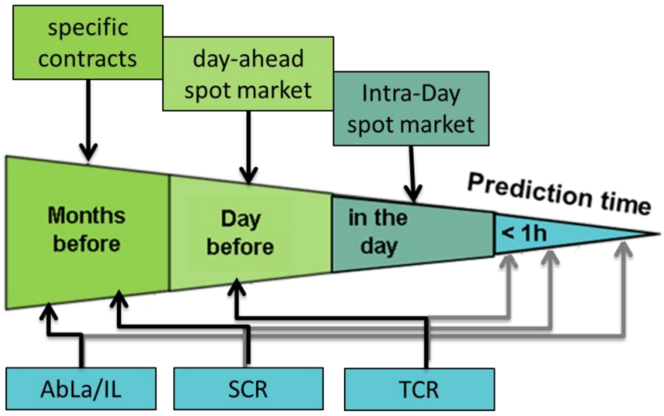

Figure 1 Price models for the purchase of electrical energy [1]

The project is focussed on the markets from the day ahead to real time.

Task 1.1 Electricity market characterization and supply profile determination

In this task the Day ahead & Intra Day markets have been deeply analysed leading to the following conclusion.

The company can access directly the Day ahead & Intra Day markets. This represent the most flexible option allowing to take full profit from hourly price differences and allowing to change the consumption profile nearer to real-time. It can be risky because it expose to the volatility of Power Exchange prices without forward contracts that fix the price for the bulk of energy consumption and it requires an internal structure that only larger companies could afford. In Germany, Belgium, Austria negative prices are present both in day-ahead and balancing markets.

Task 1.2 Characterization of grid events (slots, power fluctuations etc.) with their dynamical characteristics coming from the power network

The activities in this task aim at the categorization of events due to the grid and the grid status; this is necessary to determine the dynamical response to be activated by the steel industry in terms of typical time shifts between event and reaction. Moreover, the economic value of the ancillary services that, in principle, could be provided by a flexible electricity demand in the steel industry, is assessed.

Information about the technical regulation of ancillary services in Italy and in Germany, with a particular focus on balancing services, such as primary, secondary and tertiary regulation, as well as interruptible loads has been collected.

According to the required technical performances, tertiary regulation and interruptible loads seem the two services most suited for the provision by large industrial loads, even if in Germany also secondary regulation can be provided by flexible loads. Italy start some pilot projects for these markets in 2017.

An analysis of the situation in several other European countries with reference to the participation of the demand in the balancing markets and the presence of negative prices has been carried out.

[1] FOREnergy: "Ergebnispapier – Flexibilisierung der Energienachfrage von industriellen Verbrauchern", Ergebnisse des Arbeitskreises 1 "wirtschaftliche Synchronisation von Energieangebot und –nachfrage" des Forschungsverbundes FOREnergy, January 2015

Task 1.3 Elicitation and definition of the negotiation rules and protocols between steel manufacturing demand and grid offer

The analysis carried out in this task leads to the following opportunities for steel industries to participate in energy markets.

The first opportunity (day-ahead & Intra-day) is based on the possibility to take advantage from the oscillation of the energy price during the day and between working days and weekends / holidays. It can be noticed that the hourly price profile tends to be similar during different days therefore the production can be scheduled accessing the day ahead market privileging the utilization of energy during time slots that have lower cost. This means not only money savings but also less environmental impact due to the fact that when the price is lower electricity is normally generated by less expensive and less polluting (possibly renewable) production sources.

The second opportunity (Secondary and Tertiary Control Reserve SCR-TCR) is related to the possibility to dynamically react to grid events providing ancillary (typically balancing) services for the secure operation of the power system. This means both: decreasing or increasing the energy utilization. In Germany consumers are able to participate at the balancing market, both as a single user or as a consortium, while in Italy the regulatory authority is working on the possibility of enabling also the consumers to participate (up to now it is only possible for dispatchable generators with an installed power greater 10 MW).

The interruptible loads (AbLa-IL) are the third opportunity, more adopted in Italy where is paid only based on power (MW) offered by the plant and not on energy (MWh). This situation is more related to grid security, i.e. very critical situation, therefore the reaction time should be faster compared to the second opportunity. Since in our experience the plant offers for interruption a percentage of the total power capacity, it is very important to control the overall energy utilization in the plant during the disconnection time in order to avoid an increment of non-interruptible loads that could partially offset the interrupted amount leading to the payment of fees and the possible exclusion from the programme.

WP 2 Power demand by the steel plants: monitoring the actual engaged power and electric energy consumptions.

The aim of this Work Package is the collection of available data with reference to the process route of the industrial partners plants, the analysis of data related to events and the relevant data model derivation, the implementation of the online-monitoring system, using existing data and the additional measurement devices installed.

Task 2.1 Manufacturing routes and layout analysis

The four plants of the industrial partners considered in this project can be regarded to provide a view on different types of steelmaking plants. In fact one stainless steelmaking plant for flat products with the complete production lines from EAF melting to finishing (AST), one plant for low and medium alloyed construction and engineering long products (LSW), one plant for special steel long products for automotive and mechanical industry (ORI) and one plant for hot rolled narrow strip production mainly for cold rollers (HHO) are covered.

From the analysis performed in this task EAF and LF have been individuated as the most relevant processes to be studied for LSW and ORI, while at AST EAF and HRM will be the main objective of Electricity Flow Sheet Model (EFSM). HHO’s work is devoted to the development of additional load flexibilities in form of additional electricity usage by reacting on grid demands and the definition of the relevant processes/machines taken into consideration is done in WP4.

Task 2.2 Definition of the Data Model for power engagement and electric energy consumption analysis and tune up of existing DBs

According to the analysis of the reference plants characteristics done in Task 2.1 the general Data Model has been defined in order to describe the most important sources of power engagement and electricity use, considering the role in the project. A description of the available processes and energy data at each of the industrial partner plant is provided together with the eventually necessary enhancement.

The energy Data are available at least on a 15 min base, but mostly on a faster sampling rate, on all the involved plants globally and specifically for the processes individuated in Task 2.1. Improvement for energy measurements were individuated and implemented during the project to enhance the monitoring capabilities necessary for the implementation of DYNERGYSteel.

Task 2.3 Monitoring devices adjustment, power load characteristics analysis and characterization; preliminary data acquisition campaigns

This task aimed at the preliminary characterization of both internal (process data) and external data (grid behavior). Data from plant have been collected and statistically evaluated in order to quantify the energy necessary to each process identified in previous tasks.

Four different aspects were monitored and analyzed within the reporting period of the project. These aspects are

- an analysis of the EAF power load characteristic of single heats
- a statistical analysis of the EAF heats and operation mode,
- an analysis of the main electrical energy consumers of the steel mill (yearly energy report),
- an analysis of the power load characteristic of the steel mill with a focus on short term deviations of the 15 minutes intervals.

With the aim of better understanding the possibilities to access the Control Reserve market an analysis of the global imbalance of network have been performed based on data from Italian TSO. The aim is to develop a prediction algorithm whose result are taken into consideration in calculating the KPI and integrated in the agent system. Several sophisticated and advanced techniques in order to predict sign of imbalance of the National Transmission Network, average selling price at the Dispatching Services Market and average purchase price at the Dispatching Services Market have been applied.

Task 2.4 Monitoring the actual power engagement and historical event frequency

The monitoring systems have been enhanced or implemented in the reference plants improving not only the number of processes monitored but also the ease to use.

WP 3 Forecast of power engagement

In this WP the actual procedures for forecasting the power demand has been studied with the aim of enhancing the accuracy of the booked profile. Historical data analysis has been carried out in order to evaluate relations among energy, process and product data to determine the electricity needs based on product and process characteristics.

An electricity flow-sheet model that can forecast the energy consumption related to those plants of a steel industry characterized by a relevant energy demand, in order to estimate the energy requirement in the more plausible manner has been developed.

Based on those result control loop to manage the energy adjustment has been developed.

Finally, an analysis of the flexible disconnectable loads in steel plants has been carried out taking into consideration the specificity of the industrial partners but aiming to have general remarks for the steel companies participation in energy markets.

Task 3.1 Development of the methodology to predict the electric energy demand in the steel plant according to heat / process and product mix

The accuracy and reliability of the day-ahead forecast of the electrical energy demand is enhanced by considering energy consumption related not only to the specific process but also to the characteristics of the product. The activities are therefore focussed on the determination of the electrical energy consumption depending on the product type. In particular EAF energy demand depending on the steel grades to be produced and rolling mill energy demand based on product characteristics (such as geometry, process line and steel type) has been analysed based on data gathered from the industrial partners plants. Prosecution of the project.

Task 3.2 Development of Electricity Flow Sheet Model (EFSM) of the process/plant systems; identification of disconnectable loads, energy storage and possible switching between gas and electric sources

An electricity flow-sheet model that can forecast the energy consumption related to those plants of a steel industry characterized by a relevant energy amount consumed has been developed in order to estimate the energy requirement in the more plausible manner. The flow sheet model has been developed in order to be easily generalized, by specializing the energy time consumption of a production item for each particular plant.

Task 3.3 Forecast model development and validation

Different time frames have been taken into considerations to develop the models for forecasting the power engagement: Medium (for the next shift and up to 3 days), short (for the next 90 minutes) and very short (for the next 15 minutes). The forecasted electricity demand in medium term, integrated with information from the production schedule, is used for the preparation of the profile to be shared with the energy provider the day before, the short term can be used to adjust the energy needs participating in the intra-day market while the very short term is used to minimize the 15 min peaks, to participate in the balancing market or to recover from an unpredictable event both internal or external.

Several approaches have been developed depending on the time frame, the process and the variability of its behaviour, and the levels of precision necessary ranging from analytical to statistical approaches. In EAF in medium time frame the processing time and more the energy demand profile can vary a lot even for same type of product; so in this case a detailed profile might not be reasonable in all cases, but an average value for time and energy demand with some security margin gives already a good assumption. When considering short to very short period a detailed model has been set up able to evaluate the melting progress in order to be able to decide whether is possible to reduce the power to limit the actual energy demand. In case of HRM the profile for each type of products is modelled with a good precision, because there is not much variance between different products of the same type but the energy profile itself has a characteristic course.

Task 3.4 Methods and control-loops to adjust the power engagement according to events

Control loop methods was identified, implemented and tested aiming at modifying the loads in order to adjust the power engagement according to the request. In particular the focus is identified in the reduction of power load in EAF process at the industrial partners plant where EAFs are present.

The aims of controlling the melting power engagement of the EAFs is to reduce power peak load within the 15 min time interval reducing consequently costs for power supply. This can be achieved by:

- controlling the maximum load, avoiding to exceed the power peak load limit within the 15 min time interval
- shifting the load to the next time slot, e.g. by delaying the start of a furnace, in order to avoid exceeding the peak load

while:

- avoiding process interruptions as much as possible, to keep the productivity high
- realizing an energy demand profile as regular as possible

Task 3.5 Scenario analysis to define possible improvements aimed at increasing electricity consumption flexibility

An analysis of the flexible disconnectable loads in steel plants has been carried out taking into consideration the specificity of the industrial partners, but aiming to have general remarks for the steel companies participation in energy markets.

In general the output of a steel plant must not be affected by flexible loads at all. Only a few plants or machines of a steel mill have a reserve capacity and may be used as a flexible load. This has to be considered in detail at the relevant plant. The following flexible loads were identified and analysed:

- Electric Arc Furnaces
  EAF is the main power consumers of an EAF cycle steel plant and main responsible for the energy fluctuations. In principle the load of an EAF is adjustable depending on the phase of the process, however implication on the productivity should be considered and managed. EAF can participate in decreasing the overall plant energy demand giving also contribution in the limitation of the peak load. When more than one is present in a plant is fundamental to manage them accordingly. In Italy EAF participate in Interruptible Load market.
- pressurized air production
  Due to the fact that the use of pressurized air is not predetermined and follows a more or less stochastic flow this grid system cannot really be used as a disconnectable load.
- emergency power supply
  These emergency power supply units may be used as an aggregate to generate positive control energy on demand to support the grid.
- oxygen production
  The possibility to participate in electricity market depends on the type of oxygen prodution. Cryogenic processes need hours to restart and therefore cannot be used, while non-cryogenic type are in general suitable to participate in energy markets.
- hall lighting, air conditioning including fan, cooling towers

These loads can be used as flexible loads and are tested in the project mainly for the purpose of increasing the energy demand.

WP 4 Development of online devices to react on electric grid events

The objective of the work package 4 is to improve the power load flexibility and control capabilities through the implementation of suitable aggregates to increase (on time) instantaneous electric energy demand in order to react on grid signals.

Task 4.1 Determination of most suitable process stages for additional electric loads

The overall aim of the task 4.1 is to find suitable aggregates for enhancing the energy demand flexibility at HHO by analysing and eventually revamping suitable aggregates. The gained flexibility can be commercialized in the electricity market.

Several potentially interesting aggregates have been inspected and were taken into closer consideration and analysis considering the potential electricity consumption and the difficulty for the realization.

Task 4.2 Feasibility study of additional electrical load for the most promising process stage and estimation of economic benefits

The focus of Task 4.2 is on the feasibility study of the most promising process stages to enhance electrical load and estimation of economic benefits. An economical investigation of revenues and necessary investments costs has been carried out based on negative secondary control market analysis and offers from suppliers for new aggregates construction.

The unpredictable decline in revenues for participants in the electricity market leads to the final choice, among the ones foreseen in the proposal, to extend already existing aggregates with additional automation possibilities.

The solution foreseen is furthermore easier to apply to other plants in Europe due to lower investments while assuring the possibility to actively participate in the balancing market through an intermediary and increase efficiency of the energy consumption inside the plant.

Task 4.3 Development, construction and implementation of additional electric loads

The connections of the aggregates and the management computers have been installed in order to enable the participation of HHO on the balancing markets. One virtual machine has been installed and put in operation for this purpose at HHO. Furthermore the data about the chosen aggregates have been collected for the use in the de development of the additional loads manager software.

Task 4.4 Modelling of electric load availability

The modelling of the additional loads was essentially based on the load constraints evaluation and the cost function. The cost function must take into account all the load constraints and evaluate the optimal decision for the enabling or disabling of each additional load. Furthermore, due to the different characteristics of each load, the agent based modelling lead to optimal use of each aggregate.

Task 4.5 Development of control concepts

The agent based control has been individuated as a suitable technology to manage all the involved aggregates and efficiently ensure the availability of the requested load.

For this purpose two types of agent were designed. The load agent, which task is the internal management of each aggregate constraints, the evaluation of the cost function, and the communication to Manager Agent of its load availability.

The manager agent, which task is to manage the overall loads availabilities integrating the information received from each aggregate agent and from energy demand (Power demand, availability demand, prediction period) in order to ensure the load availability according to the energy demand.

Moreover, the manager agent has then the duty to calculate the new optimal scheduling for the production planning. The production scheduling closes the control loop by giving the new 15 min forecast.

Task 4.6 Implementation and evaluation of developed concept for additional electrical loads

For the implementation of the developed control concept at HHO two aggregates have been considered. The first was the cooling towers with a capacity of 800 kW (cooling towers, Pumps, fans). The second was the air conditioning switch House Miba with the capacity of 160 kW.

For security and reliability reasons, the additional load management software was installed a few months before the commissioning. The purpose was to collect the data for the offline examinations in order to improve the software robustness.

Once the software was deemed robust and reliable, the software was commissioned and evaluated online at HHO with the two aggregates during the production.

WP 5 Strategies for production redefinition to align and re-align actual power engagement with the forecast

Task 5.1 Analysis of the actual procedures and methodologies used in the steel companies to calculate and re-schedule a "day-ahead"-forecast of the production

The forecast of needed energy is provided to the intermediator on an hour basis in the day-ahead. The actual procedures used in the industrial partners site was analysed. In most of the steel plant the day-ahead profile was calculated based on shift (i.e. each day was divided in the three shift) using Excel files.

Task 5.2 Definition of metrics to measure and estimate the deviations between booked and consumed electrical energy

Several KPI have been proposed in order to quantify both the deviations between the forecasted (i.e. the energy bought at the day-ahead market) and actual consumption and the potential effects that such deviations can lead, taking into account the different regulations and opportunities provided by the Italian and German electricity markets. In particular the costs for the operation of the distribution grid and balancing the power network are calculated for each time slot (e.g. 1 hour) retrospectively at the end of each month and depends not only on the plant but also on the neighbours behaviour.

Task 5.3 Implementation of KPIs to be used within a calculation algorithm

The proposed KPIs have been implemented. Since some of them had some limits, the last KPI composed by the sum of two terms quantifying the deviation between booked consumptions and actual consumptions in a given time period, and taking into account the maximum load for the *actual* slot has been considered as the most appropriate one, because it is able to express in terms of euro the effectiveness of the production plan and also it is suitable to be used for the optimization of the production re-scheduling.

Task 5.4 Production Re-scheduling Criteria and relevant validation

A model aimed to find an optimal production schedule of a part of a steel making process has been developed. The proposed model minimizes the selected KPI while satisfying production constraints. The developed model is based on mathematical programing with Mixed-Integer Linear Programing (MILP).

Task 5.5 Short term power scheduling on line model development and relevant validation

The proposed model is general enough to deal with extraordinary events, such as a machine failure during the daily process: in this case, to obtain a rescheduling, it is possible to restrict the inputs of the model to the remaining products (not yet processed), taking into account only the available machines and the remaining time slots of the time production range. The algorithm is run again with this restricted input and outputs a new products schedule.

WP 6 Dynamical access to the power market through an Agent System aimed to support the Decision Makers

Task 6.1 System requirements and automation landscape

The aim of this task is to define the requirements originated from point of view of a steel producer. Starting from the analysis of the automation systems and the database infrastructure, different possible application scenarios have been investigated in order to identify broad spectrum of requirements for the system to be developed. First of all the automation landscapes and IT infrastructures which can be found at the plants has been analysed. Based on this information the requirements for the systems to be developed have been defined. This includes general requirements like "Integration", "Extendibility" and "Customization" but also specific requirements. The specific requirements are divided into two parts

- functional requirements, describing the functional elements/parts of the solution
- non functional requirements, describing the criteria's for system operation

Task 6.2 System architecture and solution strategies

The goal of this task is the development of the design for the agent software system, including the communication infrastructure, the interfaces and structural details of the solution. Additionally different approaches for the trading strategies are investigated and solution strategies are developed.

Initially the analysis of core properties of an agent approach has been investigated. This includes the definition of major characteristics like "Autonomy", "Local view", "Decentralisation" but also identification of different agent types like "passive", "active" and "cognitive" agents. Subsequently the scheme of structural components of agent systems is identified.

In parallel an investigation of trading strategies is performed. Trading strategies utilise the idea of virtual markets in order to perform optimisation tasks. The central mechanism of virtual market approaches are the auctions. An analysis of different auction types has been performed and appropriate types has been identified.

Finally an investigation of different optimisation tasks referring to opportunities of flexible energy management are done. First of all the influences and possible reactions has been identified. Based on this a schema for agent approach has been developed.

Task 6.3 Software development and implementation of strategies and algorithms

This task is devoted to the implementation of agent system core components as well as adaptation of the algorithms to the different use cases. In general this task can be seen as integrative tasks which combine the results of previous work packages to a common approach, providing generic algorithms, which then are adapted to corresponding application scenarios.

Task 6.4 Installation of the software tools into the plants infrastructure

This task is devoted to the installation of the developed solutions at the infrastructure of industrial partners.

Use cases has been implemented with the aim to verify the dynamical access to the markets and the plant reactions to both internal and external events. In particular the possibilities to limit the 15 minutes peak has been implemented on all the industrial partner site. These use cases mainly implies controlling the loads related to processes. AST and ORI have also focused on the limitation of the imbalance implying a better forecast for energy demand and possibility to access Intra Day markets. LSW and HHO tested the possibility to access the balancing market, enabling additional loads at HHO and disabling loads at LSW.

Task 6.5 Test and validation phase

Within this task the evaluation of the developed systems under practical conditions at the plant has been performed. The specific results are reported based on the use cases described in task 6.4. Limiting the 15 minutes peak lead to positive results in all the plants already achieved during the project or potentially evaluated based on industrial tests. Lowering imbalance also shows good initial results from the tests, however needs to be further improved. Participation in balancing markets downwards was tested at LSW and founded potentially positive, however there were some problems that could be resolved in the future i.e.: missing information on the end of an interrupt and necessity for the oxygen plant to be equipped with automatic ramp up after an interrupt. Participation in balancing market downwards was tested by HHO, however according to the actual state of balancing markets was considered unattractive, until the markets conditions will change.

Task 6.6 Adaptation of the system

This task is devoted to the adaptation of the systems in order to eliminate the malfunctions and faults observed during the test and validation phase. Accordingly, the operation of the systems has been monitored both in term of functionalities and problems encountered. In cases when malfunction has been observed the analysis of reasons and effects has been performed and solution for the elimination of the errors has been developed.

2 Scientific and technical description of the results

2.1 Objectives of the project

According to several sources, as the Smart Grid Initiative or International Energy Agency, the energy demand side management is considered one of the strategic key for a reliable management of systems where variable renewable energy is present

The rise of variable renewable energy sources increases power fluctuations in the power network due to daily and seasonal effects which have sensible impacts on pricing and tariffs. This context open the possibility for steel sector to implement demand side flexibility through "smart" demand-response management. Within the steel industry, especially the electric steelmaking plants have an extremely high potential that needs the implementation of active actions devoted to the intelligent access to the grid, introducing technologies and procedures for flexible load control. The main objective of the project is to develop such approaches able to help steel plants in reducing electricity costs.

The reach this general goal, a clear picture of the electricity markets, with a special focus in Germany and in Italy where the partners operate, has been taken with the aim to find out the opportunities to enhance the participation of steel industries on the markets in order to save money when buying electricity.

On the other side a clear picture of available data, with reference to the process route of the industrial partners plants, was also taken. The analysis of data related to events and the relevant data model derivation is necessary to identify the specific improvements necessary in fundamental areas not yet served by proper measurements.

Based on this situation the following objectives have been identified:

- production schedule with focus on energy cost
- minimising the imbalance (deviations between booked and actual power) through a better forecast of energy needs and production adjustment
- minimising the peak load
- manage reaction on electric grid events both ascending (increment power demand) and descending (lower power demand)

This goals have been reached through:

- definition of ways and models to forecast, measure deviations and then adjust power engagement
- the adoption of an agent system
- test of the developed system on several use cases in four steel plants with different production type and system requirement.

2.2 Description of activities and discussion

2.2.1 Work package 1: Power market characterization: tariffs, negotiation, fluctuations, events

The aim of this work package is the determination of the power market and network characteristics influencing monitoring, forecasting and management of the power engagement in the steel plants.

2.2.1.1 Task 1.1: Electricity market characterization and supply profile determination

A comprehensive analysis and evaluation of the electricity market and of the opportunities to take profit from demand flexibility in electricity purchases by energy intensive industries, both in Italy and in Germany, has been carried out. The results are documented in deliverable D1.1, that can be found in Annex I; hereafter a synthesis of the work undertaken.

In particular, after a general description of the electricity market structure in the two countries, the study focused on the two main ways to purchase electricity by large industrial consumers, i.e.:

- through the Power Exchange;
- through contracts with a supplier.

Short-term[2] electric energy purchases through the Power Exchange can be carried out in the day-ahead spot market, that is typically the most important one, in terms of volumes of energy traded and of significance of the clearing prices, or in the intra-day spot market, where adjustments to the day-ahead market schedule can be done, in order to tackle with changes in the situation that occurred after the closure of the day-ahead market session and to avoid imbalances. For these reasons, the intra-day market typically deals with volumes much lower than the day-ahead one.

Within this context, a detailed analysis of hourly price profiles in the period between December 2013 and November 2014 has been carried out for the day-ahead spot markets of the Italian Power Exchange (IPEX) and of the German one (EPEX Spot). Several charts have been included in the deliverable, such as price hourly values, monthly average, hourly average (annual and for each month), for all the days of the year and for working-days and non-working days only.

The charts reported in Figure 2 and in Figure 3, showing the Italian and German day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays, are the most significant ones. They clearly show how cheaper or more expensive can be to consume energy in each hour of each different type of day.

Price differences w.r.t. the average can be significant, ranging from about -18 ÷ +23 €/MWh in Italy and from about -15 ÷ +12 €/MWh in Germany, showing that there is a great opportunity to take profit from demand flexibility in purchasing energy from the day-ahead spot market.

As for the intra-day spot market, the Italian one is characterized by price profiles similar to the day-ahead profiles, while in the German one, that is a continuous auction, price profiles can be different from the day-ahead ones.

Instead of directly on the Power Exchange, energy can also be bought through a supplier, at an agreed price defined according to specific consumption profiles, or paying the energy at the day-ahead spot market price. In such a case, the foreseen consumption profile may have to be communicated to the supplier two days before the day of delivery, to allow the supplier itself to buy the energy on the day-ahead spot market, one day before the delivery.

In any case, contracts with a supplier are in general less flexible than purchases on the Power Exchange.

In case of deviations of consumption from the program agreed with the supplier or deriving from Power Exchange purchases, imbalance energy must be settled at specific imbalance prices. In the Italian regulation, prices are penalizing or profitable according to the concordance or discordance of the imbalance sign with the sign of the overall imbalance of the zone where the consumer is located, while in Germany imbalance energy is settled, for each quarter of an hour, at the price obtained by dividing the control energy costs sustained by the TSO in the balancing market in a specific quarter of an hour, by the balance of the deployed amount of control energy in that same time interval.

Starting from August 2016, the Italian Authority for Electric Energy, Gas and Hydric System changed the imbalance regulation.

As far as electric energy consumers are concerned, before that change imbalance prices were defined according to a "single pricing" mechanism, shown in Table 1.

Table 1 - Single pricing mechanism for imbalances.

Sign of control area imbalance	**Imbalance price**	
+	Minimum between:	- day-ahead market price - average price of downward bids accepted in the balancing market
-	Maximum between:	- day-ahead market price - average price of upward bids accepted in the balancing market

[2] We focus on short-term (day-ahead / hours-ahead) since it is the typical time horizon over which demand flexibility can more effectively be exploited. For this reason, we did not consider longer-term forward and future contracts in the analysis.

The new regulation foresees that the "single pricing" mechanism applies only to the imbalances within a threshold corresponding to ±15% of the withdrawal program. The imbalances outside that threshold are priced according to a "dual pricing" mechanism, shown in Table 2.

Table 2: Dual pricing mechanism for imbalances.

Sign of control area imbalance	Sign of unit imbalance	Imbalance price	
+	+	Minimum between:	- day-ahead market price - average price of downward bids accepted in the balancing market
+	-	Day ahead price	
-	+	Day ahead price	
-	-	Maximum between:	- day-ahead market price - average price of upward bids accepted in the balancing market

With the "single pricing" mechanism, if the sign of the imbalance of the consumption unit is the opposite of the sign of control area imbalance, the imbalance is profitable for the consumer, since the imbalance energy is bought/sold at a price typically lower/higher than the day-ahead market price.

On the contrary, with the "dual pricing" mechanism the imbalance can never be profitable: in the best case, the imbalance energy is valorized at the day-ahead market price with neither profit nor loss, while in the worst case the imbalance energy is bought/sold at a price typically higher/lower than the day-ahead market price. This aims at penalizing large imbalances, outside the ±15% threshold. This rules variation implies for the Italian steel plants that being in line with the forecasted energy demand is becoming more important from an economical point of view.

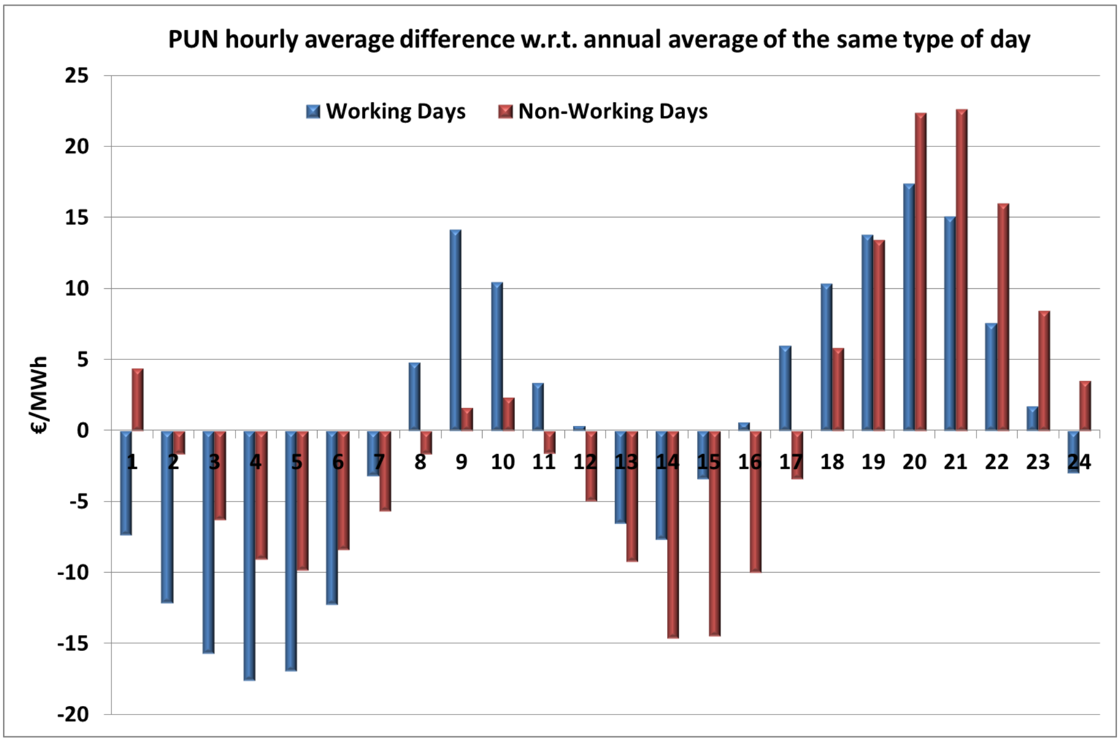

Figure 2: Italian day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on GME data).

Apart from reducing the cost of energy purchases and of possible imbalances, demand flexibility can contribute to reduce peak power consumption and the related fees. In Italy, the fee applied to the monthly peak power consumption measured in any quarter of an hour of each month is currently equal to 1.528 €/kW-month, while in Germany the monthly fee ranges from 6 to 9.38 €/kW-month, or an annual fee can be paid, ranging from 35.99 to 60.79 €/kW-year.

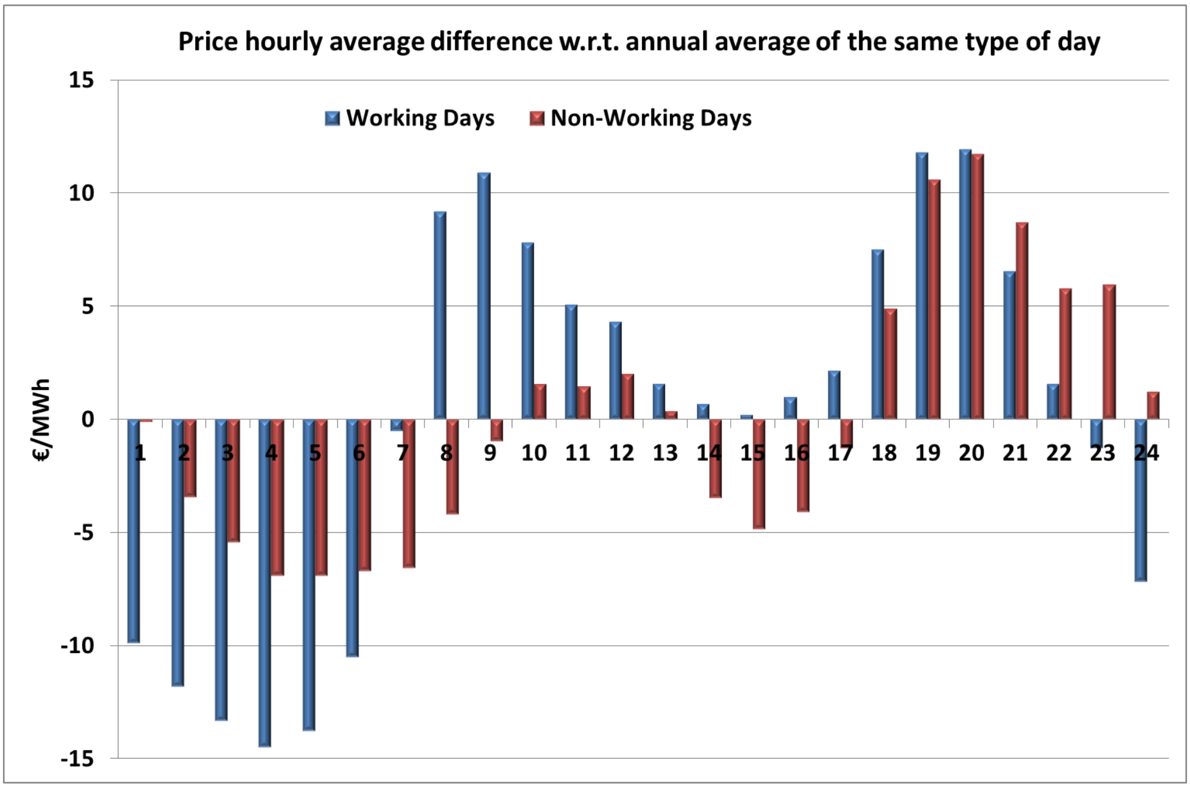

Figure 3: German day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

2.2.1.2 Task 1.2: Characterization of grid events (slots, power fluctuations etc.) with their dynamical characteristics coming from the power network

The activities in this task aim at the categorization of events due to the grid and the grid status; this is necessary to determine the dynamical response to be activated by the steel industry in terms of typical time shifts between event and reaction. Moreover, the economic value of the ancillary services that, in principle, could be provided by a flexible electricity demand in the steel industry, is assessed.

Information about the technical regulation of ancillary services in Italy and in Germany, with a particular focus on balancing services, such as primary, secondary and tertiary regulation, as well as interruptible loads has been collected.

According to the required technical performances, tertiary regulation and interruptible loads seem the two services most suited for the provision by large industrial loads, even if in Germany also secondary regulation can be provided by flexible loads.

In Italy, according to the current Grid Code by the Transmission System Operator TERNA, loads of any size are not enabled to provide ancillary services. Nevertheless, the Italian Regulatory Authority intends to remove soon this limitation, as stated in recent consultation documents, in line with the provisions of the European directive 2012/27/EU on energy efficiency. Moreover, the required technical performances of secondary regulation in Italy are more stringent: the whole band must be provided within 200 seconds and the holding period is at least 2 hours. Italy start some pilot projects for MSD in 2017.

The analysed markets are IL (Interruptible Load) only upward, SCR (Secondary Control Reserve) and TCR (Tertiary Control Reserve). SCR and TCR was already opened markets in Germany at the beginning of the project while in Italy in 2017 some pilot projects has been activated where consumers with power less than 10MW can participate in these markets being part of a pool with the lower limitation of 10MW on the whole aggregate. In Germany the companies can participate solitarily or as part of a pool both downward-negative (cut-in of aggregates, increase electricity use) and upward-positive (shutdown of aggregates, decrease electricity use) ways. The bidding processes are both for capacity and energy and are payed as bid.

Table 3: Reaction time

	Italy	Germany
IL/AblaV	< 200 ms Instantaneous < 5 s Emergency	< 1 s Immediately < 15 min Quickly
SCR/SRL	< 200 s	< 300 min
TCR/MRL	< 15 min	< 15 min

Table 4: Load / generation alteration

	Italy	Germany
IL	1MW	50-200 MW
SCR/SRL	± 10 MW	±5MW
TCR/MRL	± 10 MW	±5MW

Table 5: Holding period

	Italy	Germany
IL/AblaV	No limits	1-2-4 h
SCR/SRL	> 2 h	< 15 min
TCR/MRL	No limits	< 4 h

In Figure 4 more details for German markets are reported.

	SRL	MRL	AblaV
Load alteration	+/- 5 MW	+/- 5 MW	+ 50 -200 MW
Call for bids	weekly	daily	monthly
Announcing time	Wednesday, 15:00 for next week	10:00 for next day	15. of month for the next month
Reaction time	< 5 min	< 15 min	SOL: 1 sec SNL: < 15 min
Holding period	up to 15 min	up to 4 hours	1, 4, 8 hours
Compensation	Addition: per kW Call: per kWh	Addition: per kW Call: per kWh	2.500 €/MW LP 100-400 €/MWh AP
Call	automatically	automatically, manually, by telephone, by schedule	SOL: automatically SNL: controlled by grid operator
Time slots	a) Mo-Fr 8-20 b) Mo-Fr 20-8, Sa, So, H	6 x 4 h	different times

FOREnergy: Flexibilisierung der Energienachfrage von industrieellen Verbrauchern, Jan. 2015

Figure 4: Technical characteristics of secondary (SRL) and tertiary (MRL) regulation and of the interruption service (AblaV) provided by loads in Germany.

The fundamental characteristic to be taken into consideration in order to identify how the steel companies can participate in those markets are reaction time, Load / generation alteration and Holding period. In Table 3, Table 4, Table 5 the comparisons between these factors in Italy and Germany are shown.

Moreover, information on the Italian and German ancillary services and balancing markets and on the characteristics of the products traded on such markets has been collected.

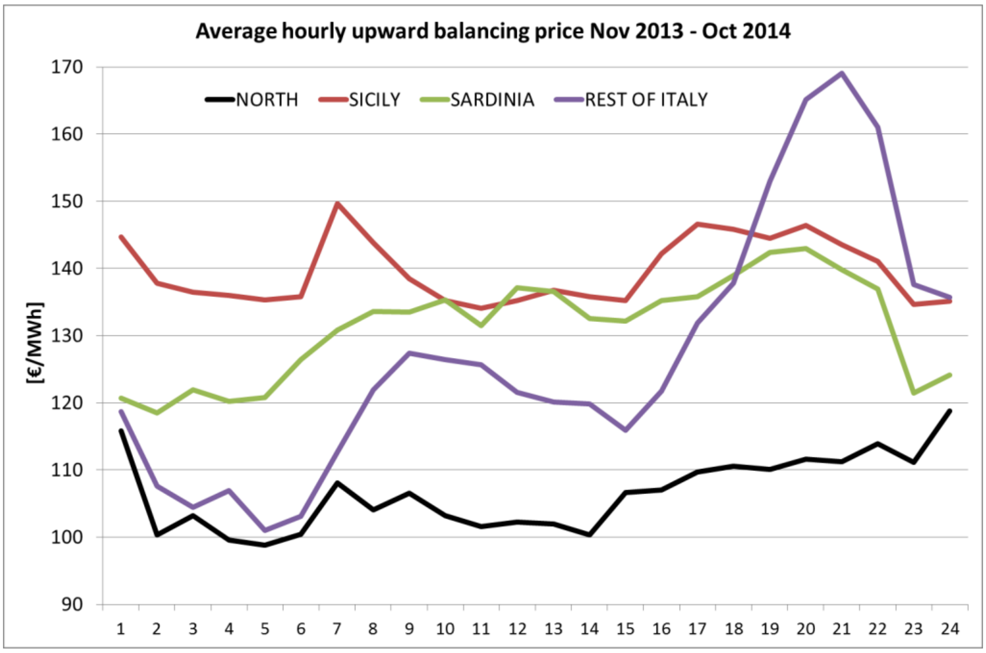

Figure 5: Hourly average upward balancing price profiles in different Italian market zones in the year between November 2013 and October 2014.

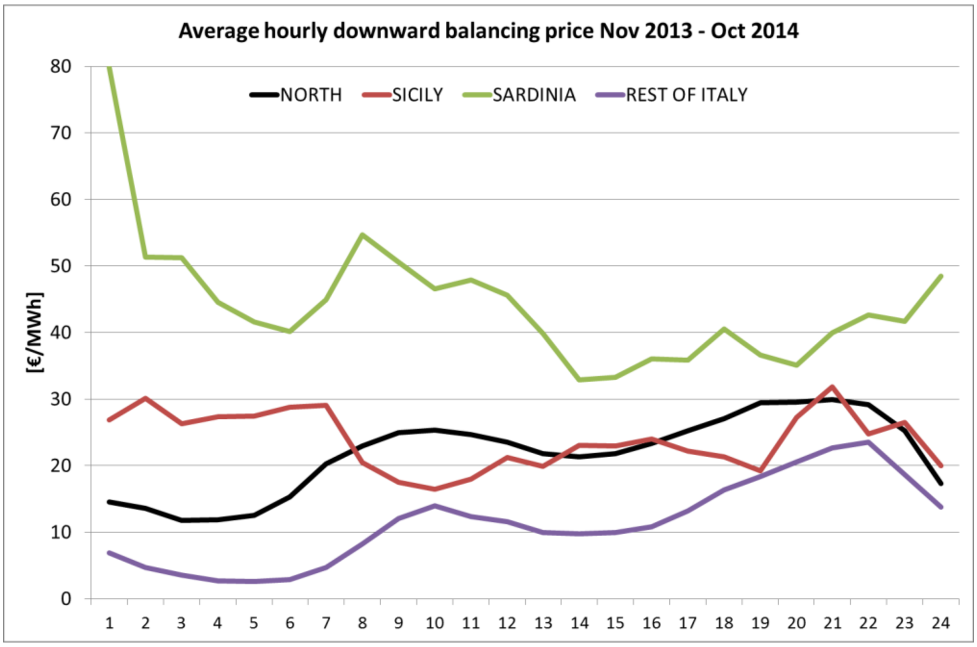

Figure 6: Hourly average downward balancing price profiles in different Italian market zones in the year between November 2013 and October 2014.

As far as the Italian ancillary services market is concerned, the bids submitted in the year between November 2013 and October 2014[3] have been collected and structured into a data base, in order to carry out an analysis of price profiles.

A first analysis has been carried out on the hourly average price profiles of upward and downward balancing in different market zones, i.e. the same prices used to settle load imbalances, shown in Figure 5 and in Figure 6.

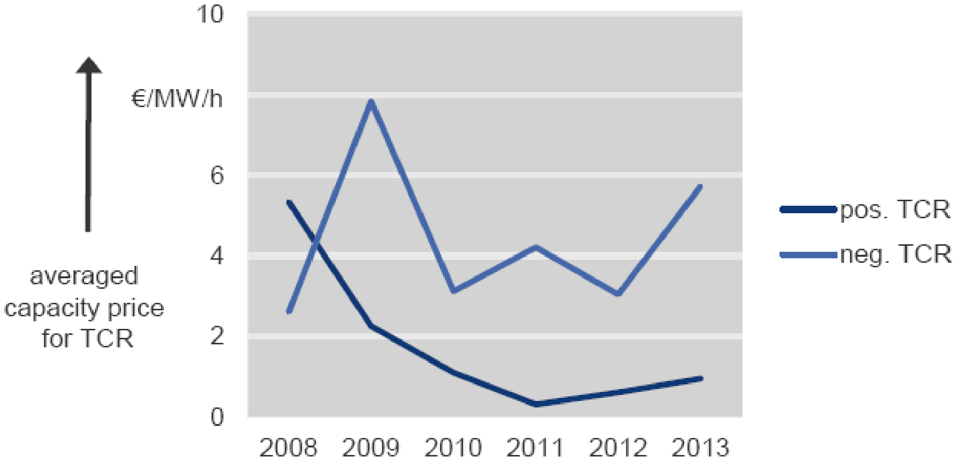

Figure 7: Development of averaged capacity price of accepted bids for TCR (data base www.regelleistung.net).

As for upward balancing, prices are the lowest in the North zone and are the highest in Sicily, except for hours between 18 and midnight, where the Rest of Italy shows the highest prices.

As for downward balancing, prices are the lowest in the Rest of Italy and are the highest in Sardinia.

As for the German ancillary services market, the volumes of secondary and tertiary regulation have significantly changed along the last years due to changing behavior of network users as well as on structural changes of load-frequency control management.

Also capacity prices have undergone significant variations, as shown in Figure 7. Nevertheless, it is not feasible to apply these average figures to single use cases directly, since the capacity price strongly varies according to offered boundary conditions of the industrial plant. These requirements comprise:

- Time response for providing balancing power (positive/negative)
- Amount of balancing power offered in total
- Possible duration of activation time
- Allowable amount of possible activations (per week/month/year)
- Robustness during possible activation (rejection rate, acceptance rate)

<u>Situation in Other European Country</u>

A comparison among several European country with reference to the participation of the demand in the balancing markets and the presence of negative prices has been carried out and is shown in Table 6.

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[3] Same period considered for the analysis of day-ahead spot market price carried out in Task 1.1.

Table 6: Comparison among European countries for demand participation and negative prices

Country	Demand participation	Negative prices
Belgium:	demand can participate to strategic reserve (for structural problems during winter time). Specifically demand connected to transmission can participate in Frequency containment reserves and in Frequency restoration reserves; while demand connected to distribution can participate in Frequency restoration reserves	available (both in day-ahead and services markets)
Spain:	demand can be reduced to 5MW to 90MW blocks in three ways: • Immediate • Quick: notified 15 minutes before • Hourly: notified 2 hours before Maximum holding period is 1 hour. 5MW products can be activated not more than 40 times weekly and 240 hour yearly, while 90 MW products not more than 60 hours weekly and 360 hours yearly	not available
Austria:	Demand can participate both in SCR and TCR	available (both in day-ahead and in services markets); downward prices have been always negative in last years
Denmark, Finland, Island, Norway, Sweden (Nordel countries):	Frequency restoration reserves regulation in Nordic countries doesn’t make difference between demand and generation when the technical requirements are fulfilled (full activation within 15 minutes and minimum of 10 MW hourly). Energy Intensive Industries (e.g. papers, metals) actively participate in these markets	not available

2.2.1.3 Task 1.3: Elicitation and definition of the negotiation rules and protocols between steel manufacturing demand and grid offer

The following paragraph represents the deliverable D1.3.

After the analysis performed in the first two tasks different opportunities to participate in the energy market have been found that are shown in the overview given in Figure 1**.**

The first opportunity (day-ahead & Intra-day) is based on the possibility to take advantage from the oscillation of the energy price during the day and between working days and weekends / holidays. It can be noticed that the hourly price profile tends to be similar during different days therefore the production can be scheduled accessing the day ahead market privileging the utilization of energy during time slots that have lower cost. This means not only money savings but also less environmental impact due to the fact that when the price is lower electricity is normally generated by less expensive and less polluting (possibly renewable) production sources.

The second opportunity (Secondary and Tertiary Control Reserve SCR-TCR) is related to the possibility to dynamically react to grid events providing ancillary (typically balancing) services for the secure operation of the power system. This means both: decreasing or increasing the energy utilization. In Germany consumers are able to participate at the balancing market, both as a single user or as a consortium, while in Italy the regulatory authority is working on the possibility of enabling also the consumers to participate (up to now it is only possible for dispatchable generators with an installed power greater 10 MW). Primary Control Reserve are mainly participated by power generators, besides them, some aggregators of both generators and loads, begin to participate in the market; moreover several researches on how demand-side units can participate are still ongoing trying to identify how a very fast and precise load regulation, necessary to follow electricity frequency variation, could be achieved. Therefore this market has been considered out of the scope of DYNERGYSteel.

A report from USA asserts that the grid offer can be divided into two main parts: The incentive-based offers and time-variable electricity prices tariffs.[4]. The first one is mainly used to motivate changes in electric use by end-use customers and therefore it's not applicable to our case. The possible applicability to steel industries of the second one is more described in detail within deliverables 1.1 and 1.2.

The interruptible loads (AbLa-IL) are the third opportunity. This situation is more related to grid security, i.e. very critical situation, therefore the reaction time should be faster compared to the second opportunity.

Moreover, in Germany the technical requirements are more strictly formulated. The actual law ended in December 2015.[5] but meanwhile it has prolongated until 01. July 2016. The political and industrial partners are actually discussing about future modifications of this law in order to expand the participation of interruptible loads.

In Italy is paid only based on power (MW) offered by the plant and not on energy (MWh). Since in our experience the plant offers for interruption a percentage of the total power capacity, it is very important to control the overall energy utilization in the plant during the disconnection time in order to avoid an increment of non-interruptible loads that could partially offset the interrupted amount.

The elicitation of contracts and compensation details are very different for each industrial partner.

Still, the main important criteria for negotiation rules in this case have been elaborated.[6]:

- Load-change:
  How high is the load which can be provided for switching on/off
- Duration of preannouncement:
  How long in advance has to be an official request for the load change to be announced
- Reaction time:
  How fast can the load be switched on/off
- Holding period:
  How long can a load-change be maintained
- Compensation:
  Amount of compensation which can be offered by various possible programs described in deliverable 1.1

It has been highlighted by the Italian partner that it's very difficult to make a good prediction of the electricity necessary for the production even the day before. The imbalance with respect to the booked energy can lead both to fees or revenues based on the accordance or discordance with the surrounding zone. This means that there is a correlated risk. The risk appetite lead to different approaches to the electricity market and in particular we found that accessing the market through an intermediator is preferred according to the following behaviors:

- the intermediator can takes the risks on its how increasing the electricity cost paid by the plant by a fixed fee, but avoiding penalties when imbalances occur
- the smaller plants can create a consortium with the surrounding plants in order to improve the bargaining power
- the plant will take the risks leading to a lower medium price enhancing the possibilities to get paid when imbalance but also to pay fees.

LSW has studied the possibilities to sell the flexibility of disconnectable loads. This is only possible if the disconnectable loads are aggregated by a service provider to more than 50 MW in total. Therefore LSW has organized a workshop with the company ENERNOC that offers this service for industrial power clients. The aggregator organizes the cooperation of the clients with the power supplier and the grid operators in order to summarize the flexibility for a start or stop of disconnectable loads.

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[4] DOE 2006 Department of Energy: Benefits of demand response in electricity markets and recommendations for achieving them – A report to the United States Congress pursuant to section 1252 of the energy policy act of 2005. Washington: U.S. Department of Energy 2006

[5] Decree of the Energy Industry Act (EnWG): „Ordinance on Interruptible Load Agreements (AbLaV)", § 13 Abs. 4a EnWG, 20.12.2012

[6] FOREnergy: "Ergebnispapier – Flexibilisierung der Energienachfrage von industriellen Verbrauchern", Ergebnisse des Arbeitskreises 1 "wirtschaftliche Synchronisation von Energieangebot und –nachfrage" des Forschungsverbundes FOREnergy, January 2015

Figure 8 shows the principles and rules of a cooperation between an aggregator and the power clients that want to sell their flexibility. The aggregator cares about all agreements with power supplier and the operators of the transmission and distribution network. He also supports the client within the prequalification that is required.

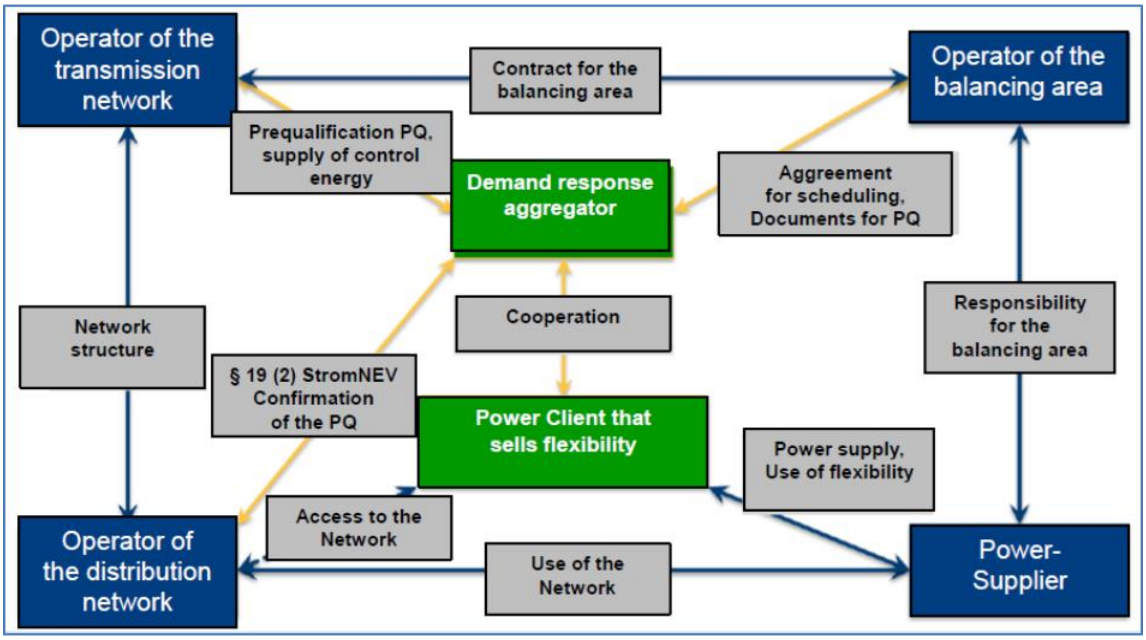


Figure 8: Principles of a cooperation between an aggregator and a power client (ENERNOC)

Within this cooperation different tasks have to be fulfilled by the client and the demand response aggregator that are listed below.

<u>Tasks of the power client: to sell the flexibility of the production</u>

Prequalification phase
- Gives the aggregator all allowances to contact the grid operators
- Implements the interface for plant control
- Supports the prequalification tests

Commercialization phase
- Signals the availability of flexibility
- Cares about the reliability of the plant
- answers on automatic requests

<u>Tasks of the demand response aggregator: to operate as a service company with the grid</u>

Prequalification phase
- Identifies flexibility
- Cares for approvals of all stakeholders of the energy net
- delivers interface for communication
- Configures the pool of participants
- Performs the prequalification tests

Commercialization phase
- Operates the pool-platform (24/7)
- Configures the product and sells the flexibility
- Forwards the requests for disconnections to the participants
- Cares for unplanned non availability of flexibility
- Cares about all activities with grid operators

2.2.2 Work package 2: Power demand by the steel plants: monitoring the actual engaged power and electric energy consumptions

The aim of this Work Package is the collection of available data with reference to the process route of the industrial partners plants, the analysis of data related to events and the relevant data model derivation, the implementation of the online-monitoring system, using existing data and the additional measurement devices installed.

2.2.2.1 Task 2.1: Manufacturing routes and layout analysis

The four plants of the industrial partners considered in this project can be regarded to provide a view on different types of steelmaking plants. In fact one stainless steelmaking plant for flat products with the complete production lines from EAF melting to finishing (AST), one plant for low and medium alloyed construction and engineering long products (LSW), one plant for special steel long products for automotive and mechanical industry (ORI) and one plant for hot rolled narrow strip production mainly for cold rollers (HHO) are covered. Hereafter description of the plant layout and analysis of data related to energy utilization are given. From this analysis EAF and LF have been individuated as the most relevant processes to be taken into consideration for LSW and ORI, while at AST EAF and HRM will be the main objective of Electricity Flow Sheet Model (EFSM). HHO's work is devoted to the development of additional load flexibilities in form of additional electricity usage by reacting on grid demands and the definition of the relevant processes taken into consideration is done in WP4.

Being the analysis performed in this Task intrinsically needed for each industrial partner the following chapters are also organised in this way. For each of them a description of the situation on the relevant plant is reported.

<u>Manufacturing route and relevant data at Acciai Speciali Terni</u>

Acciai Speciali Terni is the Italian leading company for stainless steel and forging production. The plant produces 1,2 Million tons of hot products and 650,000 tons of cold products. Moreover it is one of the world's leading producers of stainless steel and is known, thanks to its experience of over 100 years, as a global leader because of its size and modern and sophisticated machinery, for its innovation in technology and production processes.

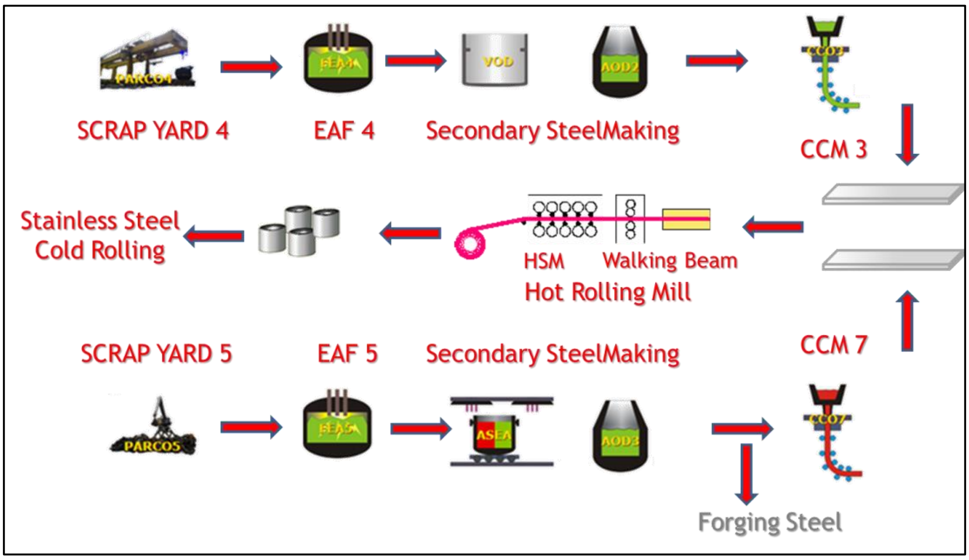


Figure 9: Hot Area Layout at AST

The Hot Area is equipped with one 150t EAF and one 165t EAF, followed by secondary metallurgy composed by three LF (Ladle Furnace), two AOD (Argon oxygen decarburization) and one VOD (Vacuum oxygen decarburization); the liquid steel can then be solidified through two CCM (Continuous Casting Machine) or used for forging products. The Hot Rolling Mill (HRM) is composed by 1 Walking Beam furnace and 1 HSM (Hot Strip Mill) (see Figure 9).

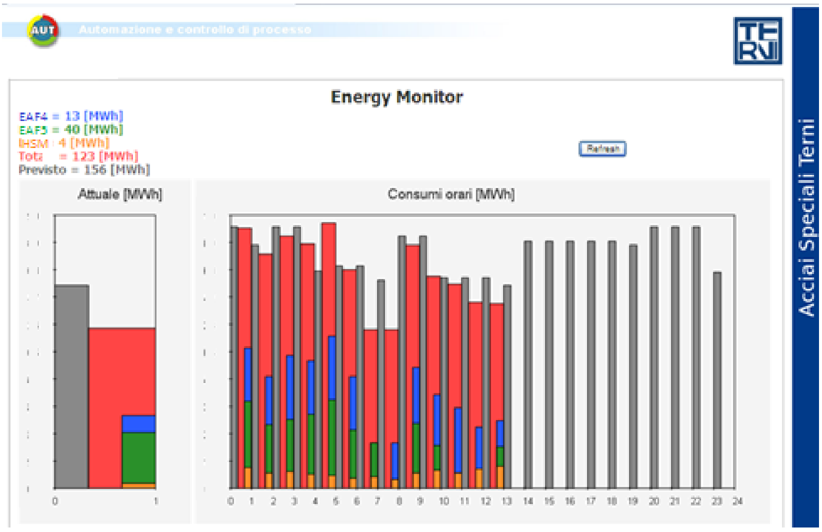


Figure 10: Typical Electrical Energy utilization at AST

The hot coils can then be processed through three annealing and pickling lines for hot-rolled strips and six Sendzimir mills. The Finishing Lines are composed by two bright annealing lines for cold-rolled strips, two annealing and pickling lines for cold-rolled strips, two Skin-pass rolling mills, and one stretching line.

The products can be further be processed in a Finishing Centre composed by slitting and cutting to measure, Scotch Brite or Butter Finish and a coating line for VIVINOX.

In Figure 10 a typical Electrical Energy profile utilization is shown. As can be seen the two EAFs (green and blue bars) and the HSM (orange bar) are responsible for about 50% of the total electrical energy consumption. This percentage depends more on the EAF consumption itself than on the other plant necessity in fact, from a first analysis of the available data, the rest of the plants have a more or less constant utilization of electrical energy. For this reason the main effort will be focused on the two EAFs, being responsible for the fluctuation of the electrical energy demand.

For these plants not only the data related to energy management but also all the necessary data necessary to model the process and to predict the electrical energy demand will be taken into consideration.

<u>Manufacturing route and relevant data at ORI Martin</u>

ORI Martin is specialized in high quality long products steel production, the ORI Martin Brescia plant is a modern EAF steel mill for production of continuous casting billets and hot rolling of wire rod, bars and bars in coils (Figure 12) for special applications in the automotive business as: fasteners, spring suspension, torsion bars. It is also equipped with thermal treatments for annealing and Q&T (Figure 13). The production in 2013 was around 700.000 tons.

The Steel Making Area is equipped with a Consteel® EAF, two LF, one VD (Figure 11) followed by one continuous casting machines with 5 strands 140x140mm.

One hot rolling mill (bars/bars in coils/wire rod), three straightening and controls lines, twelve bell annealing furnaces for wire rod, one continuous annealing furnace for wire, and one annealing furnace for bar and two Q&T treatment for bars complete the Brescia plant.

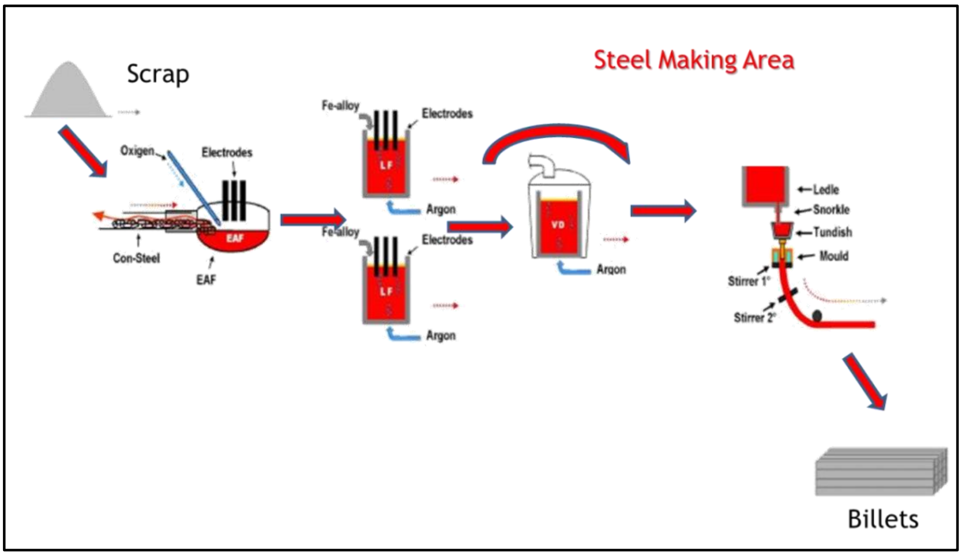


Figure 11: Steel Making Area at ORI Martin

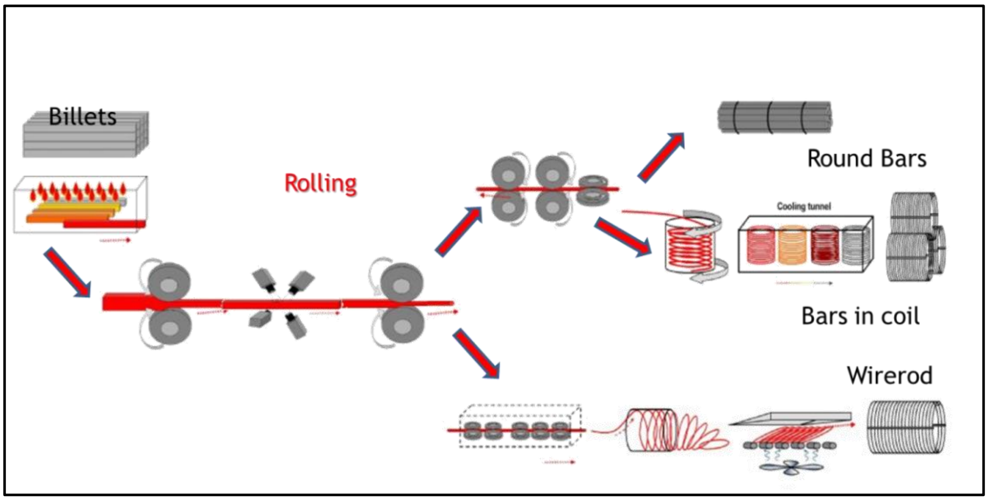


Figure 12: Rolling Area at ORI Martin

Figure 13: Quenching & Annealing Area at ORI Martin

A typical behavior of electricity use during the day is shown in Figure 14.

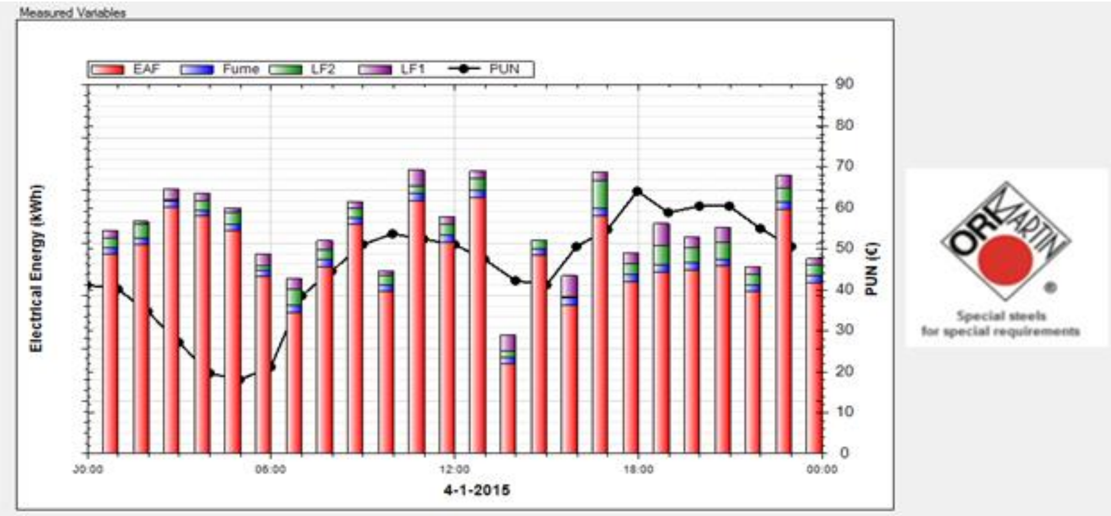


Figure 14: Example of electricity profile during a working day at ORIMartin

In Figure 15 the distribution of energy use in ORIMartin Brescia plant is shown. More than 60% of the energy is utilized by the EAF while 8% by the two LF, together with fume treatment this leads to around 75% in steel making area.

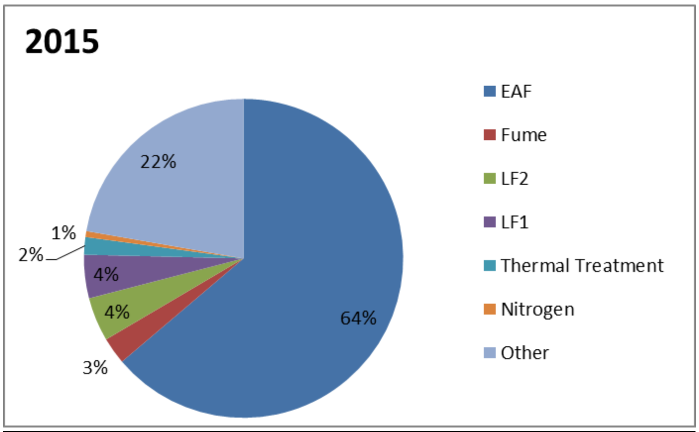


Figure 15: Distribution of the electrical energy used by the different processes in the ORIMartin plant in 2015

Manufacturing route and relevant data at Lech-Stahlwerke LSW

Lech-Stahlwerke GmbH (LSW) is a leading company in Germany for production of low and medium alloyed construction and engineering steel. The yearly production of 1,1 Million tons of steel (800.000 t quality steel and 300.000 t structural steel) is achieved in the steel plant equipped with two UHP Electric Arc Furnaces with a tap weight of 100 t each. The secondary metallurgy treatment is performed in two Ladle Furnaces and two VD degassing plants, which are equipped with mechanical vacuum pumps using electrical energy. The liquid steel is casted with two 4 strand continuous casting plants.

The billets are cooled down and then reheated in gas-fired reheating furnaces for rolling. However, within the project the activities will be focused only on the steel plant with their large consumers of electrical energy, i.e. the two EAFs and the two LFs.

The steel plant consists of two process routes, both of them equipped with one EAF, one LF and a VD vacuum degassing plant, see Figure 16.

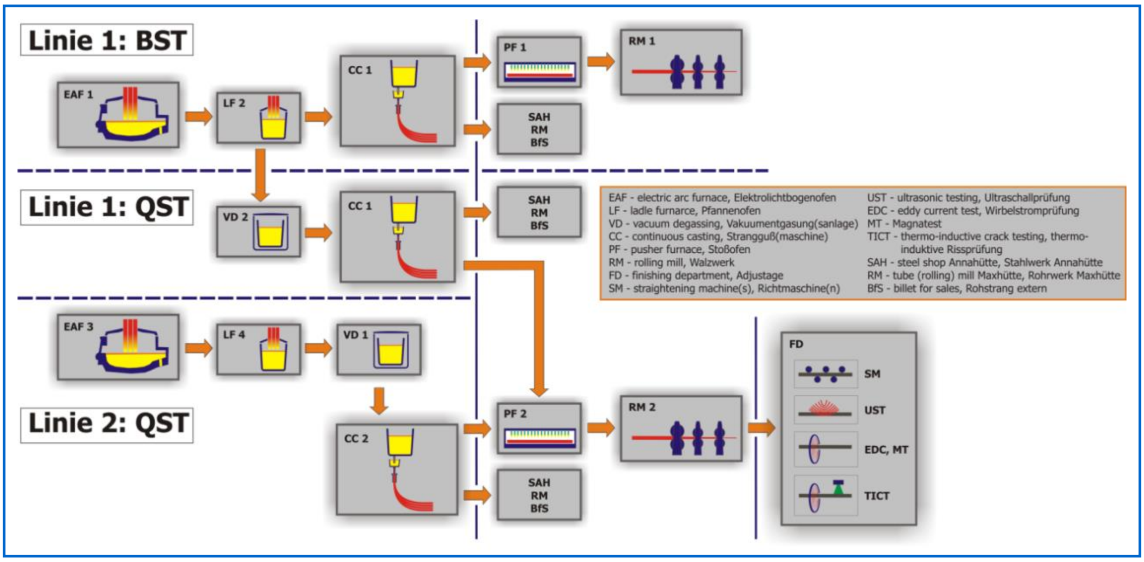


Figure 16: Production routes for structural (BST) and quality (QST) steel at LSW

The production of Line 1 focusses on structural steel along EAF 1 and LF 2, and on quality steel with additional vacuum degassing treatment in the VD plant 2. In Line 2 mainly quality steel is produced along the process route EAF 3, LF 4 and VD 1. About 300.000 t of the total production of 1.1 Mt are structural steels.

Figure 17 shows the process route for the production of structural steel in the grid for energy supply.

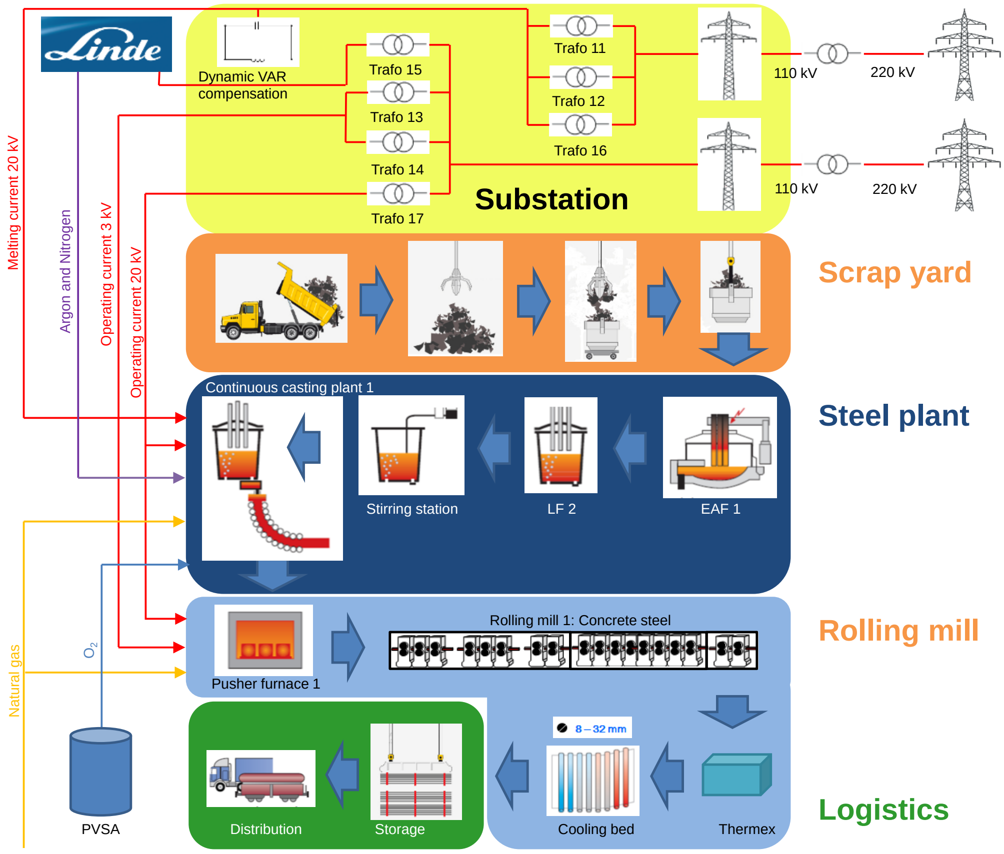


Figure 17: Process route at LSW for production of structural steel with energy grid

At the scrap yard of the LSW steel plant, ca. 30 different scrap types are stored in separate boxes. For the production of structural steels, the lower quality scrap types are used.

For the yearly steel production of 1,1 Mt, about 1,2 Mt of scrap and about 0,1 Mt of alloy materials and slag formers are used. The internal recycling rate of home return scrap and re-use of slag is about 96 %.

In the steel plant, primary steelmaking is performed by scrap melting in an AC Electric Arc Furnace (EAF 1) with a capacity of 100 t and a nominal connecting power of 75 MVA. The electric power is distributed to three graphite electrodes. Furthermore natural gas burners with a total power of 12 MW are used for chemical energy input. The scrap is charged in 2 – 3 portions via scrap baskets, which needs 1-2 min. for each charging process. The tap-to-tap time is lower than 60 minutes. For each charge about 45 MWh electrical energy, 600 Nm³ natural gas and 3.300 Nm³ of oxygen (coming from an own VPSA plant) are used. The average tapping temperature is 1650 °C. The heat is tapped into the ladle via an eccentric bottom tapping system, which takes about 10 – 15 minutes. During tapping, first alloy materials are added, and the heat is deoxidised.

Secondary steelmaking for the structural steel grades is performed in a ladle furnace and a stirring station. The ladle furnace has a nominal connection power of 24 MVA and an average active power of 10 MW. Secondary metallurgy treatment comprises desulphurisation, deoxidation and adjustment of the chemical composition and the casting temperature. For mixing and stirring of the steel melt and acceleration of the chemical reactions, inert gas (Argon or Nitrogen provided externally by Linde) is used. The liquid steel is casted to billets in a 4 strand continuous casting plant.

The dedusting plant comprises 4 filter systems (2 direct dedusting systems for the EAFs, two for the furnace halls) with 6 x 800 kW fans.

Figure 18 shows the process route for production of quality steel in more detail.

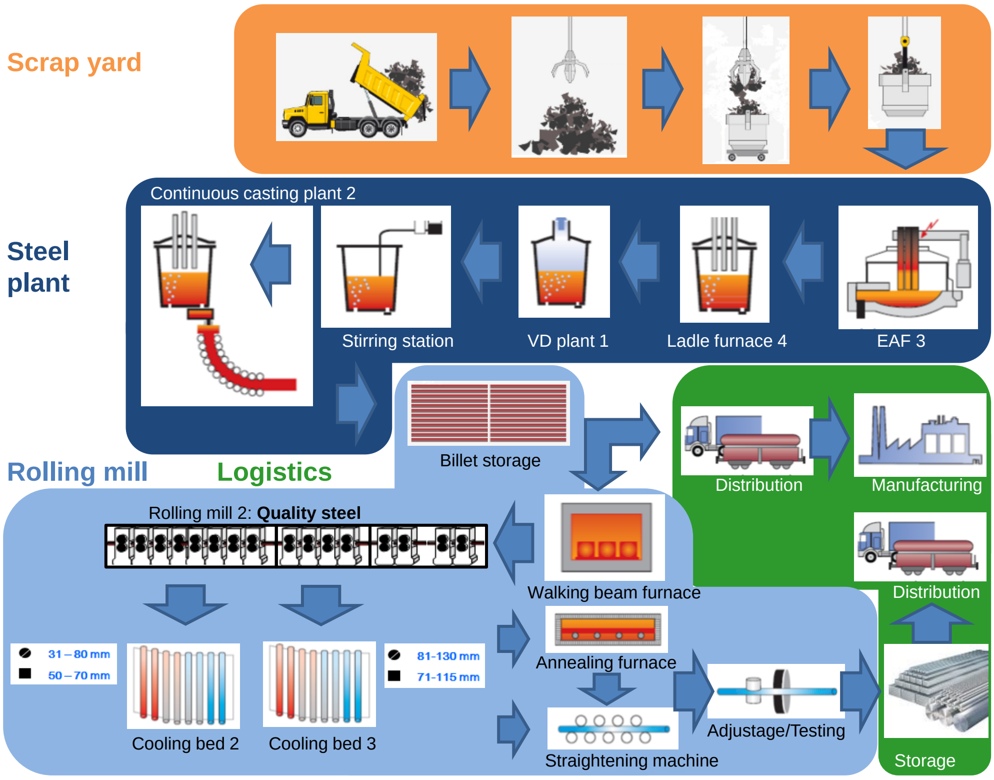


Figure 18: Process route at LSW for production of quality steel

The process route dedicated for the production of quality steel includes EAF 3 with a nominal connecting power of 82 MVA, a ladle furnace LF 4 and a vacuum degassing (VD) plant. To produce steel qualities with highest cleanness demands, the steel melt is treated in the VD plant under vacuum, to remove dissolved gases like hydrogen and nitrogen. Such a vacuum degassing plant is also included in the process route Line 1.

As shown in Figure 19, the main consumers of electrical energy in the plant of LSW are located in the steel plant. Together with the auxiliary plants, the liquid steelmaking aggregates in the steel plant cover 93 % of the total electrical energy consumption. 73 % of this electrical energy consumption is covered by the two EAFs as the by far largest consumers in the steel plant. They are followed by the two ladle furnaces with only 8% of the electrical energy consumption in the steel plant.

For LSW, monitoring and management of the electrical energy demand will focus on the most important consumers, i.e. the two EAFs and the two LFs in the steel plant. For this purpose, two kinds of process data groups will be acquired and evaluated:

Cyclic process data for dynamic, short-term monitoring and prediction (15 minute intervals) of electrical energy demand:

- Active power (EAF, LF)
- Electrical energy input (EAF, LF)
- Oxygen and natural gas flow via injectors and burners (EAF)
- Further data to monitor the energy demand of the connected auxiliary aggregates in the steel plant (Primary and secondary dedusting, PVSA plants, water treatment)

Consumption figures for complete heats, to determine the quality dependent energy demand for medium-term prediction (one production day):

- Steel quality and quality group
- Scrap charge (weights of the different scrap types) incl. charge coal (EAF)
- Electrical energy consumption (EAF, LF)
- Natural gas consumption (EAF)
- Oxygen consumption (EAF)
- Foam coal consumption (EAF)
- Lime consumption (EAF, LF)
- Tapping temperature (EAF)
- Tap-to-tap time (EAF)
- Treatment time (LF)

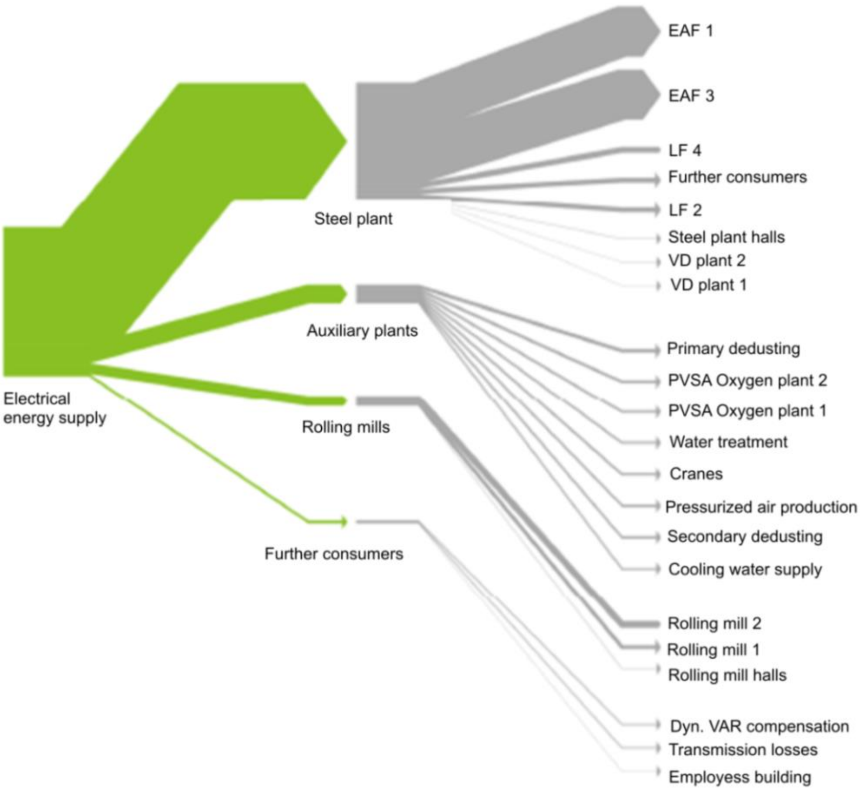


Figure 19: Distribution of the electrical energy supply to the different consumers in the LSW plant

<u>Manufacturing route and relevant data at Hoesch Hohenlimburg HHO</u>

Hoesch Hohenlimburg GmbH (HHO) is specialized on hot rolled narrow strip production. The plant mainly consists of the narrow strip mill and a pickling-/length- and annealing adjustage, as well as the appertaining auxiliary aggregates.

The processing stages are:

- Slab storage,
- Walking beam furnace,
- Reversing roughing mill,
- Cropping shear,
- Intermediate stands,

- Finishing mills,
- Cooling section (laminar),

The subsequent process stages, namely the pickling-/length-/annealing adjustage, are structured by the following subsequent main aggregates:

- Continuous pickling line with stretch leveller,
- Push pickling line,
- Leveller machines with edge trimmer,
- H2-high convection bell type furnace.

Moreover, the auxiliary aggregates play an important role, especially regarding WP4 within this project. Important auxiliary aggregates for our purposes are e.g.:

- Compressed air network,
- Feed water preheating,
- Temperature control of server rooms,
- Hall heating,
- Acid-/annealing preheating,
- Steam generation,
- Energy distribution station cooling,
- Enhanced cooling power of cooling tower,
- Increased flow rate into the cooling tower via pumps,
- Hall lighting,
- Hot water preparation.

2.2.2.2 Task 2.2: Definition of the Data Model for power engagement and electric energy consumption analysis and tune up of existing DBs

This chapter represents the Deliverable D2.1.

According to the analysis of the reference plants characteristics done in Task 2.1 the general Data Model has been defined in order to describe the most important sources of power engagement and electricity use, considering the role in the project. A description of the available process and energy data at each of the industrial partner plant is provided and depending on the specificity of each the eventually necessary enhancement are described.

The energy Data are available at least on a 15 min base on all the involved plants globally and specifically for the processes object of the project (i.e. at least EAF for LSW, AST & ORI). The eventually necessary improvement for energy measurements are detailed below for each industrial partner. No improvement was foreseen for product/process data at any plant.

<u>Already available data bases at Acciai Speciali Terni</u>

A preliminary analysis of available data at Acciai Speciali Terni has been performed.

Two main types of data need to be considered:

- Electrical energy utilization
- Product/process data to be used in Electricity Flow Sheet Model (EFSM) and forecast model

Detailed information regarding Electric Energy on both EAF and HSM were available (Figure 20). The data are acquired directly from the PLC and then merged for historical storage. Therefore they are available at different timescale depending on the necessity and the time of the measure. Data from soft sensors able to correlate the energy demand to the specific product is available and will be enhanced based on the requirement of the project. Moreover, because the steel making area as the higher request of electricity, new meters have been identified to be added in this area and in particular the two LFs and the AOD.

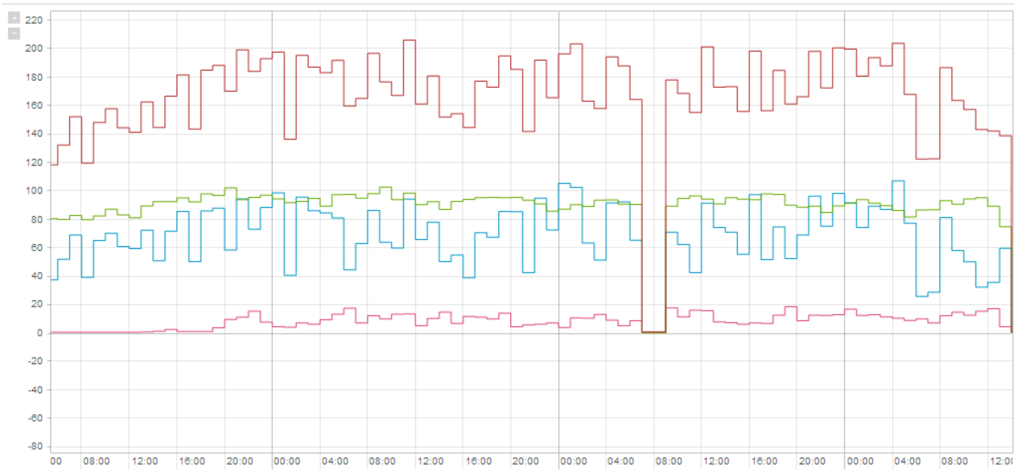


Figure 20: Example of Electrical Energy utilization at Steel making Area (blue), HSM (pink), others (green) and Total (red)

Regarding the Product/process no improvement are foreseen.

<u>Already available data bases at Lech-Stahlwerke LSW</u>

The following cyclic process data for dynamic, short-term monitoring and prediction of the (electrical) energy demand at the two EAFs and the two LFs are stored in a data base with a time interval of 1 second:

- Electrical energy consumption since first power-on, active power, cos Phi (EAF, LF)
- Arc Voltage and Current for 3 phases (EAF, LF)
- Flow rates of natural gas and oxygen for three Cojet burners (EAF)
- Consumption of natural gas and oxygen for three post combustion injectors (EAF)

In Figure 21 and Figure 22 the parameters of the electrical energy input in the EAF are shown for an example heat. Figure 23 shows the gas flow rates and consumption figures of the chemical energy input for the same heat. In Figure 24 and Figure 25 the parameters of the electrical energy input in the LF are shown.

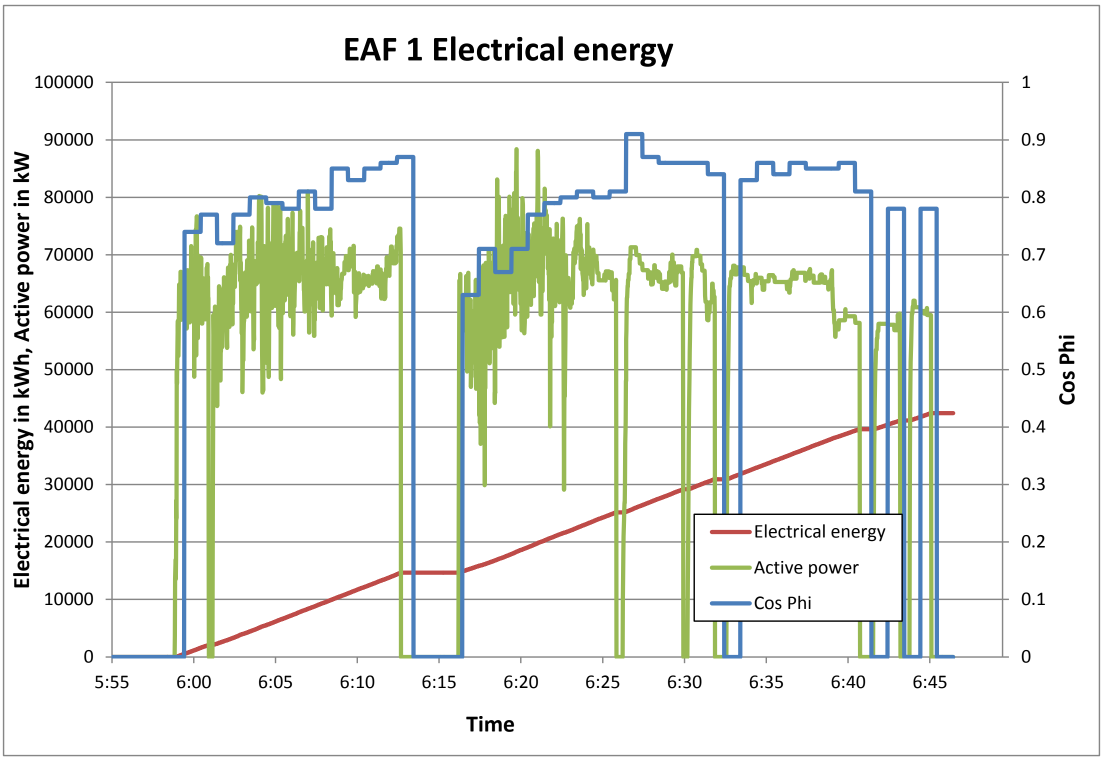


Figure 21: Parameters of electrical energy input at the EAF for an LSW example heat: Electrical energy, active power and cos Phi

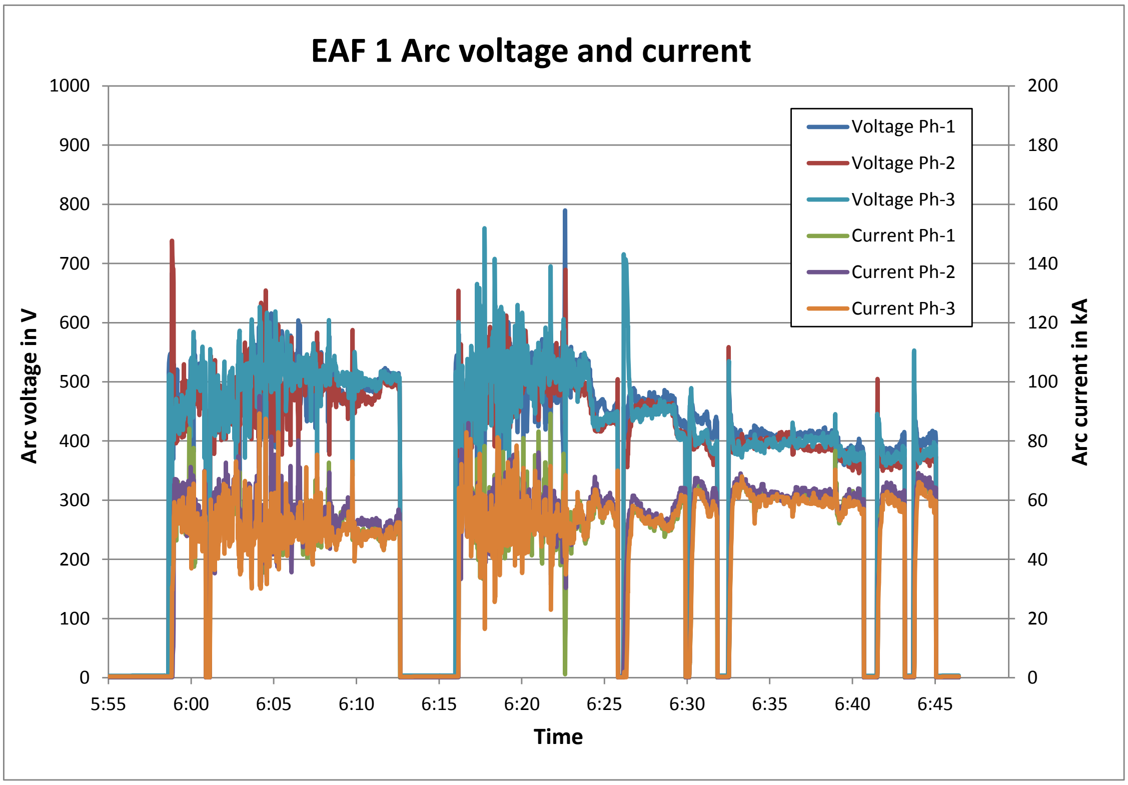


Figure 22: Parameters of electrical energy input at the EAF for an LSW example heat: Arc voltages and currents of the three phases of the AC EAF

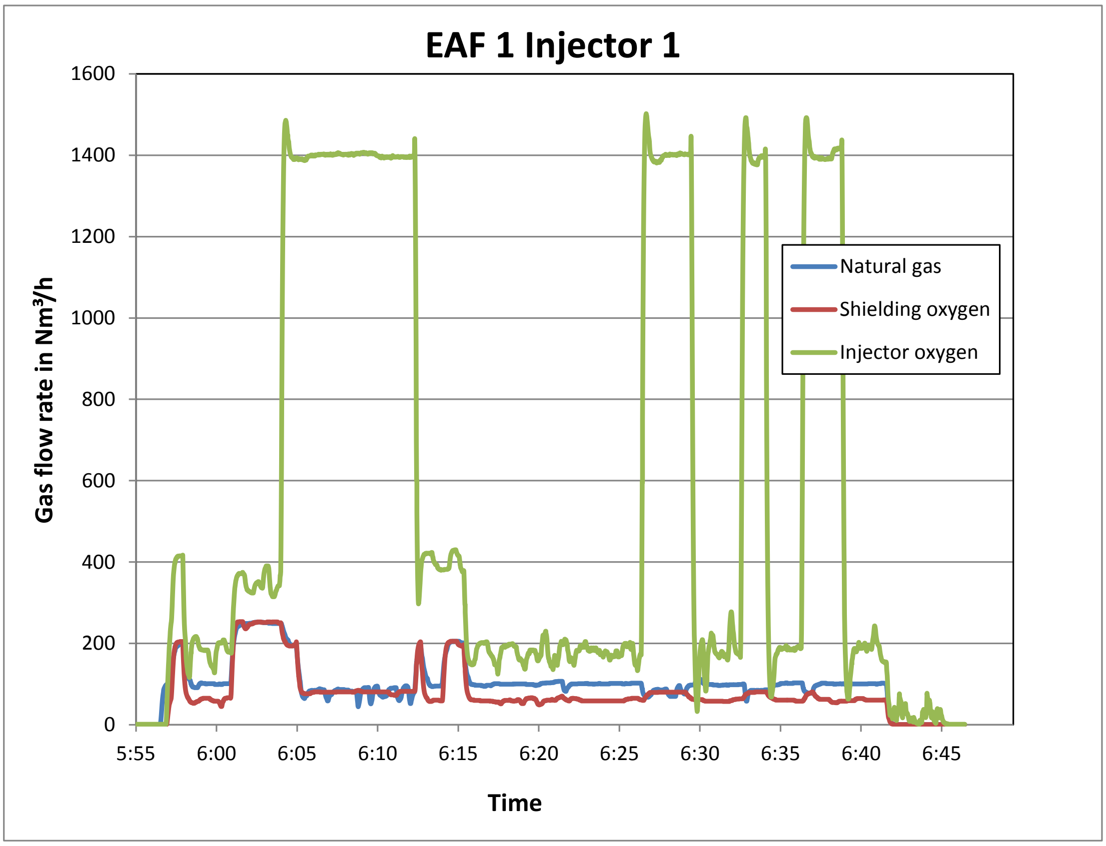


Figure 23: Parameters of chemical energy input at the EAF for an LSW example heat: Oxygen and natural gas flow rates for the Cojet injectors

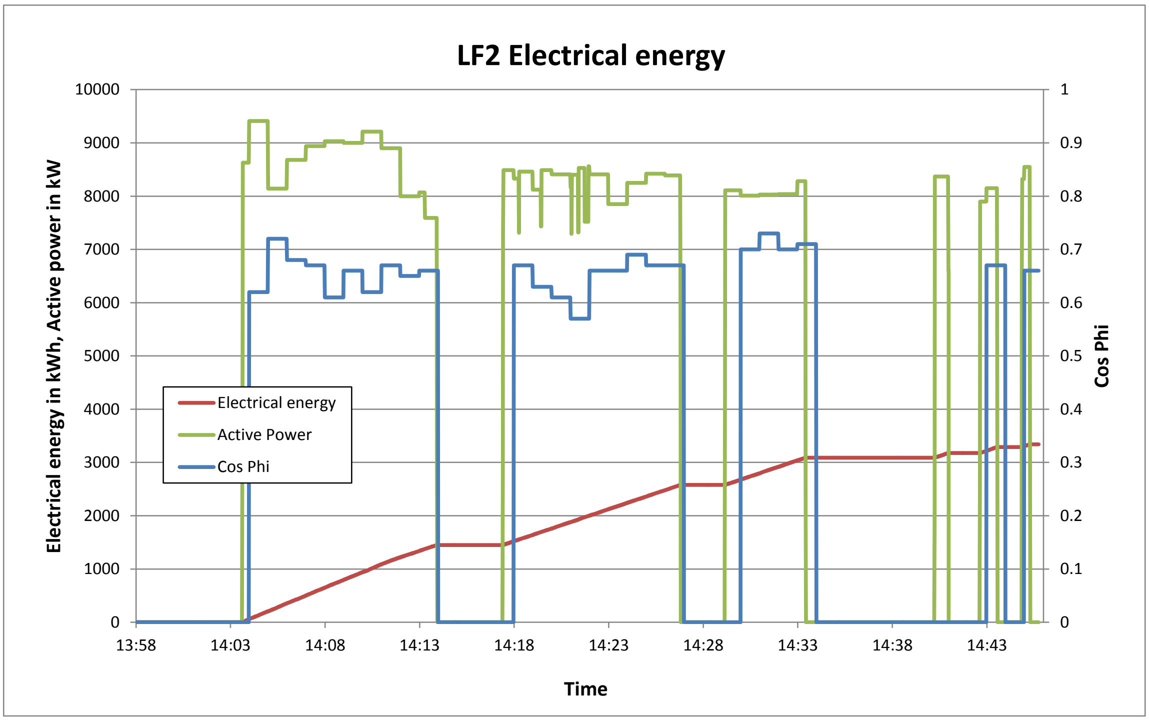


Figure 24: Parameters of electrical energy input at the LF for an LSW example heat: Electrical energy, active power and cos Phi

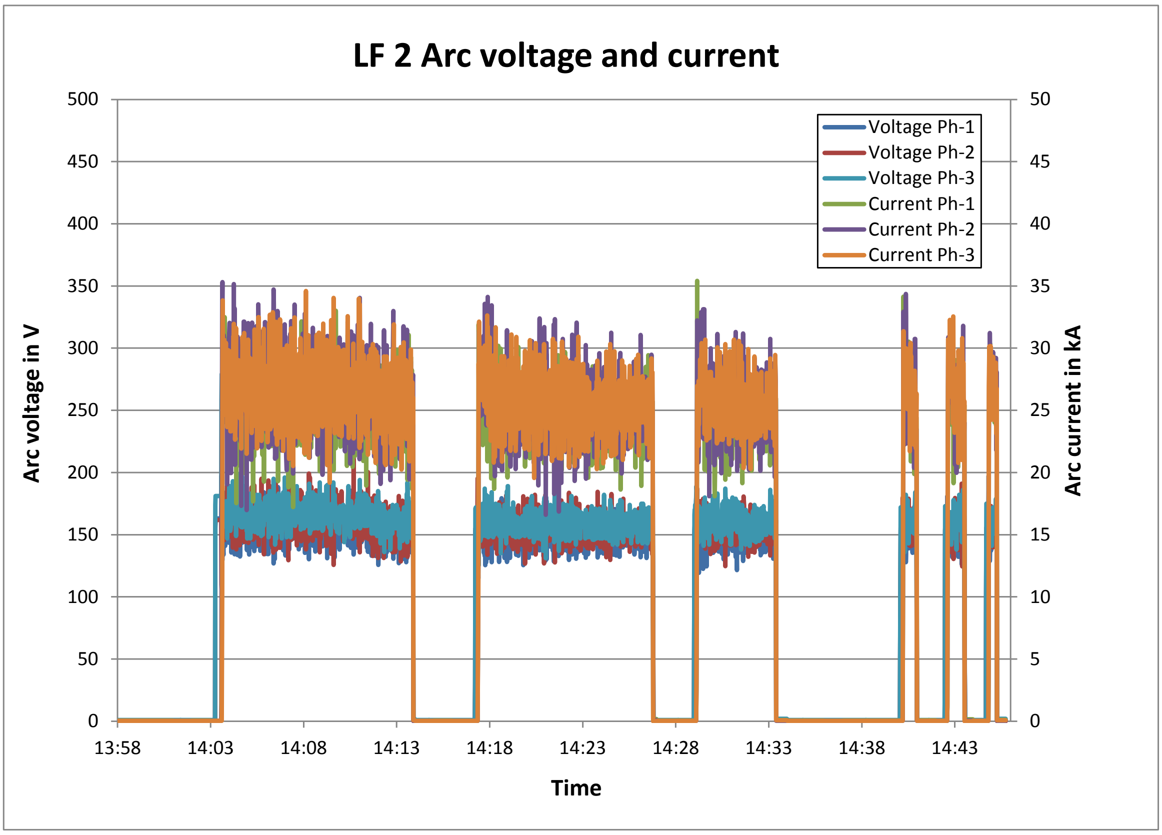


Figure 25: Parameters of electrical energy input at the LF for an LSW example heat: Arc voltages and currents of the three phases of the AC LF

In addition the following data and consumption figures for each produced heat are stored in a production data base:

- Steel quality and quality group

- Scrap charge (weights of the different scrap types, no. of scrap baskets) incl. charge coal and dololime (EAF)
- Electrical energy consumption (EAF, LF)
- Average Cos Phi (EAF)
- Natural gas consumption (EAF)
- Oxygen consumption (EAF)
- Foam coal consumption (EAF)
- Lime consumption (EAF, LF)
- Graphite electrode consumption
- Tapping temperature and liquid steel weight (EAF)
- Power-on and Tap-to-tap time (EAF)
- Power-off times with differentiation regarding reasons (charging, tapping, disturbances etc.) (EAF)
- Treatment time (LF)
- Alloy material consumption (weights of different types at EAF tapping and LF)
- Ar and N2 stirring gas consumption (LF)

The existing data bases at LSW can be regarded as complete for the purpose of the project.

Already available data bases at ORIMartin Brescia

For ORIMartin, monitoring and management of the electrical energy demand was initially focused on one of the two LFs, Nitrogen production and thermal treatment accounting for less than 10% of the total amount of electricity needed. A gradual increase of the processes under monitoring was individuated as necessary and therefore during 2015 the EAF the other LF and the fume treatment was added while further improvement in order to have a complete mapping of electricity needed is still on going. Actually the Electrical Energy data are available every 15 min.

Product/Process data necessary to the project are available and doesn’t need improvement.

Already available data bases at Hoesch Hohenlimburg HHO

As depicted in Figure 26, the main consumers of electrical energy in the plant of HHO are located in the steel plant. Together with the auxiliary plants, the rolling mill aggregates in the plant cover about 50% of the total electrical energy consumption. 45 % of this electrical energy consumption is covered by the main drives. The second main consumer is the spring plant with about 30%. Subsequently, pickling line and the furnaces of the hot rolling mill have to be included as a mentionable part of the overall electricity distribution as well.

The Energy data are available on a 15 min basis. For the purpose of the project the available data doesn’t need any enhancements.

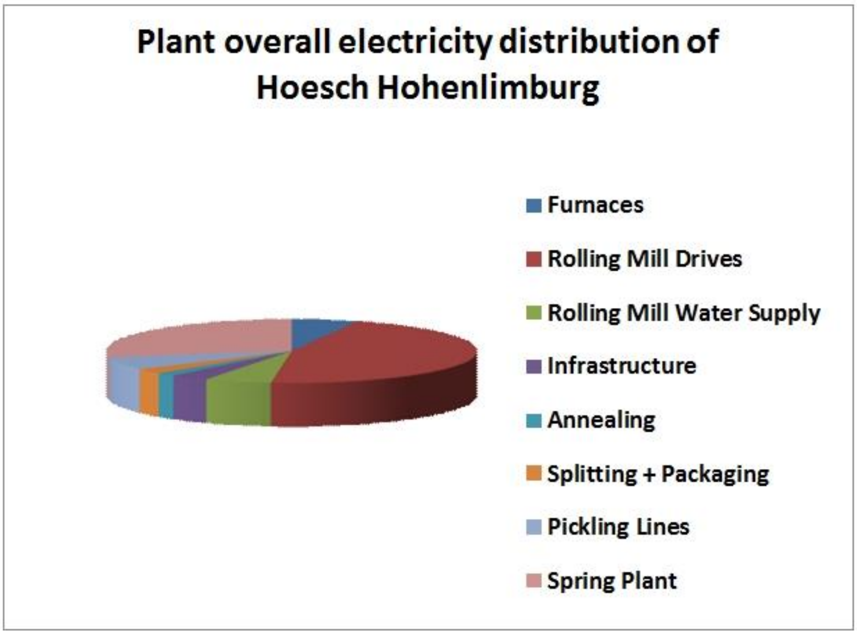


Figure 26: Distribution of the electrical energy supply to the different consumers in the HHO plant

2.2.2.3 *Task 2.3: Monitoring devices adjustment, power load characteristics analysis and characterization; preliminary data acquisition campaigns*

This task aimed at the preliminary characterization of both internal (process data) and external data (grid behavior). Data from plant have been collected and statistically evaluated in order to quantify the energy necessary to each process identified in previous tasks. With the aim of better understanding the possibilities to access the Control Reserve market an analysis of the global imbalance of network have been performed.

<u>Plant Data Analysis</u>

At LSW, AST and ORI the behavior of EAFs have been evaluated from different points of view. For HHO a specific analysis has been performed due to the completely different plant structure.

As described in Task 2.1 LSW has two AC EAFs, ORI one Consteel® EAF, and both produce carbon steel, while AST has two EAFs and produces stainless steel. The EAFs represent a high percentage of the total electricity needed in the production.

From a theoretical point of view the total energy required to melt the scrap and to superheat it to the typical tap temperatures requires from 350 kWh/t of steel for a Consteel® to 380 kWh/t of steel for a conventional EAF. Actual electricity use in EAFs are reported to range between 360 – 590 kWh/t.[7]

Four different aspects were monitored and analyzed within the reporting period of the project. These aspects are

- an analysis of the EAF power load characteristic of single heats,
- a statistical analysis of the EAF heats and operation mode,
- an analysis of the main electrical energy consumers of the steel mill (yearly energy report),
- an analysis of the power load characteristic of the steel mill with a focus on short term deviations of the 15 minutes intervals.

<u>a. Analysis of the EAF power load characteristics</u>

The power load characteristics at the electric steelmaking plant of LSW were analysed on the basis of the acyclic process data listed under Task 2.2. Figure 27 shows the treatment of a typical EAF heat together with the power-on and power-off times.

The tap-to-tap time of 57 minutes can be first divided into a power-on time of 40.3 min and a power-off time of 16.7 min. The power-off time itself mainly consists of the times for scrap basket charging and tapping, and operation stoppages due to waiting times, electrode nippling or other unplanned disruptions.

[7] Steel production - energy efficiency working group Final report, January 2014

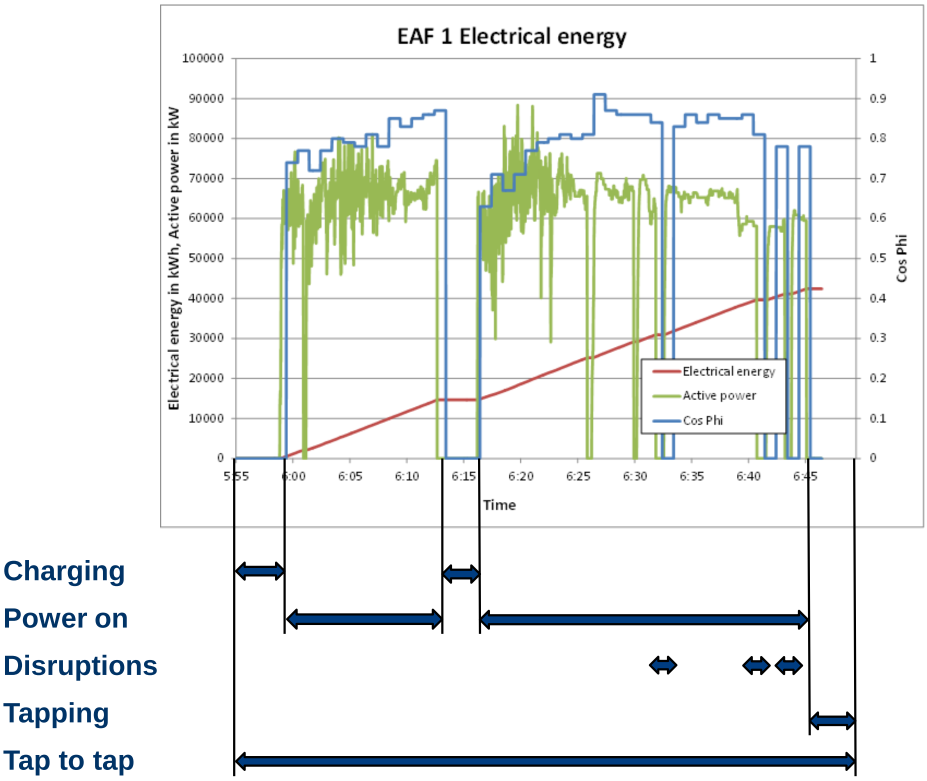


Figure 27: Power load characteristics of a typical EAF heat at the LSW steel plant

In Figure 28 a similar behavior is shown for a heat where three scrap baskets were charged to one of the two EAFs in AST. The measured tap to tap time was 79 minutes with 57 minutes of power on.

In Figure 29 a heat with two scrap baskets of the same EAF in AST is shown.

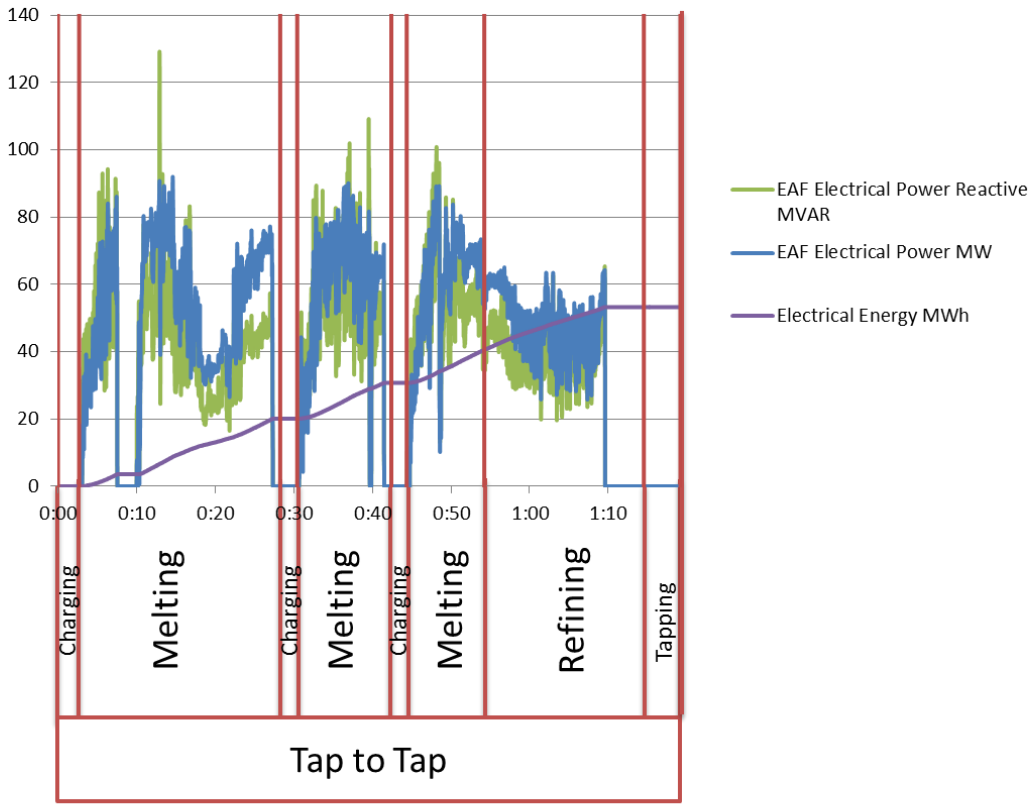


Figure 28: Power load characteristics of an EAF heat with three baskets at the AST steel plant

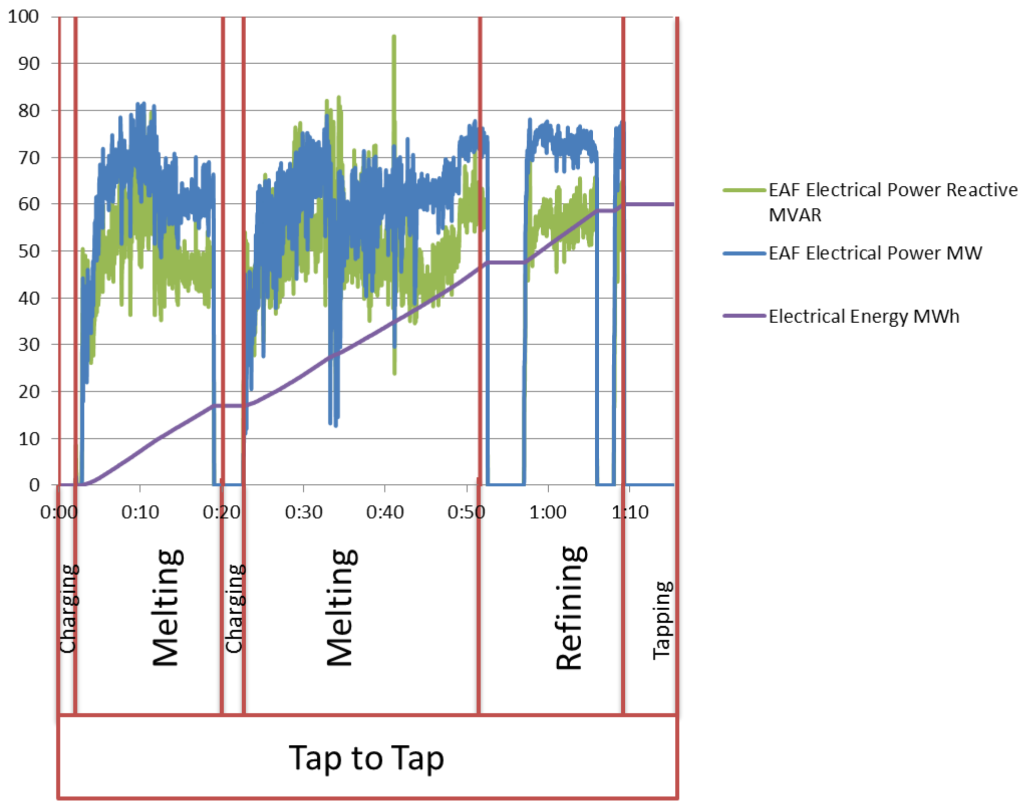


Figure 29: Power load characteristics of an EAF heat with two baskets at the AST steel plant

b. Statistical analysis of the EAF operation

Statistical analyses of data coming from LSW, AST and ORI have been performed.

A statistical analysis for a 8-months-period of the LSW EAF-operation shows that the EAFs have been in operation in 86-88 % of the available time. The remaining 12-14 % of the available time have been spent for stoppages and shut downs of the plant, e.g. for planned maintenance shifts within a four weeks period.

The results of the statistical analysis of the operation time are shown in Figure 30.

Figure 30 shows that the power-on-time of the two EAFs has been determined with a mean value of 43,9 minutes respectively 41,1 minutes. The tap-to-tap-time shows a total variation between 50 - 100 minutes with a mean value of 69,1 respectively 63,7 minutes. This means that the actual time sequence of a single heat may vary to a high extent due to different reasons of quality management and unplanned stoppages.

The maximum load of both EAF has been controlled within the control periods of 15 minutes and has usually been set to 125 MW as a maximum mean value for the melting power of EAFs and LFs in this period. The two EAFs have been shut down for a short time if this set point could not be met. The results are shown in Figure 30 in the diagrams "no power" for the EAF1 and EAF3. Both EAF have been shut down simultaneously for a short time period between 0 - 3 minutes. The total time spent for this shut down was about 0,15 % of the total operating time. About 13 to 15 % of the heats were influenced by this short shut down to control the maximum load of the factory.

Figure 31 shows the specific electrical energy measured in the two EAFs in AST during one month production. The EAF5 shows a worse performance in comparison to the other EAF. To improve the EAF5 yield plant and operative modifications have been planned for the beginning of 2016.

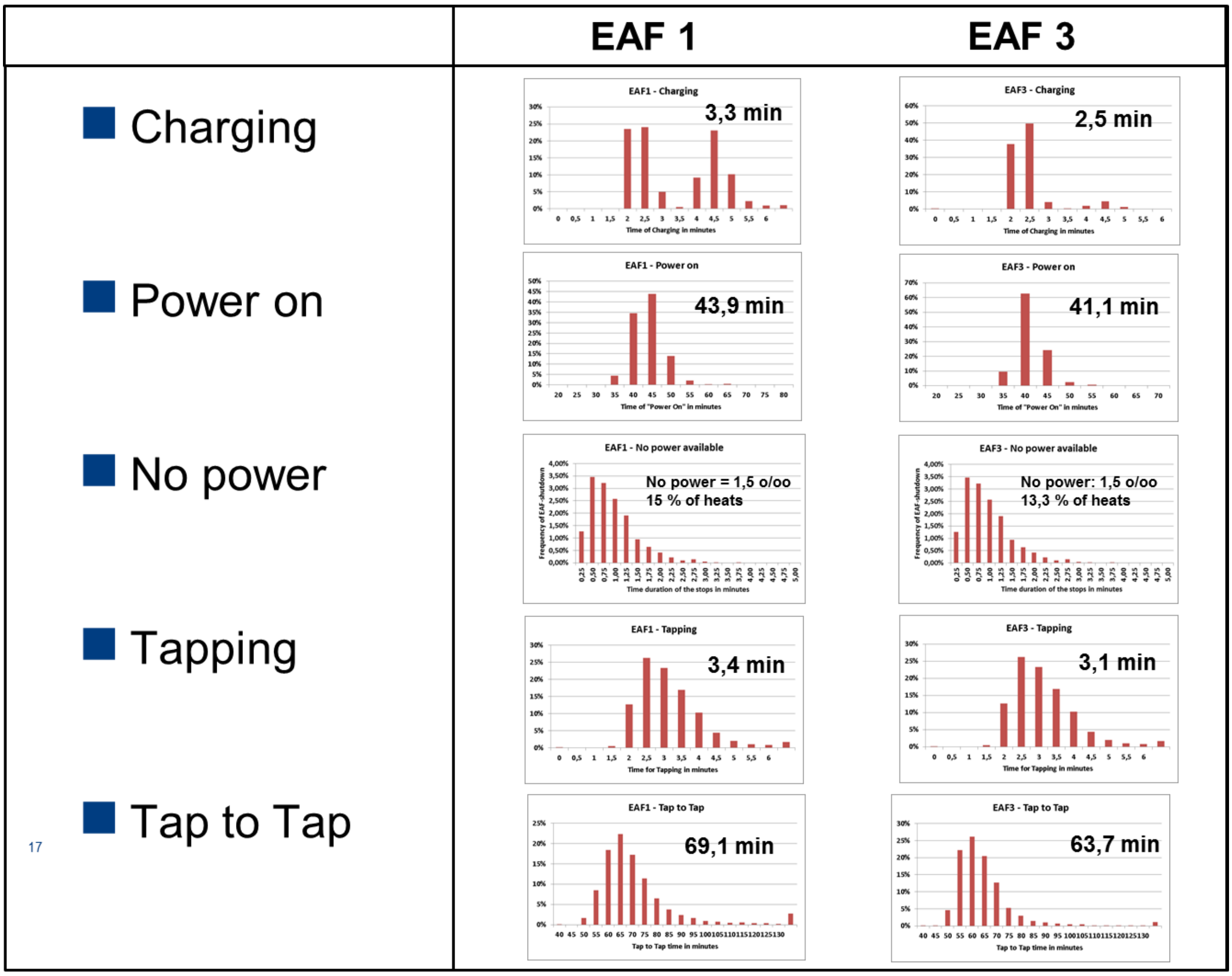


Figure 30: Statistical analysis and mean values of the EAF cycle times per heat at Lech-Stahlwerke LSW

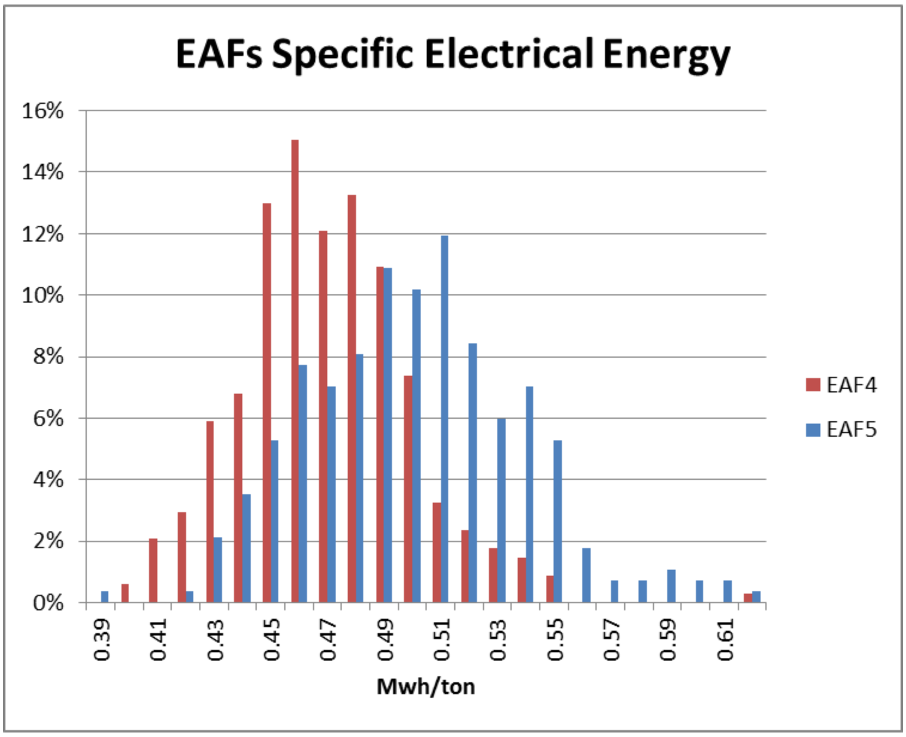


Figure 31: EAFs Specific Electrical Energy at AST during one month production

Figure 32 shows the Tap to Tap time of one of the two EAFs in AST during one month production. As can be seen more than 50% of the heats are in the range between 80 and 90 minutes, but the spread is fairly wide, which implies, together with the spread of Specific Electrical Energy, more difficulties in making a correct day ahead forecast of the electricity needs and therefore corrective actions should be taken during time to reach the accordance between booked and actual profile.

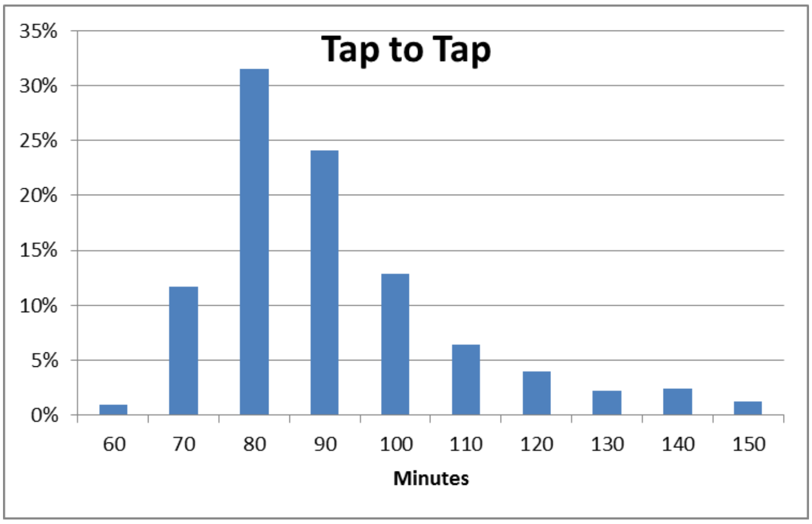


Figure 32: Tap to Tap time of one Terni EAF during 6 months production

A similar behaviour in terms of spread has been recorded also at ORI as shown in Figure 33 and Figure 34. The mean value is different due to the fact that ORI has a Consteel® instead of a traditional EAF.

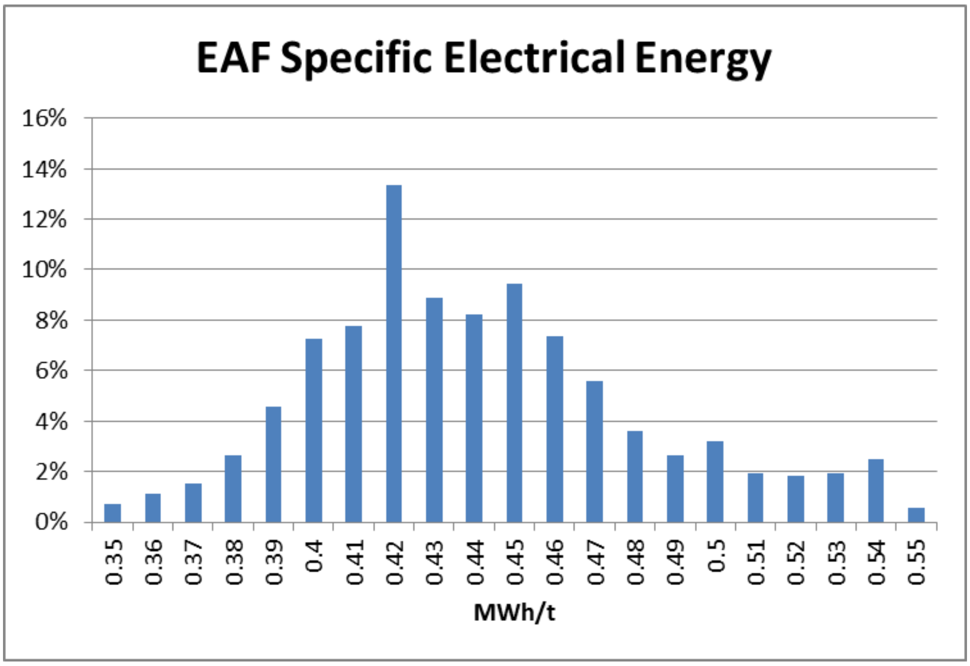


Figure 33: EAF Specific Electrical Energy at ORI during one month production

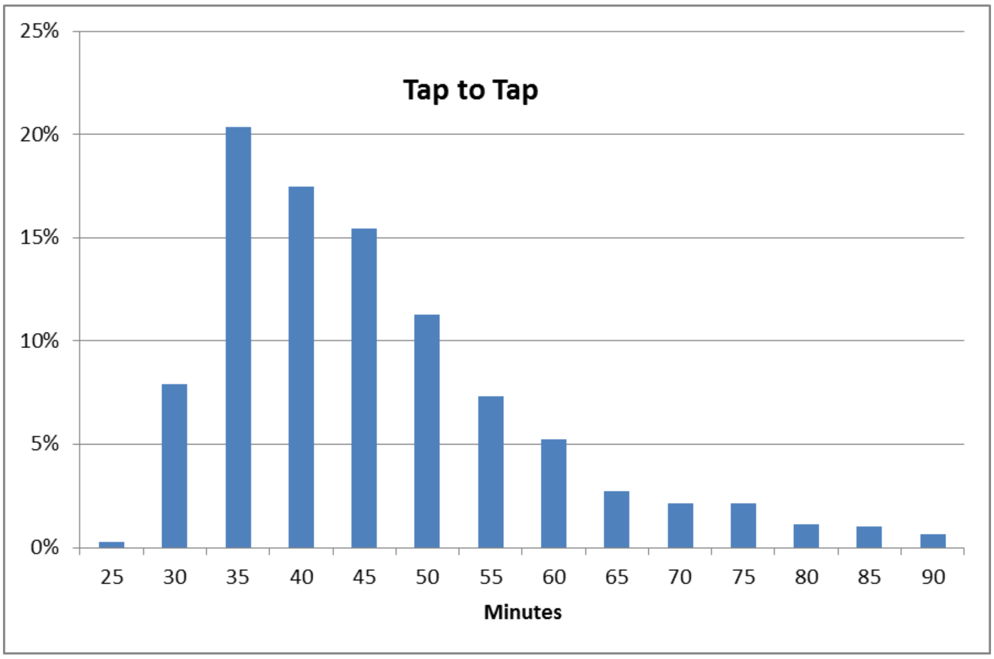


Figure 34: EAF process duration at ORI during one month production

c. Analysis of the main electrical energy consumers of the steel mill

The analysis of the main electrical energy consumers of the LSW steel plant on a basis of a yearly energy report has been given in Figure 19. The figure shows that together with the auxiliary plants, the liquid steelmaking aggregates in the steel plant including the auxiliary plants cover about 93% of the total electrical energy consumption. 73% of this electrical energy consumption is covered by the two EAFs as the by far largest consumers in the steel plant. They are followed by the two ladle furnaces with only 8% of the electrical energy consumption. Due to the fact that the main consumers of electrical energy are the two electric arc furnaces it has been decided that the future monitoring and management of the electrical energy has to focus on the operation of the two EAFs and those auxiliary plants that support the EAF operation.

As depicted in Figure 26, the main consumers of electrical energy in the plant of HHO are located in the rolling plant. Together with the auxiliary plants, the rolling mill aggregates in the plant cover about 50% of the total electrical energy consumption. 45% of this electrical energy consumption is covered by the main drives. The second main consumer is the spring plant with about 30%. Subsequently, pickling line and the furnaces of the hot rolling mill have to be included as a mentionable part of the overall electricity distribution as well.

In Figure 15, a distribution among the monitored machines at ORI including the new measurements activated during 2015 is shown. The Steel making Area accounts for more than 70% of the total electrical energy and is the major responsible for the fluctuations in the energy requests. The remaining processes have almost a flat electricity demand and account for more than 20%.

d. Analysis of the power load characteristic of the steel mill with a focus on short term deviations of the 15 minutes intervals.

Finally the power load characteristic of the total LSW plant has been monitored. The analysis of the power load characteristic of the steel plant has been performed with a focus on short term deviations of the 15 minutes intervals.

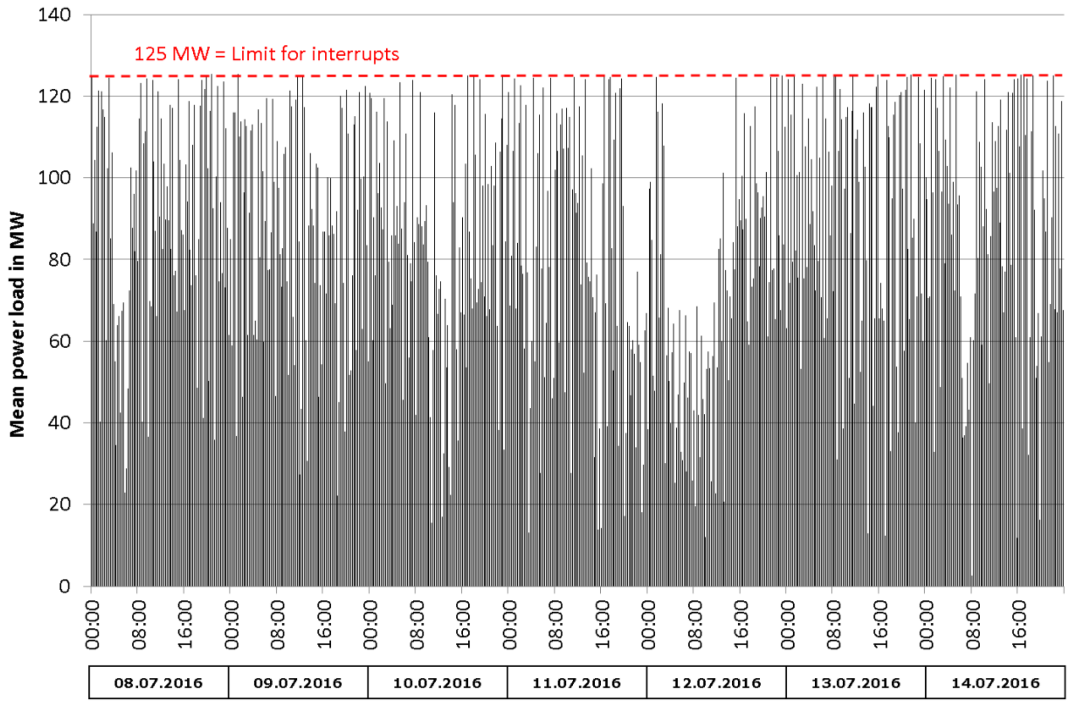


Figure 35: Example of the melting power demand of the LSW steel plant in 15 minutes intervals for the time period of 08.07.2016 to 14.07.2016.

It has to be mentioned that at LSW the power supply is separated into the so called "Schmelzstrom" (Melting power) for operation of the two EAFs and the two LFs, and the so called "Betriebsstrom" (Operating power) for the other consumers (auxiliary aggregates, rolling mill etc.) of the plant. Only the melting power is limited to a peak value of 125 MW, which has to be monitored and controlled within the 15 min time intervals. A typical example of the melting power demand during one week can be found in Figure 35 showing that a high scatter over the time occurred due to non-continuous production.

The big consumers with significantly differing power demand that have been identified were mainly

- the two electric arc furnaces EAF1 and EAF3 and
- the ladle furnaces LF2 and LF4.

The fluctuating power demand of the steel mill depends to a high extent on different parameters of these furnaces like

- the selected operating point (voltage tap) of the EAF and the LFs,
- the charge materials,
- the status of the melting progress and the production process.

In Figure 36 an example of electrical energy demand during one week is shown. It can be notice that ORI has a similar behavior with a high scatter due to the non-continuous processes. Periods of very low electricity demand is due to stop of the production during the week end. In Figure 37 a typical behavior of electricity demand during a working day at ORI is shown. The black line indicates the overall objective to reach the more flat situation possible according to production requirements. A comparison between Figure 36 and Figure 37 shows that this scattering is mainly due to the EAF and less to the two LFs, while the other processes have a very low influence.

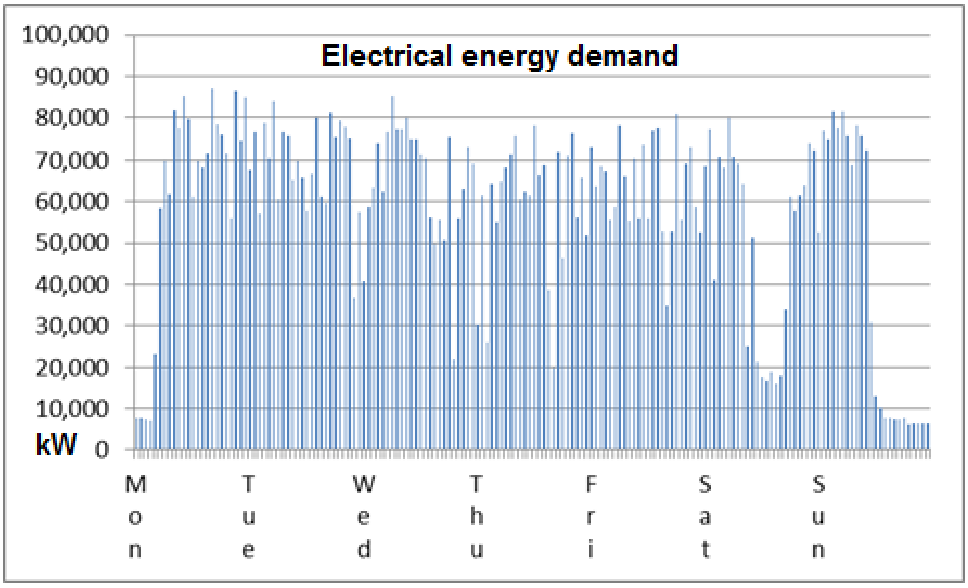


Figure 36: Electrical energy demand of the ORI steel plant in 1 h intervals for a week

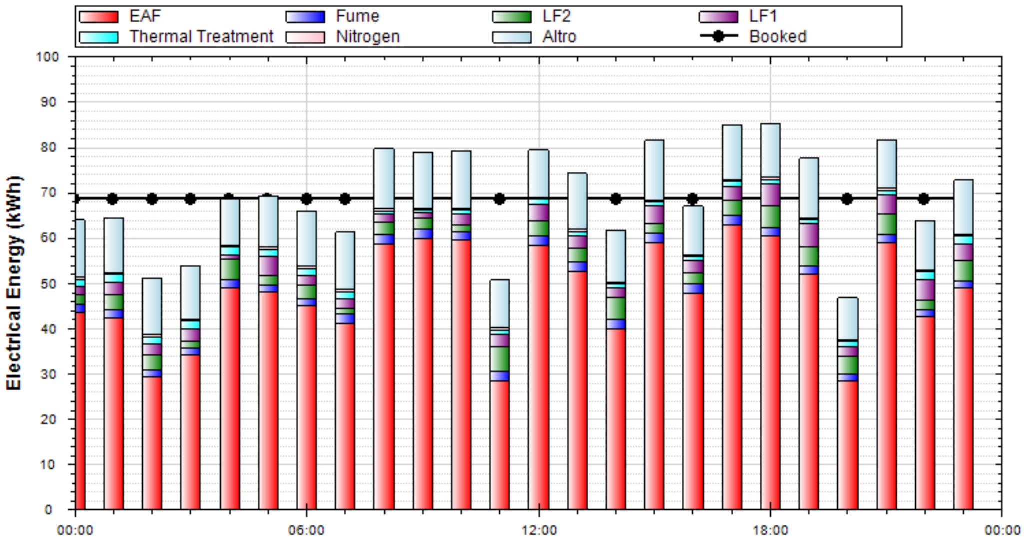


Figure 37: Effective electricity demand compared to booked one in a day at ORI

Figure 38 shows the subdivisions of different logical groupings with their electric meter in HHO. The total energy requirement of HHO is distributed by individual electricity meters to electricity meter groups. There are three main subgroups which are the "Area of Responsibility", the "Cost Center" and the "Function groups", the Area of Responsibility are the largest and contain several cost centers, which also contain several smaller Function groups.

The specified collection with separate electric meters was realized in the project and makes possible a more exact allocation of the load per aggregates.

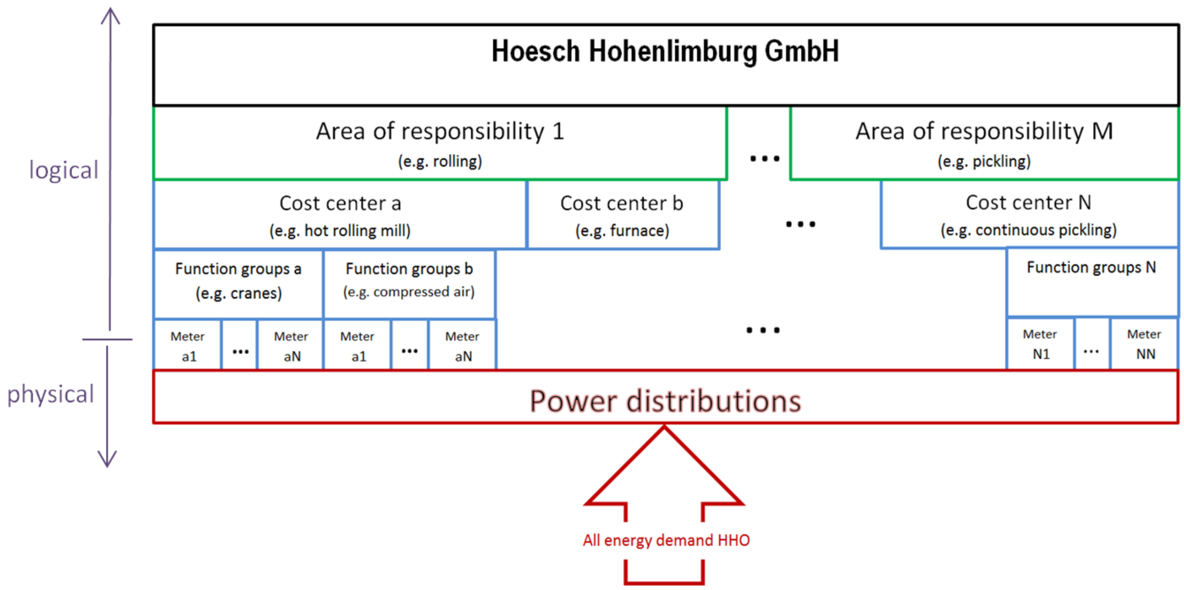


Figure 38: Energy flow and power distributions in HHO

Figure 39 shows the physical representation of the energy feed and the energy distribution with their meters of some aggregates in HHO.

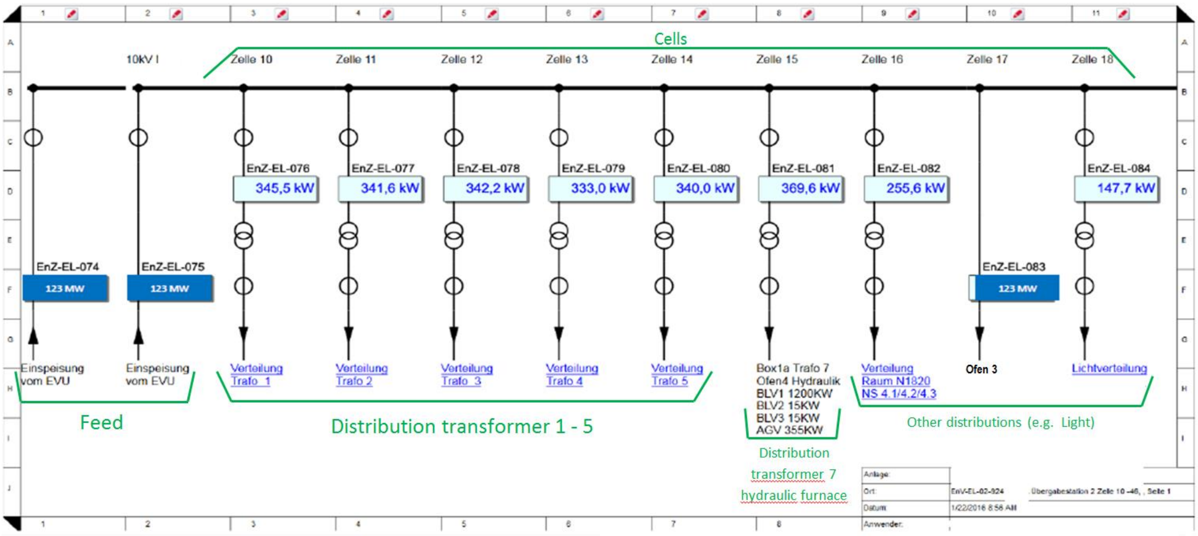


Figure 39: Physical representation of the energy data acquisition

Figure 40 shows the online measurement device view of the current values acquisition of the energy with other features like database, statistic or system protocol. For example we can visualize the actual power consumption of each line (L1, L2 and L3) and the total consumption of all the lines.

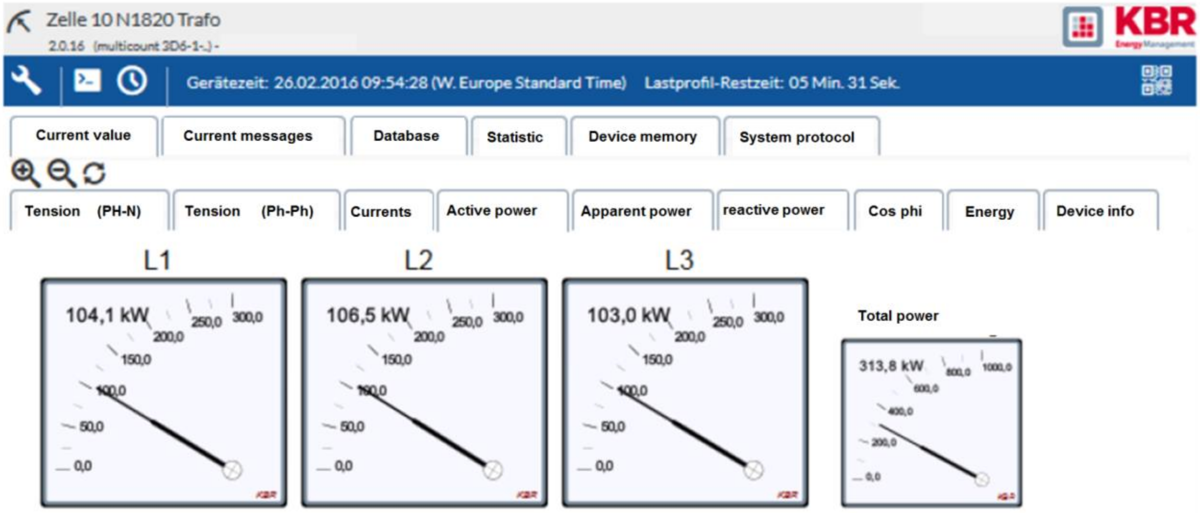


Figure 40: View of the measurement device for the energy data acquisition

Grid Data Analysis

More details are reported in Annex 3

Data from TERNA

RSE has provided SSSA with data about both energy production through renewable sources (such as photovoltaic, hydroelectric, geothermal and wind power) and power requirement in the day-ahead spot market of the Italian Power Exchange, as well as other data concerning with the imbalances of the National Transmission Network and with electricity balancing prices at the Dispatching Services Market.

The period of reference is between November 2014 and September 2015.

In more detail, the provided data belong to the following categories:

- wind power production prevision
- energy production through some renewable sources
- power requirement in the day-ahead spot market
- signs of imbalances of the National Transmission Network
- electricity balancing prices at the Dispatching Services Market

Some of the provided data are associated to market zones or limited production poles, while others to macro zones. In both cases, every data item is related to a time stamp, which represents a specific hour of a day. No data about foreign virtual zones have been provided.

Zone data

- Hourly previsions of wind power production, in MWh, are specified for each market zone or limited production pole. The prevision is made at day N for the next day N+1.
- Hourly energy production actual values, in MWh, are given for each market zone and for each type of renewable source taken into account.
  Energy production data are related to renewable sources of the following types: Geothermal, Hydro (River), Photovoltaic Estimated, Photovoltaic Measured and Wind.
  Specifically, our attention is directed to Geothermal, Hydro (River) and Photovoltaic Estimated.
- Hourly power requirement actual values in the day-ahead market are specified for each market zone (in MWh).

Macro zone data

- Hourly sign of imbalance of the National Transmission Network for each macro zone. A positive/negative imbalance means that the actual injection of electric energy is greater/lower than the actual withdrawal of electric energy.
- Hourly average selling price of the Dispatching Services Market (in €/MWh) for each macro zone.
- Hourly average purchase price of the Dispatching Services Market (in €/MWh) for each macro zone.

Data preprocessing

The value of the average selling or purchase price, for a specific hour, can be undefined, meaning that TERNA didn’t need to resort to the Dispatching Services Market for balancing purposes. In these cases, TERNA solved the imbalance of the National Transmission Network with a redistribution of energy among the zones.

However, for our statistical analysis it is necessary to have a complete time series for both selling and purchase prices. The percentage of undefined price values is quite low, less than 13% for both prices in each macro zone, as shown in Table 10. Therefore, the undefined hourly values have been filled up by using linear interpolation procedures on each price time series.

Furthermore, for each day, the information about the day being a working or a non-working day has been computed.

Data aggregation

The aim of data aggregation is to obtain the overall energy production data and power requirement data for each macro zone. For this purpose, each category of zone data has been aggregated by sum on all the market zones belonging to a macro zone.

The limited production pole contributions have been included into the market zone to which they belong. Furthermore, in order to find out the overall energy production data related to the renewable sources of interest (Geothermal, Hydro (River) and Photovoltaic Estimated), only energy production data associated to the above-mentioned sources have been summed.

Dataset

Starting from the preprocessed and aggregated data, a dataset has been created for each macro zone (NORTH and SOUTH). The macro zone dataset has been represented by a matrix, where each row corresponds to one hour of a day in the reference period, while columns correspond to the different types of collected information.

An example of the dataset organization can be found in Annex 3.

The dataset has been divided into two parts: input data and target data.

The target variables correspond to the variables to be predicted:

- Hourly sign of imbalance of the National Transmission Network
- Hourly average selling price at the Dispatching Services Market
- Hourly average purchase price at the Dispatching Services Market

Statistical Data Analysis

The main goals of time series analysis are to identify the nature of the phenomenon represented by the sequence of observations and to predict future values of the time series target variable.

SSSA has made a separate study for each target variable and for each macro zone. The aim of each study is to build a model that can predict the future values of the target variable, learning from the observations taken from the available dataset (supervised method). Several modeling and forecasting techniques have been tested.

a. Network imbalance sign analysis

The target variable is the network imbalance sign and its possible values are ‘+1’ for positive imbalance and ‘-1’ for negative imbalance.

First SSSA analysis on the imbalance sign has been the study of the change of the sign between sequential times in the time series. The imbalance sign is a constant function for most of the times (about 84% of times in the North macro zone and 83% of times in the South macro zone) and only a few changes of the sign happen between sequential times during the time period (about 16% of times in the North macro zone and 17% of times in the South macro zone). The results of the change of sign study are shown in Table 7.

Macro zone	Imbalance sign unchanges %	Imbalance sign changes %
North	84.15	15.85
South	83.11	16.89

Table 7: Imbalance sign changing between sequential hours for macro zone

Therefore, even a very simple and trivial algorithm, which predicts the value of the imbalance sign for the next hour (t + 1) equal to the value of the sign at the actual hour (t), allows to gain a quite satisfactory prediction accuracy (about 84% for the North macro zone and about 83% for the South macro zone). Every further predictor is to be considered significant only when the prediction accuracy is greater than 84%, which represents the baseline performance.

MARKOV CHAIN for imbalance sign

The Markov chain-based technique has been developed in order to calculate the probabilities of moving from the positive state to the negative state represented by a transition matrix. A Markov model can be visualized through a state diagram as shown in Figure 41.

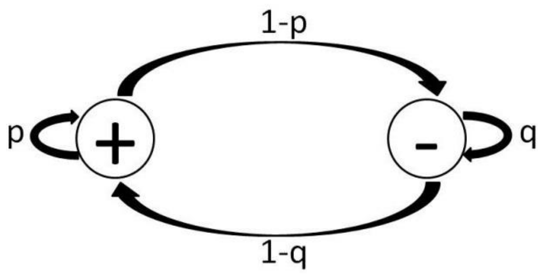


Figure 41: Markov chain state diagram

The transition matrix of the imbalance sign, concerning to the macro zone NORTH and SOUTH, is represented respectively in Table 8 (a) and (b).

North	+	-
+	0.87	0.13
-	0.20	0.80

(a)

South	+	-
+	0.80	0.20
-	0.15	0.85

(b)

Table 8: Transition matrix related to NORTH (a) and South (b) macro zone

From Table 8, we can conclude that if the imbalance sign at the time t is positive, it has a probability of 87% (in the NORTH macro zone) or 80% (in the SOUTH macro zone) to remain in the same state, while it has a probability of 13% (in the NORTH macro zone) or 20% (in the SOUTH macro zone) to switch to the negative state at time t+1; on the other hand, if the imbalance sign at the time t is negative, it has a probability of 80% (in the NORTH macro zone) or 85% (in the SOUTH macro zone) to remain in the same state, while it has a probability of 20% (in the NORTH macro zone) or 15% (in the SOUTH macro zone) to switch to the positive state at the next time.

Using the Markov chain, we can also calculate the probability to remain in the same state or to move into the other one at the time t+K, knowing only the state at the time t. The results for K=10 are reported in Annex 3.

Other advanced techniques for imbalance sign

In order to increase prediction performance, SSSA has experimented several more sophisticated and advanced techniques. The different types of techniques used by SSSA to represent time series data and generate predictions are the following:

- Decision trees
- Support Vector Machines (SVM)
- Naïve Bayes classifier
- Non linear autoregressive neural networks (NAR)
- Non linear autoregressive neural networks with exogenous inputs (NARX)

All the considered methods are supervised machine learning methods, meaning that the model is built by learning the mapping between input and target data from data examples. These methods are used for classification and regression, depending on whether the variable to be predicted is a categorical (qualitative) variable or a quantitative variable. Specifically, NAR and NARX are neural networks commonly used for time series modeling and prediction.

Time series model

The model, which has been used in time series modeling, can be defined by the following equation:

$$\boldsymbol{target(t) = f(target(t-1), target(t-2), .., target(t-n), input(t-1), input(t-2), .., input(t-n))} \quad (1)$$

This equation states that the next value of the dependent output variable target(t) is a function of the previous values of the output variable and previous values of an (exogenous) independent input variable.

This model can be implemented by using a statistical method to approximate the function f. SSSA implemented this model by using, in turn, each of the enunciated statistical methods to approximate the function f

Building the data examples

For n = 6, each data example has been created with the six previous values of target and input data (time t-1, .., t-6) and, moreover, the next value of the target (time t).

Data Example = [target(t-1), ..,target(t-6), input(t-1), …, input(t-6) target(t)]

Predicting the network imbalance sign at time t is equivalent to classify the six previous times data instance into one of two classes (+1, -1).

Building and evaluating the model

Data examples are divided into two portions: training set and validation set.

Training data are used to build the model, while validation data are classified using the built model. The model is evaluated by measuring the percentage of correctly classified examples in the validation set.

The classification algorithm

After having randomly shuffled input and target data, data are divided into training set (75%) and validation set (25%), so that the two classes are equally distributed among training and validation sets. Each training builds a binary classification model that can classify an input data instance into one of two classes (+1, -1). Ten trainings per test have been performed in order to assess and check the stability of results. Classification performances have been calculated by using the Balanced Classification Rate (BCR), explained in the Annex 3. Afterwards, performance averages have been calculated on the ten trainings.

Classification performance results

The classification algorithm has been applied by using the different statistical techniques and by training the model in two different ways:

- with data examples including all the input data variables together with target data variables at the previous six times (model with exogenous inputs: the target to be predicted depends both from previous values of itself and from previous values of an external input time series)
- with data examples including only target data variables at the previous six times (model without exogenous inputs)

The results turned out to be comparable in the two approaches, meaning that most of informative contents is already included inside the historical target.

Table 9 shows the results achieved by training the model with the different statistical techniques and in the two ways (with or without exogenous inputs), respectively for each macro zone.

	NORTH		*SOUTH*	
Statistical Method	*BCR – Only historical target*	*BCR – Historical input and target*	*BCR – Only historical target*	*BCR – Historical input and target*
Decision Tree	0.8374	0.7434	0.8306	0.7381
SVM	0.8350	0.8348	0.8311	0.8241
Naïve Bayes	0.7865	0.7711	0.7879	0.7574
NAR /NARX	0.8338	0.8316	0.8222	0.8257

Table 9: Imbalance Sign - BCR performance results for North and South macro zone (n = 6)

SSSA has also experimented different values for the number of delays (n = number of previous times) and a number of delays equal to six represents a good tradeoff between the performance and the complexity of the model.

A remark about the cases of neural networks (NAR/NARX) should be given. Since the output of a NARX/NAR neural network is a value in the range [-1 1], the predicted value has been set to 1 if the network output value is greater or equal to 0, to -1 otherwise.

Conclusions

None of the advanced statistical methods examined has been able to go over the limit imposed by the baseline.

b. Analysis of the need to resort to the Dispatching Services Market

SSSA made an attempt to predict the fact that TERNA did or did not need to resort to the Dispatching Services Market. In fact, all the original undefined values for the average selling / purchase price represent the hours when no recourse was needed, while defined values represent those hours in which a recourse happened.

Since the percentages of no recourse are quite low, as showed in Table 10, SSSA tried to improve performance results by using specific techniques for imbalanced dataset, such as SMOTE[8], random under-sampling and other algorithms[9], without achieving any satisfactory results.

Macro zone	**No MSD recourse % - Selling**	**No MSD recourse % - Purchase**
North	13.13	1.78
South	4.48	0.28

Table 10: Percentage of recourses to MSD

c. Analysis of hourly average selling/purchase price at the Dispatching Services Market

The time series model is still the one defined by equation (1) and the statistical methods used to approximate the function *f* are respectively NAR and NARX neural networks. In this context, SSSA used these types of networks to make a prediction of the price for the next ten hours (multi-step-ahead prediction).

Multi-step-ahead prediction algorithm

[8] N.V. Chawla, K.W. Bowyer, L.O. Hall, W.P. Kegelmeyer, "SMOTE: synthetic minority over-sampling technique", *Journal of Artificial Intelligence Research* , 16, pp. 321–357, 2002.
[9] S. Cateni, V. Colla and M. Vannucci, "A method for resampling imbalanced datasets in binary classification tasks for real-world problems", *Neurocomputing* 135, pp. 32-41, 2014.

- The data examples time series is divided into two continuous blocks, the first of 75% and the second of 25% of data. The training set corresponds to the first block, while the validation set corresponds to the second block.
- The model has been trained from the training set.
- The model has been validated on the validation set by predicting ten hours at a time.
  For this purpose, the validation set has been scanned, hour by hour, from the beginning to the end with steps of ten hours.
- Each step of the algorithm makes a prediction for the next ten hours, starting from input and target values at the six previous hours, according to the model equation.
- All predictions, made on all the steps, for the same (next) hour are gathered together and the measured and predicted values are visualized in a plot.
- An estimation of the prediction error is calculated by evaluating all predictions for the same hour and by means of NSRMSE performance function (Normalized Square Root Mean Square Error)[10].

The NSRMSE performance function and other performance functions taken into account in the analysis are explained in Annex 3.

The results of Multi-step-ahead prediction on selling and purchase prices are reported in Annex 3.

2.2.2.4 Task 2.4: Monitoring the actual power engagement and historical event frequency

The following paragraph represents the Deliverable *D2.2*

The monitoring systems have been implemented in the reference plants improving not only the number of processes monitored but also the ease to use. Nevertheless the importance of monitoring and improving the quality of the energy measures is so important for the steel plants that the process is on a continuous improvement, which means that further measurements will be added or more performing Db server will be installed; that’s why in the GANNT the end of this task has been prolonged without affecting the development foreseen in the following WPs.

A selection of the most relevant processes mostly with reference to the volatility of the energy demand has been performed in order to identify the more important process to be continuously monitored besides the overall energy need of the whole pant. Typically some processes like continuous casting show an electricity demand almost constant in time, apart from downtime due to e.g. maintenance and therefore it was decided not to monitor independently their energy demand continuously. In any case monthly reports are available for most of the steel plants processes.

For AST the focus has been in processes in steel shop (EAF, AOD, LF) and the HSM, similarly also in ORI the EAF and the LF together with the HSM has been considered. The new monitoring system of AST and ORI are accessible through Web browser and the profile of the monitored processes and the total plant energy is available continuously. In AST data related to energy price (PUN) are displayed and a specific interface has been developed to monitor specifically the 15 minutes peak. Figures of the implemented system can be found in WP6.

Lech-Stahlwerke has designed a new monitoring and visualization system of the actual power engagement and all energy flows of all aggregates in the electric steelmaking plant. The system is called STWISS (STahlWerksInformationsSyStem). It is linked to the data base of a new Level 2 process control system. The enhanced system includes new hardware (server, work stations, user displays) and adequate software for an energy and power load monitoring.

[10] Shcherbakov, Maxim Vladimirovich, et al. "A survey of forecast error measures." World Applied Sciences Journal 24: 171-176, 2013

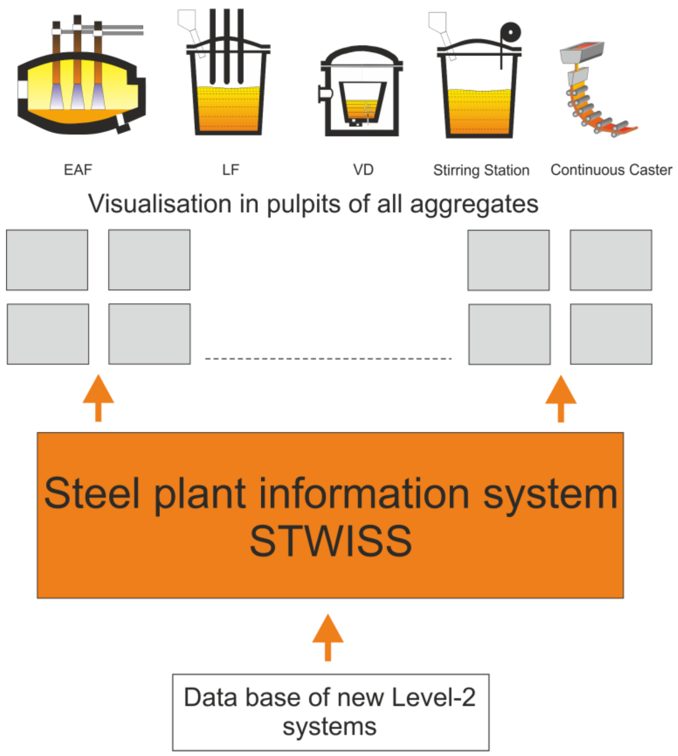


Figure 42: Structure of the monitoring and visualisation system at LSW

The structure of the system is shown in Figure 42.

This monitoring system provides an online overview of all aggregates of the process route (EAFs, LFs, VDs, Stirring stations, Continuous casting plants) in the electric steelmaking plant, and visualizes the process flow and the status of the process for every heat, comprising among others the following data:

- Charge number
- Position within the process route
- Steel grade
- Ladle number
- Steel weight
- Start time and status of the process at each aggregate
- Status of the continuous caster (start, weight, temperature)
- Chemical analysis of each heat

Figure 43 shows the outline of the user display of the system.

The online terminal at HHO is able to show the actual consumption of each measure point including Steam, Compressed air, Current, Natural gas and city water for the last 30 days with a resolution of 15 minutes. In order to visualize data with higher resolution a special software has been developed which collects the data on base up to 1 Sec.

The main events that are taken into consideration are synthetized in Table 11. They can be either internal or external, predictable or unpredictable. As it will be better described in WP6 the events represent the trigger to activate the energy demand system.

In particular the predictable schedule maintenance and downtime are useful for the determination of a more reliable energy demand profile for accessing the day after market. When a process is faster than the previous one or the product requests are not enough to justify a 24hour a day and 7days a week production the process is stopped for at least one shift during week end. In these case the maintenance is normally done before restarting the process or just after the planned stop resulting in a longer downtime.

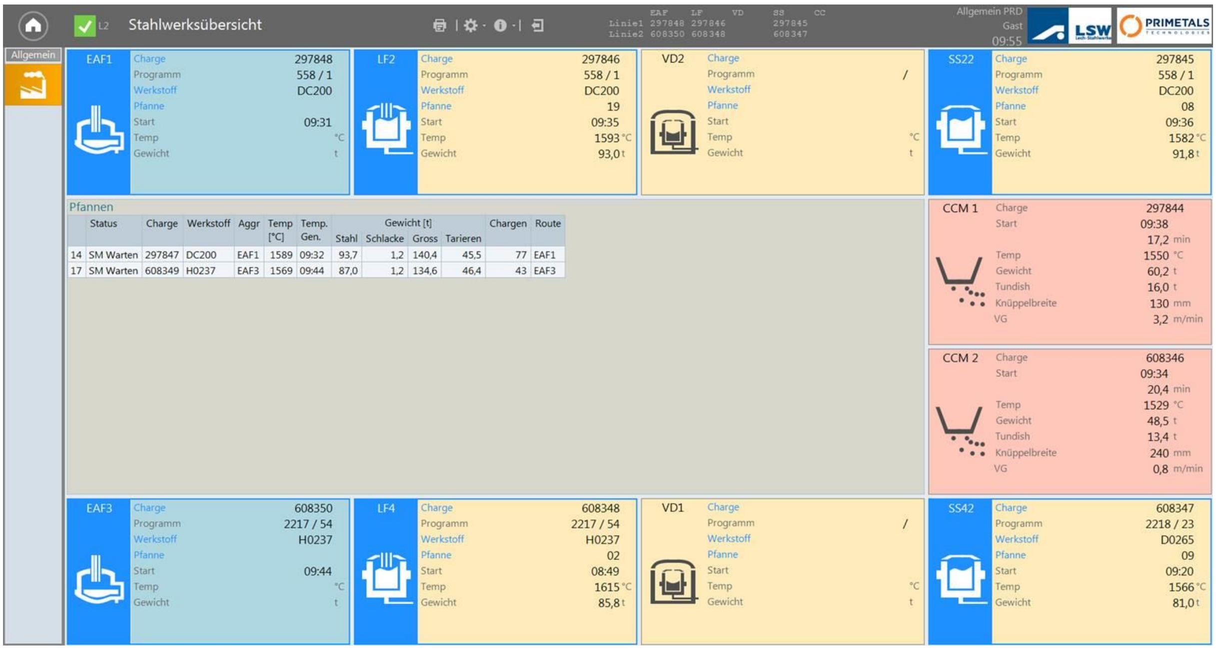


Figure 43: User display of monitoring and visualisation system at LSW

The interruptibility represents an external unforeseen event, as described in WP1 the involved process is automatically disconnected by the TSO. This is a normal practice in Italy; despite it has no upper limit for the duration it normally lasts at maximum some minutes (in 2016 at ORI the longest detachment was less than 7 minutes and the others between 1 and 3 minutes, at AST the only one was less than 6 minutes) and happens just few time in the year (in 2016 at ORI four times and at AST just one); this means that normally it has little impact on the production. The challenge is that during the detachment the other loads cannot exceed the power measured at the beginning of the detachment and therefore should be monitored carefully.

There are no historical data on plant experience on energy markets request because the market is not still open in Italy and the two German industrial partners are going to test this possibility within the project (see WP3 and WP4 for more details).

Table 11: type of events

	Predictable	Unpredictable
Internal	Scheduled Maintenance Scheduled downtime	Unplanned process downtime
External		Energy market requests Interruptibility

The unplanned process downtime has impact both on the difference between booked and actual energy profile and in the 15 minutes peak for the next periods due to the necessity to overcome the loss of production.

The process data of LSW have been analysed in order to find the main reasons for deviations of the power engagement. Figure 44 shows exemplarily an analysis of the operation of EAF No. 1 in 2016. A mean tap-to-tap time of 68 minutes has been determined. However it can be seen that only 57 minutes have been spent to the planned operation of the EAF, including the power-on time as well as power-off times required for scrap charging, tapping and regular furnace maintenance. Further 11.2 minutes were devoted to unplanned events and stops due to machinery failures and required maintenance work. This will also cause deviations within the predictable energy demand.

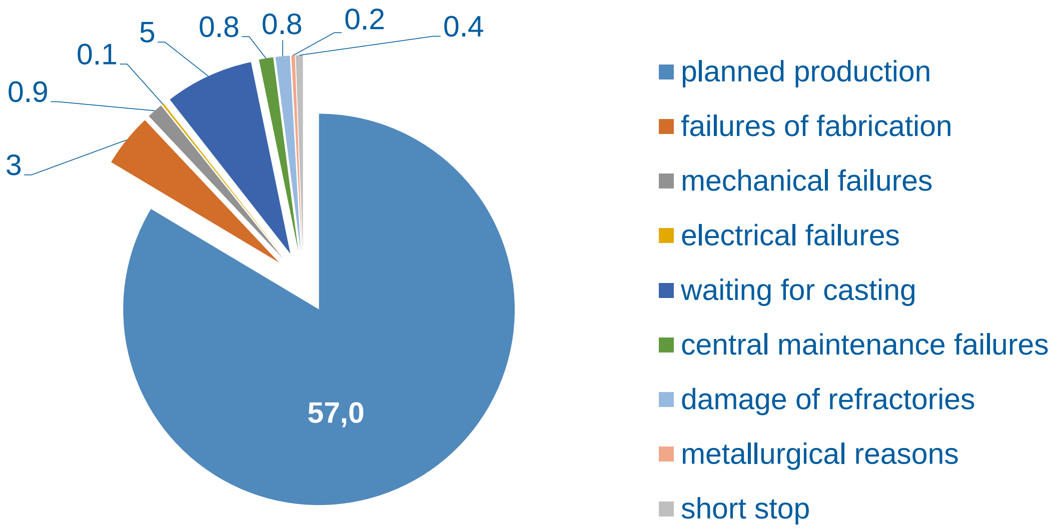


Figure 44: Time intervals in minutes of the tap-to-tap time needed for planned production and unplanned events and maintenance of the production of EAF1 at Lech-Stahlwerke

2.2.3 Work package 3: Forecast of power engagement

In this WP the actual procedures for forecasting the power demand has been studied with the aim of enhancing the accuracy of the booked profile. Historical data analysis has been carried out in order to evaluate relations among energy, process and product data to determine the electricity needs based on product and process characteristics.

An electricity flow-sheet model that can forecast the energy consumption related to those plants of a steel industry characterized by a relevant energy demand, in order to estimate the energy requirement in the more plausible manner has been developed.

Based on those result control loop to manage the energy adjustment has been developed.

Finally, an analysis of the flexible disconnectable loads in steel plants has been carried out taking into consideration the specificity of the industrial partners but aiming to have general remarks for the steel companies participation in energy markets.

2.2.3.1 Task 3.1: Development of the methodology to predict the electric energy demand in the steel plant according to heat / process and product mix

Several statistical analysis, mainly on EAFs, based on the historical data have been performed in order to define the methodologies to calculate specific process/product electricity needs to be used for enhancing the overall energy profile forecasting.

<u>Improvement of the electricity demand prediction</u>

A first task to improve the accuracy and reliability of the day-ahead forecast of the electrical energy demand at LSW was to determine the electrical energy consumption at the EAF depending on the steel grades to be produced. For that purpose, historical data of about 2000 heats from 469 different steel qualities produced in the first 6 months of 2014 were evaluated. The different steel qualities were grouped according to the sum of the most important alloy elements (C, Mn, Si, Cr, Mo, Ni) which influence the electrical energy consumption. Furthermore the tap weight was considered, which is lower for quality steel grades (< 93 t) according to the required freeboard in the ladle for the vacuum treatment. Figure 45 shows the actual electrical energy consumption of the evaluated EAF heats depending on the alloy element concentration for the two different groups of tap weights.

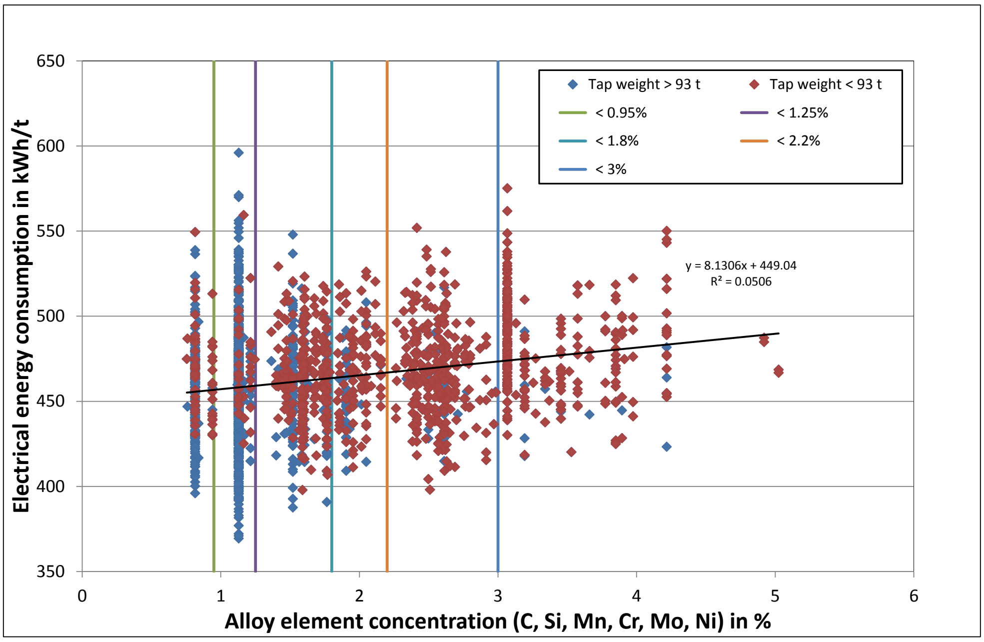


Figure 45: Electrical energy consumption of EAF heats vs. alloy element concentration and tap weight

These dependencies were used to set up a grouping of the steel qualities produced at LSW. As can be seen from Figure 46, in total 6 quality groups (quality steel grades) for the lower tap weight (< 93 t) and 5 quality groups (mostly structural steel grades) for the higher tap weight (> 93 t) were defined.

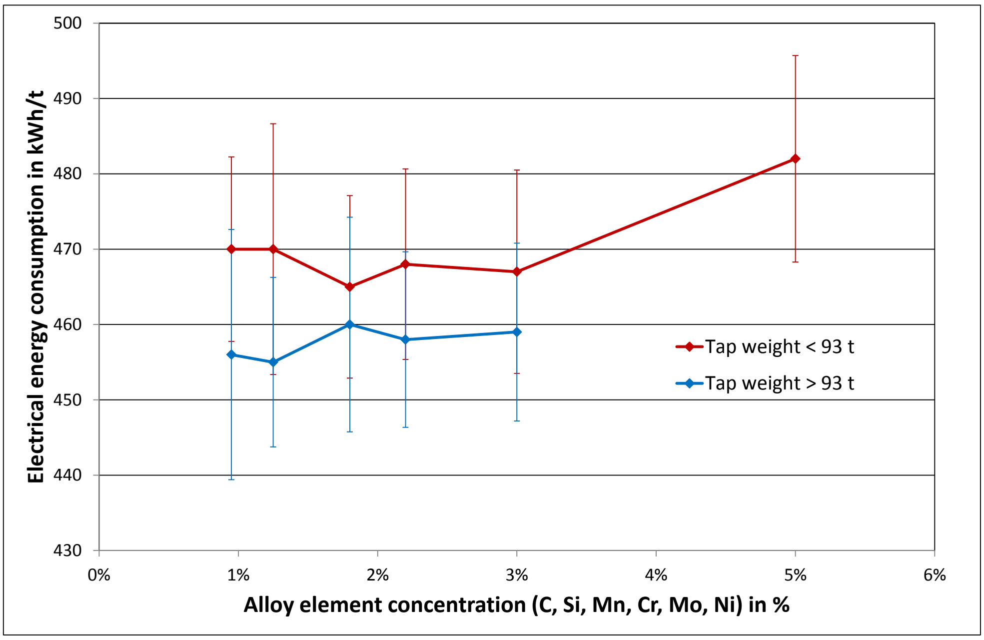


Figure 46: Grouping of LSW steel qualities according to alloy element concentration and tap weight

In addition, the electrical energy consumption of the EAF heats was analysed with the help of a statistical model for the electrical energy demand which has previously been developed by BFI [Koehle 2002]. With the help of this simple model, which is shown in Figure 47, the specific electrical energy demand of an EAF, related to the liquid tap weight, can be predicted depending on the charge materials, the chemical energy inputs like natural gas and oxygen, and several further production parameters like tapping temperature and tap-to-tap time.

$$\frac{W_R}{kWh/t} = 375 + 400 \cdot \left[\frac{G_E}{G_A} - 1\right] + 80 \cdot \frac{G_{DRI/HBI}}{G_A} - 50 \cdot \frac{G_{Shr}}{G_A} - 350 \cdot \frac{G_{HM}}{G_A} + 1000 \cdot \frac{G_Z}{G_A}$$

$$+ 0.3 \cdot \left[\frac{T_A}{°C} - 1600\right] + 1 \cdot \frac{t_S + t_N}{min} - 8 \cdot \frac{M_G}{m^3/t} - 4.3 \cdot \frac{M_L}{m^3/t} - 2.8 \cdot \frac{M_N}{m^3/t}$$

G_A	Tap weight	t_S	Power-on time
G_E	Metallic charge weight	t_N	Power-off time
G_{DRI}	DRI	M_G	Burner gas
G_{HBI}	HBI	M_L	Injected oxygen
G_{Shr}	Shredder-Scrap	M_N	PC oxygen
G_{HM}	Hot metal		
G_Z	Slag formers		
T_A	Tapping temperature		

Figure 47: Statistical model to calculate the electrical energy demand of EAFs

This model was used to predict the electrical energy demand of the heats treated at the EAF 1 of LSW. In total 2065 heats with information on the different charged scrap types and amounts were evaluated. Figure 48 shows for all evaluated heats a comparison between predicted electrical energy demand and actual electrical energy consumption in kWh/ t of tapped liquid steel. The accuracy of this prediction is with a standard deviation of around 20 kWh/t quite good.

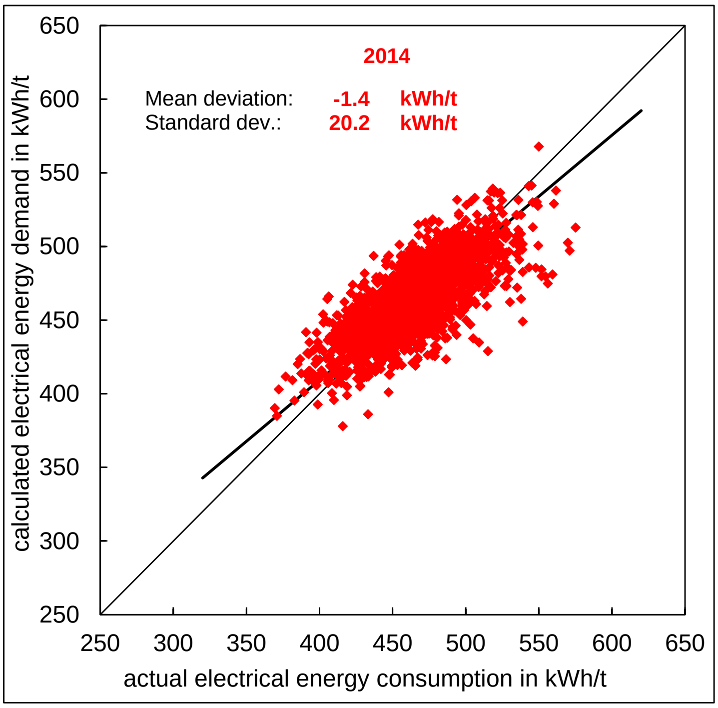


Figure 48: Calculated vs. actual electrical energy consumption for EAF heats at LSW

The evaluation also revealed that the actual electrical energy consumption (WE) depends on the specific charge material weight gE, that means the amount of charged scrap in kg related to the tap weight in t. Figure 49 shows that heats with a very low specific charge weight have a significantly lower specific energy consumption. Such heats are produced before repair shifts and other planned maintenance stops, when the furnace is completely emptied and thus the liquid heel complete accounts for the liquid tap weight. On the other hand, heats with a higher specific charge weight are produced after such repair shifts to build up again the hot heel. Those heats have a higher specific electrical energy consumption. Both effects have to be considered for a precise prediction of the electrical energy demand within a day-ahead schedule.

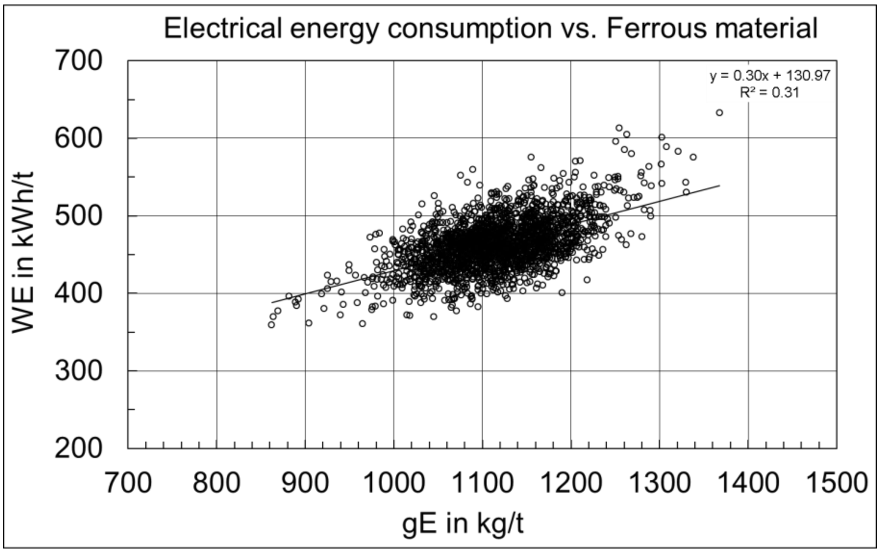


Figure 49: Actual electrical energy consumption depending on specific charge weight

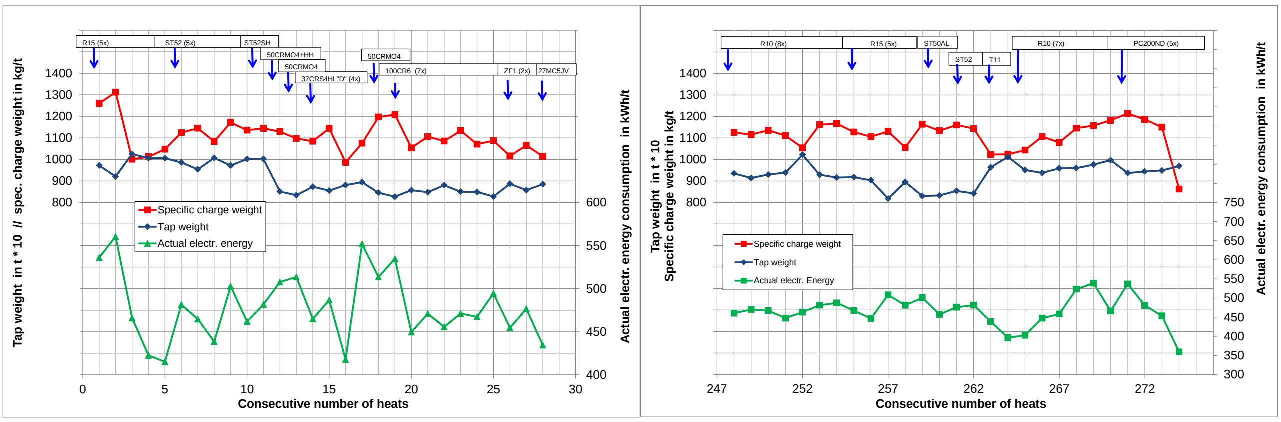


Figure 50: Specific charge weight, tap weight and specific electrical energy consumption for a sequence of EAF heats after (left) and before (right) a planned maintenance stoppage

Figure 50 shows on the left hand side the evolution of specific charge weight, tap weight and actual specific electrical energy consumption for a sequence of heats which were produced at LSW after a longer planned maintenance stop. The produced steel qualities are indicated in the top of the figure. It can be clearly seen that the first two heats of this sequence were performed with a higher specific charge weight, to build up the amount of the hot heel after start with an empty furnace. For these heats also the specific electrical energy consumption is significantly higher as for the other heats. On the right hand side of Figure 50, the same evolution is shown for a sequence of heats produced before a planned maintenance stop. Here for the last heat the specific charge weight was reduced, as the furnace is completely emptied to perform the maintenance work. As the tap weight stays the same, the specific electrical energy consumption is lowered accordingly.

In the following Figure 51, for the first sequence of heats additionally predicted values for the quality-dependent tap weight and for the electrical energy consumption, based on the quality grouping illustrated in Figure 46 and on the statistical model results shown in Figure 48 are displayed. It can be seen that the predicted electrical energy consumption of the statistical model follows the actual consumption quite accurately. However, this model cannot be fully applied for a day-ahead forecast, as it needs detailed information on the chemical energy supply and the actually charged scrap mix, which is not available in advance. The prediction based only on the information of the produced quality groups is of course not so accurate.

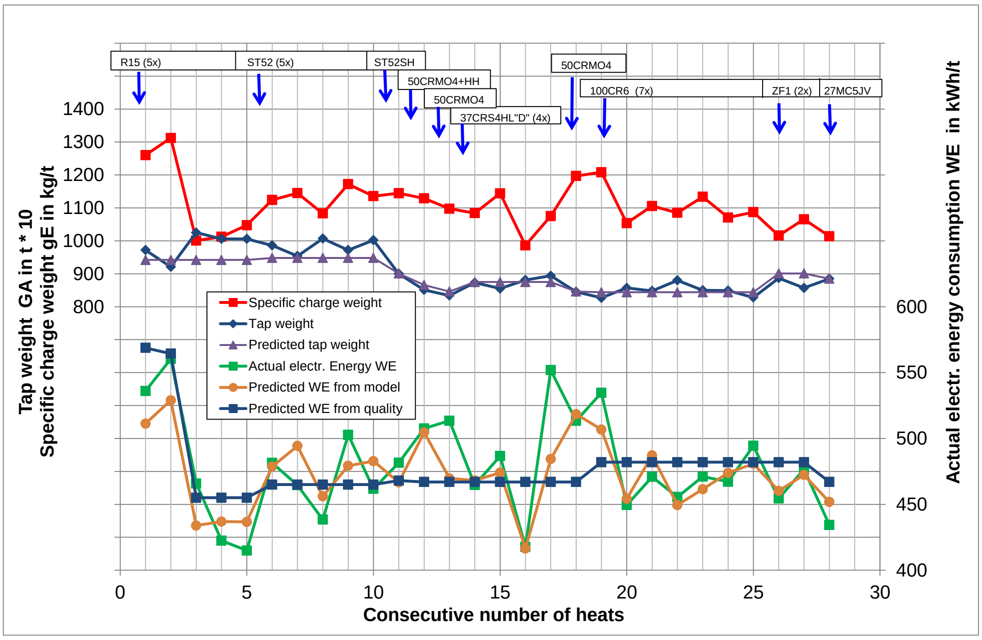


Figure 51: Actual and predicted tap weight and specific electrical energy consumption for a sequence of EAF heats after a production stoppage

The accuracy of the prediction according to both approaches is displayed in Figure 52. With regard to the whole production day, the statistical model shows a systematic deviation of around 100 kWh/t, whereas the prediction solely based on the quality information ends up with a deviation of almost zero. Thus the latter prediction seems to be the more practical and accurate one for a day-ahead forecast of the electrical energy demand.

For a day-ahead forecast, the prediction accuracy regarding the sum of the energy contingent of one production day is relevant. In Figure 53 the cumulative values of the actual and the predicted energy consumption of one EAF are plotted for the evaluated sequence in one figure, together with the deviation. It can be seen that the prediction is quite accurate, with a maximum cumulative error of only 8 MWh, i.e. less than 1 %.

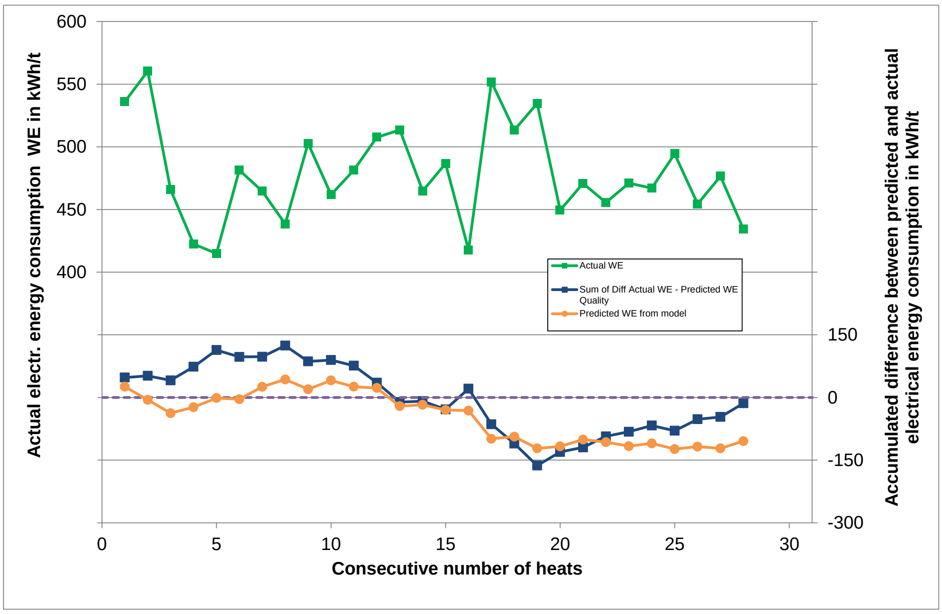


Figure 52: Prediction error of two model approaches for specific electrical energy consumption

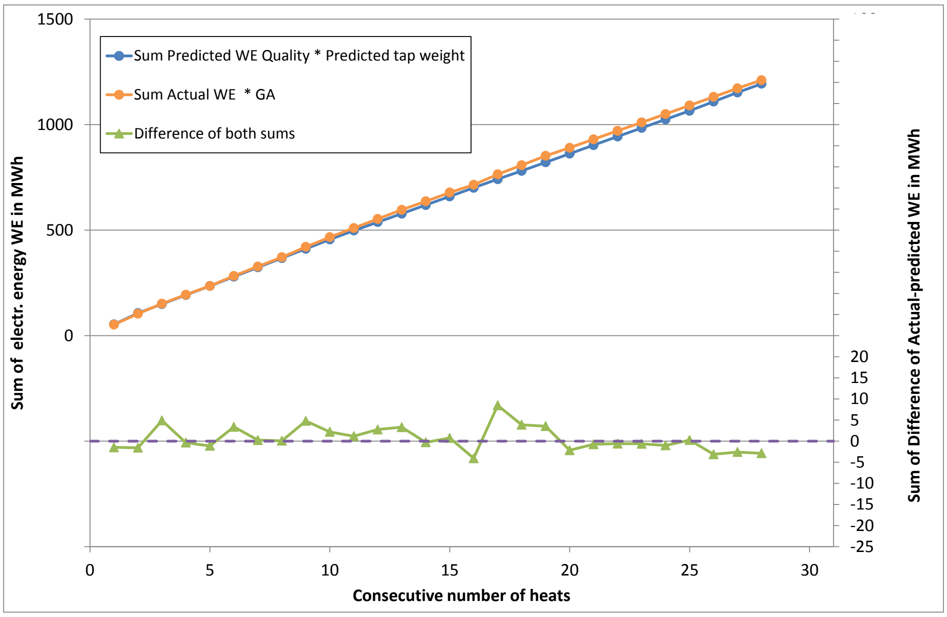


Figure 53: Prediction error of accumulated electrical energy consumption for a sequence of EAF heats

At HHO the power distribution has been determined by a measurement campaign, the average consumption of all individual aggregates is calculated on the basis of historical data in the central data model. The results of these calculations are the forecast of the average consumption of the future energy demand for the responsible energy provider.

At AST plant a correlation among energy, process and product data has been carried out in order to determine the electricity needs based on product and process characteristics.

In particular for each of the most relevant plant i.e. both EAFs and HSM the specific electrical needs have been elaborated.

For the two EAFs the data has been analyzed to individuate the specific needs in term of MWh/ton, i.e. material unit at tapping, with relation to the typical steel type produced at AST Terni (304, 316, 430, 409 and 441).

Three months of production have been taken into consideration. The results show that an appreciable difference can be seen only in the differentiation between austenitic and ferritic steel. Within these classes the variation are very small and therefore is reasonable to use these classes and the relative mean value in the plant electricity needs calculation.

In Figure 54 and Figure 55 the result of this elaboration is shown.

The variability range with respect to the mean value is around 4% for both classes.

In case of the AST HSM the specific electricity needs are directly joined to the steel type and geometry of the product (thickness, width, diameter). Specific mean values have been elaborated and will be used for the booked power profile determination.

AT ORI a statistical analysis of the rolling mill production has been performed to calculate energy needs specific to product characteristics (implying also some differences on production route)

At HHO based on an historical evaluation of the energy needs a medium value for the booked energy demand of each hour production has been calculated.

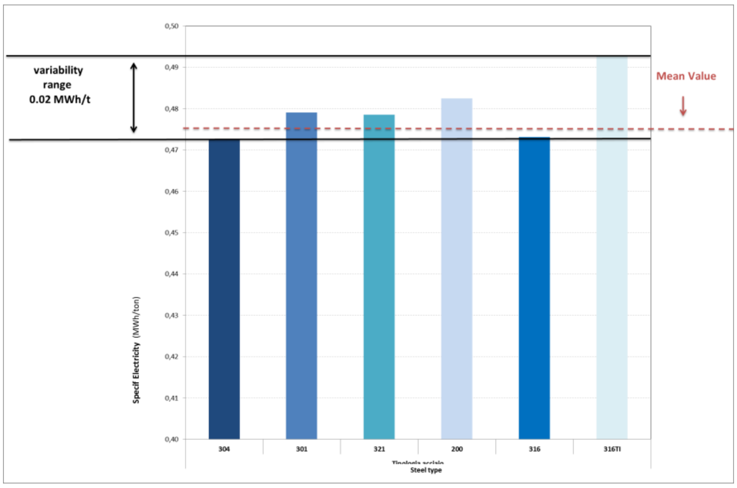


Figure 54: Austenitic Stainless Steel specific electrical energy needs

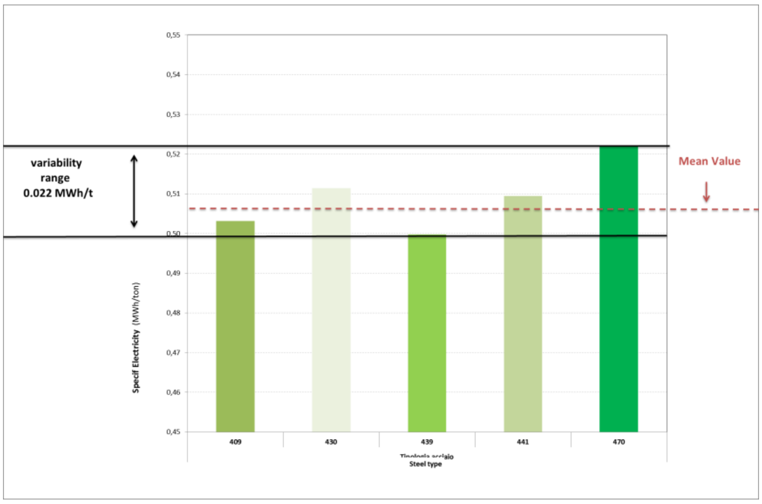


Figure 55: Ferritic Stainless Steel specific electrical energy needs

2.2.3.2 Task 3.2: Development of Electricity Flow Sheet Model (EFSM) of the process/plant systems; identification of disconnectable loads, energy storage and possible switching

The aim is to create an electricity flow-sheet model that can forecast the energy consumption related to those plants of a steel industry characterized by a relevant energy amount consumed, in order to estimate the energy requirement in the more plausible manner. Among the components that can influence the consumption of energy during steel production, certainly there are the quantity of steel to be produced and its steel quality. Both these factors determine the sequence of production processes to be followed to produce the final product and influence the treatment, and its duration, in each single plant of the sequence. For each production item, the sequence of plants where the item goes through and the undergone treatment in each of them is included in a production plan.

A first simplified version of the flow sheet model has been developed on the basis of the following hypotheses:

- The total consumption and the duration of the treatment of a production item in a plant are both *priori* known.
- The consumption of a production item is constant during the duration of the treatment.

<u>Configuration of plants</u>

The single plants of a steel industry, whose contributions to the energy consumption should be taken into account, are configured in an xml file. An example of the plants configuration file is shown Figure 56. Each plant is identified by a unique identifier and has other tags to explain the type of the plant and its number.

Production Plan

The production plan is a list of elements, where each element represents a production item, which is processed in a specific plant, for a certain period and with a certain amount of energy. The production plan contains all the production items processed in all plants during a day.

Each production plan item includes the following information:

- cast number
- plant identifier
- starting time
- duration in minutes
- total energy consumption

Each production plan item is related to a plant through the plant identifier: only items related to the configured plants are taken into account. The production plan is stored in an Excel file. An example of a test production plan, made of abstract data, which absolutely do not correspond to reality, is represented in Table 12. This production plan has been shown only as an example to explain the production item data structure.

Cast Number	Plant id	Starting time	Duration [min]	Energy consumption
1	EAF1	13:50	60	6000
1	LF1	14:55	30	3000
1	AOD1	15:30	20	2000
1	CC1	15:55	15	100
1	HRM	16:15	10	100
2	EAF2	13:55	50	5000
2	LF2	14:50	20	2000
2	AOD2	15:15	25	2500
2	CC2	15:45	30	100
2	HRM	16:25	40	400
3	EAF1	14:55	65	6500
3	LF2	16:05	25	2500
3	AOD2	16:35	30	3000
3	CC2	17:10	20	100
3	HRM	17:35	20	200
4	EAF2	14:50	55	5500
4	LF1	15:50	35	3500
4	VOD	16:30	15	1500
4	CC2	16:50	20	100
4	HRM	18:00	25	250
5	EAF1	16:05	70	7000
5	LF1	17:20	30	3000
5	VOD	17:55	15	1500
5	CC1	18:10	15	100
5	HRM	18:30	30	300

Table 12: An example of a test production plan

```
<Steel_Plants IndustryName="Acciai Speciali Terni" IndustryId="AST">
 - <Steel_Plant>
     <Id>EAF1</Id>
     <Type>Electric Arc Furnace</Type>
     <Number>1</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>EAF2</Id>
     <Type>Electric Arc Furnace</Type>
     <Number>2</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>LF1</Id>
     <Type>Ladle Furnace</Type>
     <Number>1</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>LF2</Id>
     <Type>Ladle Furnace</Type>
     <Number>2</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>LF3</Id>
     <Type>Ladle Furnace</Type>
     <Number>3</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>AOD1</Id>
     <Type>Argon Oxygen Decarburization</Type>
     <Number>1</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>AOD2</Id>
     <Type>Argon Oxygen Decarburization</Type>
     <Number>2</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>VOD</Id>
     <Type>Vacuum Oxygen Decarburization</Type>
     <Number>1</Number>
   </Steel_Plant>
 - <Steel_Plant>
     <Id>HRM</Id>
     <Type>Hot Rolling Mill</Type>
     <Number>1</Number>
   </Steel_Plant>
</Steel_Plants>
```


Figure 56: An example of plant configuration file for AST steel industry

The algorithm computing energy consumptions

For a given production plan, the algorithm computes the energy consumptions of each configured plant of the steel industry and the total energy consumption of all the configured plants. The energy consumptions are computed for each minute of a day, both for each single plant and for all the plants, and stored in an output excel file. The main steps of the algorithm computing energy consumption are shown in Figure 57. The algorithm has been developed in C# as a class library, i.e. an independent module that can be integrated also in other software.

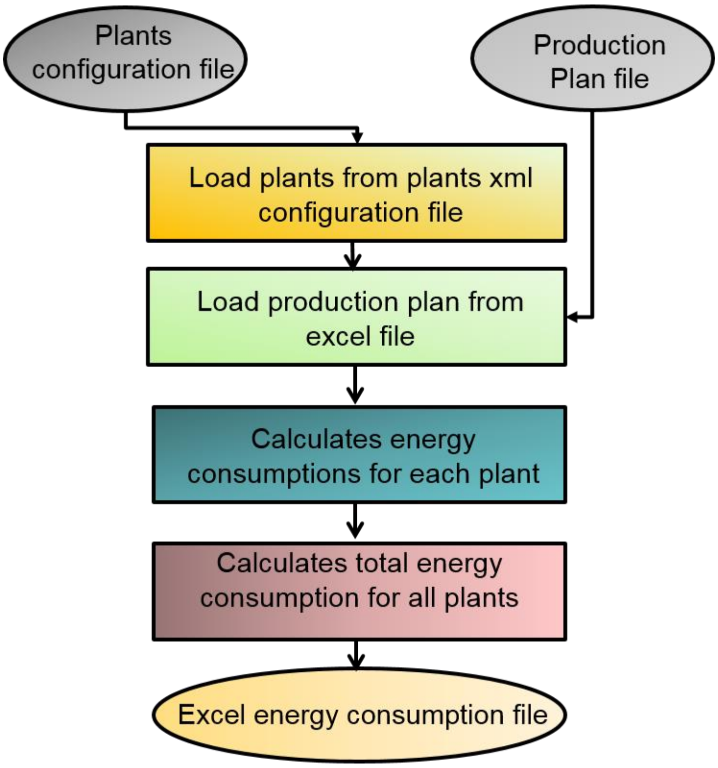


Figure 57: Algorithm calculating energy consumptions

An example of the excel output file, produced by the algorithm, is shown in Table 13.

Time	EAF1	EAF2	LF1	LF2	LF3	AOD1	AOD2	VOD	HRM	TOTAL
00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00:01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
...	...	...	...	...	...	...	...	...	...	...
16:35	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	10.00	310.00
16:36	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	10.00	310.00
16:37	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	10.00	310.00
16:38	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	10.00	310.00
...	...	...	...	...	...	...	...	...	...	...
23:58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23:59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 13: An example of the excel output consumption file

The simplified flow sheet model has been applied to a test production plan, represented in Table 12, and plots for plant energy consumption and total energy consumption have been generated from the output file produced by the model. These plots are shown in Figure 58.

As future works, this simplified flow sheet model can be generalized, by specializing the energy time consumption of a production item for each particular plant. An approximation of the duration and the consumption during the time could be deduced from historical data. Furthermore, the energy consumption model can be extended and specialized in C# by using polymorphism.

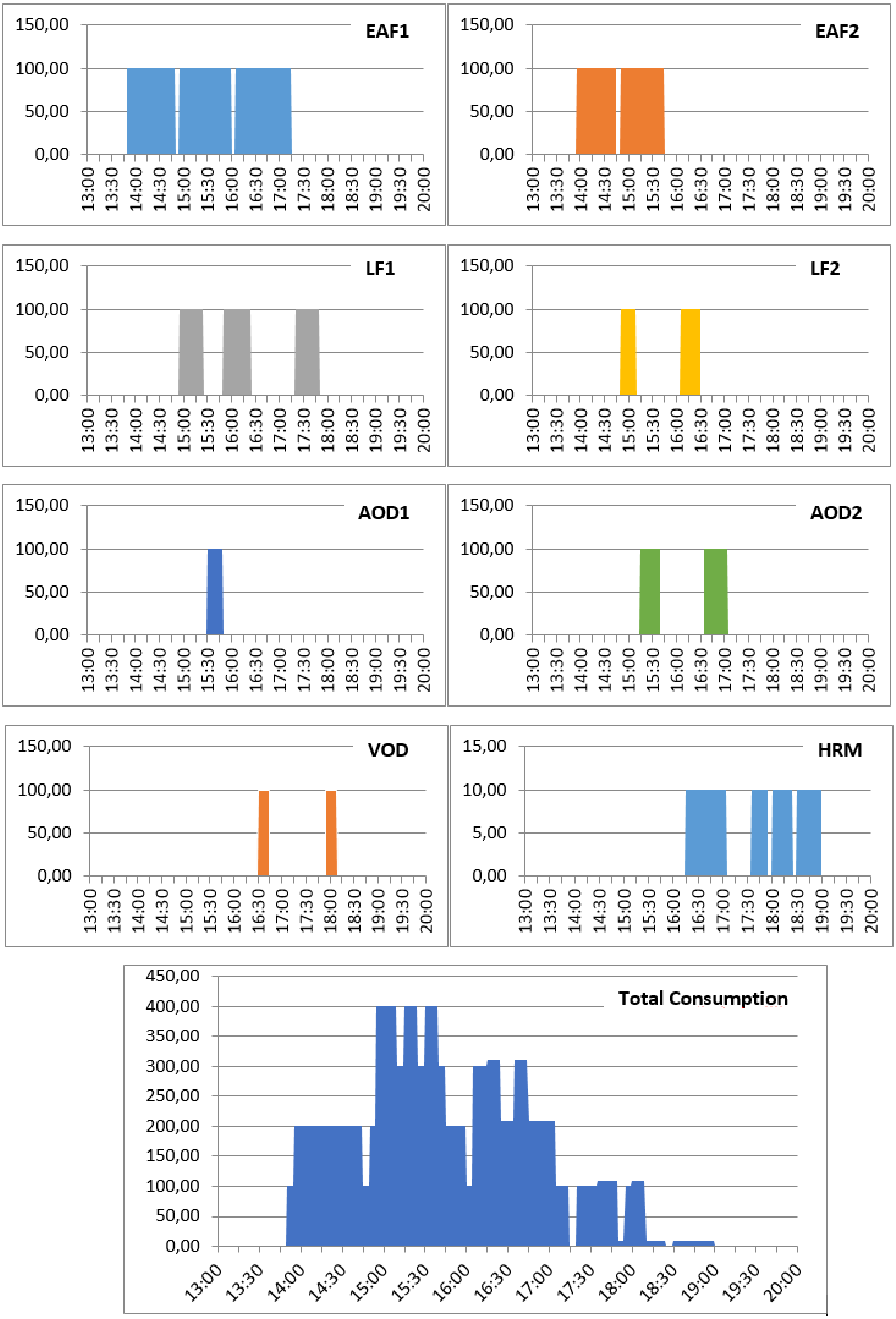


Figure 58: Energy consumption plots

2.2.3.3 *Task 3.3: Forecast model development and validation*

This task is dedicated to the development of forecast models and the relevant software modules. The following paragraph describes the Deliverable *D3.2.*

Different time frames have been taken into considerations to develop the models for forecasting the power engagement: Medium (for the next shift and up to 3 days), short (for the next 90 minutes) and very short (for the next 15 minutes). The forecasted electricity demand in medium term is used for the preparation of the profile to be shared with the energy provider the day before, the short term can be used to adjust the energy needs participating in the intra-day market while the very short term is used to minimize the 15 min peaks, to participate in the balancing market or to recover from an unpredictable event both internal or external.

The energy profiles generated through the forecast models is integrated when necessary with information from the production schedule in order to evaluate the total energy demand.

Several approaches have been developed depending on the time frame, the process and the variability of its behaviour, and the levels of precision necessary ranging from analytical to statistical approaches. For example in EAF the processing time and more the energy demand profile can vary a lot even for same type of product; so in this case a detailed profile might not be reasonable in all cases, but an average value for time and energy demand with some security margin gives already a good assumption. In case of HRM the profile for each type of products can be modelled with a good precision, because there is not much variance between different products of the same type but the energy profile itself has a characteristic course.

The approach based on the analysis of historical data able to extract a profile for each type of products is handled by "Profile Extractor" agent. For more details please see the description of Task 6.3.

As explained in task 3.1, at LSW the EAF heats for production of different steel grades have been grouped according to alloy element concentration and tap weight. For each of these groups the average tap-to-tap and power-on times were determined. Within this averaging, standard process interruptions like charging, electrode nippling, tapping, refractory repair etc. were considered. Also, unpredictable process interruptions like mechanic or electric malfunctions, waiting for casting, actions for regrading or even dilution of heats due to deviations in chemical analysis are included with average figures determined by a statistical evaluation, as shown in Figure 44 exemplarily for EAF1. Figure 59 shows the average tap-to-tap and power on times for the different steel grade groups.

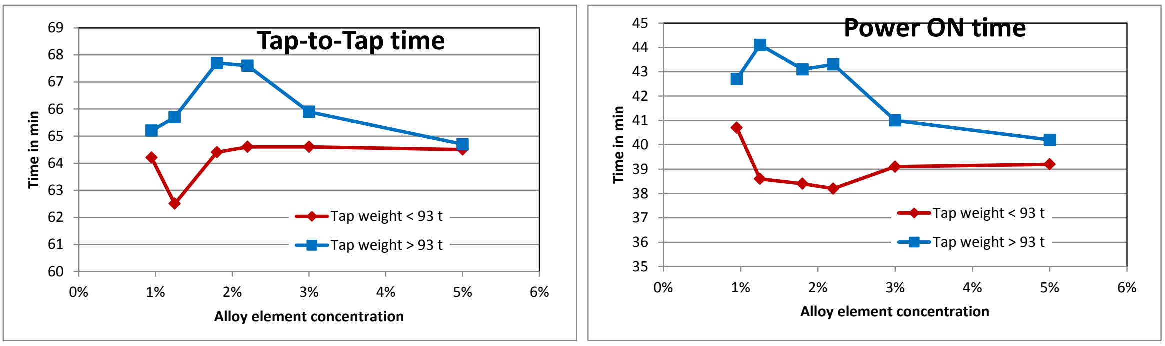


Figure 59: Average tap-to-tap and power on times for LSW steel grade groups

The product of specific electrical energy consumption in kWh/t and average tap weight gives the total electrical energy consumption of a heat for a certain steel grade. The average power demand during the production of this heat is given by relating the energy consumption to the average tap-to-tap time.

Thus for the production schedule of one day, the average power demand of both EAFs can be determined by consecutively adding the average power demand for each heat according to the produced steel grade.

At LSW, a daily production plan with a forecast on the peak load per 60 min intervals is sent to the power supplier. Planned maintenance interruptions of the different production plants (Two EAFs, two Rolling Mills, four Filter plants, two oxygen plants, minor auxiliary plants) are considered within this forecast.

Figure 60 shows a typical Day-ahead schedule for two production days. For the schedule on the left hand side, all plants are in full operation with the exception of one rolling mill which contributes with a power demand of 4 MW. The schedule on the right hand side considers a planned maintenance stop of one EAF for two hours (7-8), so that the power demand is reduced by 40 MW.

E.ON Vertrieb Deutschland GmbH
Day-Ahead-Fahrplan-Geschäfte

Kunde: LSW
Übergabestelle: D_EO_N

		in MW	
		Kunde kauft	Kunde verkauft
Lieferdatum	Stunde	EET verkauft	EET kauft
13.03.2016	1	103.0	0.0
13.03.2016	2	103.0	0.0
13.03.2016	3	103.0	0.0
13.03.2016	4	103.0	0.0
13.03.2016	5	103.0	0.0
13.03.2016	6	103.0	0.0
13.03.2016	7	103.0	0.0
13.03.2016	8	103.0	0.0
13.03.2016	9	103.0	0.0
13.03.2016	10	103.0	0.0
13.03.2016	11	103.0	0.0
13.03.2016	12	103.0	0.0
13.03.2016	13	103.0	0.0
13.03.2016	14	103.0	0.0
13.03.2016	15	103.0	0.0
13.03.2016	16	103.0	0.0
13.03.2016	17	103.0	0.0
13.03.2016	18	103.0	0.0
13.03.2016	19	103.0	0.0
13.03.2016	20	103.0	0.0
13.03.2016	21	103.0	0.0
13.03.2016	22	103.0	0.0
13.03.2016	23	103.0	0.0
13.03.2016	24	103.0	0.0
	TOTAL	2472.0	0.0

E.ON Vertrieb Deutschland GmbH
Day-Ahead-Fahrplan-Geschäfte

Kunde: LSW
Übergabestelle: D_EO_N

		in MW	
		Kunde kauft	Kunde verkauft
Lieferdatum	Stunde	EET verkauft	EET kauft
16.03.2016	1	107.0	0.0
16.03.2016	2	107.0	0.0
16.03.2016	3	107.0	0.0
16.03.2016	4	107.0	0.0
16.03.2016	5	107.0	0.0
16.03.2016	6	107.0	0.0
16.03.2016	7	67.0	0.0
16.03.2016	8	67.0	0.0
16.03.2016	9	103.0	0.0
16.03.2016	10	103.0	0.0
16.03.2016	11	103.0	0.0
16.03.2016	12	103.0	0.0
16.03.2016	13	103.0	0.0
16.03.2016	14	103.0	0.0
16.03.2016	15	107.0	0.0
16.03.2016	16	107.0	0.0
16.03.2016	17	107.0	0.0
16.03.2016	18	107.0	0.0
16.03.2016	19	107.0	0.0
16.03.2016	20	107.0	0.0
16.03.2016	21	107.0	0.0
16.03.2016	22	107.0	0.0
16.03.2016	23	107.0	0.0
16.03.2016	24	107.0	0.0
	TOTAL	2464.0	0.0

Figure 60: Day-ahead schedule for two exemplary production days at LSW

In case the actual energy consumption deviates from the schedule, additional power is automatically bought or sold on the balancing market by a corresponding transmission provider. This may result in positive or negative deviations of the energy costs. However, the effective costs cannot be predicted beforehand, as they depend on the current costs on the balancing market in each time interval. For each month, afterwards a detailed calculation of these energy costs is provided for every production day.

Figure 61 shows for the two exemplary production days the deviation between scheduled power demand and actual energy consumption. For the production day shown on the left hand side, the actual consumption was on the average lower than the scheduled demand, so that negative energy costs resulting in a refund from the transmission provider occurred. For the production day on the right hand side, extra energy costs had to be paid as the actual energy consumption was slightly higher than the ordered contingent.

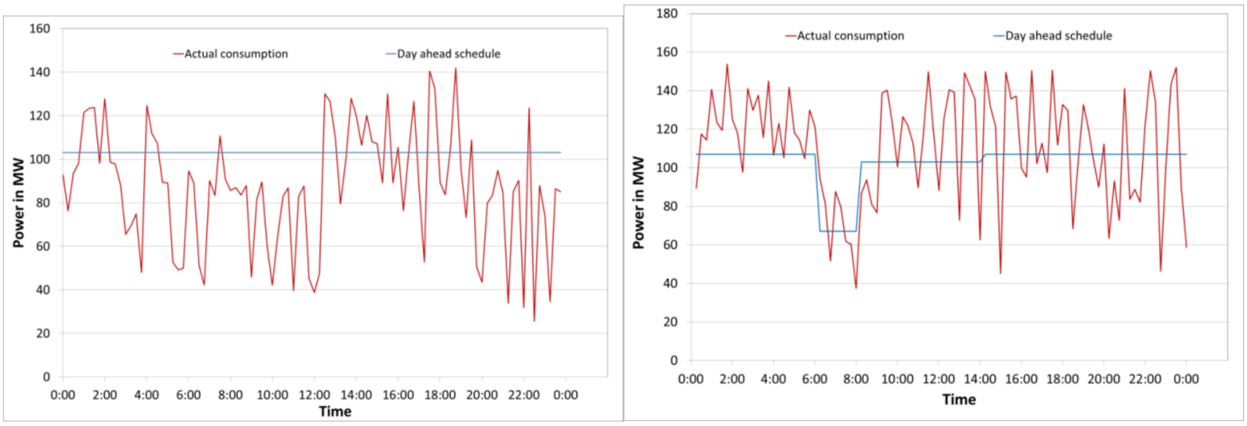


Figure 61: Deviation between scheduled power demand and actual energy consumption for two exemplary production days at LSW

A draft for a more detailed day ahead schedule has been set up by BFI on the basis of the quality depended forecast described above. For each production day a schedule of steel grades to be produced at the two EAFs is available. Thus the forecast of the energy demand for the whole production day can be detailed according to the mean values for specific electric energy consumption, tap weight and tap-to-tap time which have been determined for the different steel grade groups. Figure 62 shows exemplarily for EAF 1 the result of such a prediction in comparison to the values of the day ahead schedule and the actual consumption for the same production days as shown in Figure 60.

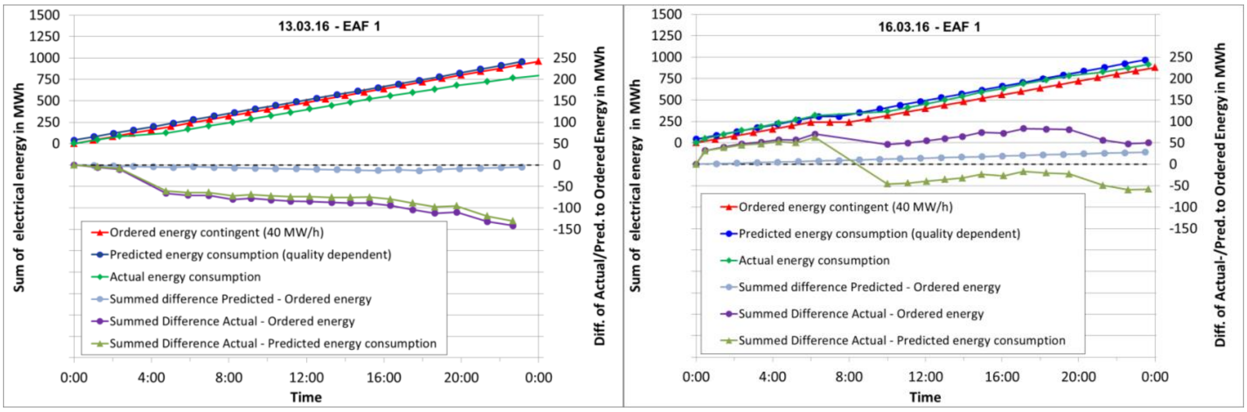


Figure 62: Predicted, scheduled and actual energy consumption for two exemplary production days at LSW

For the production day shown at the left hand side, the actual energy consumption is lower than the ordered and also the predicted energy contingent, as an unscheduled interruption of production occurred between 3:00 and 5:00. For the production day on the right hand side, the actual energy consumption is higher than the ordered contingent, although a maintenance stop for EAF1 was scheduled. In this case, the quality dependent prediction would have resulted in an increased energy contingent.

The procedure to use the quality dependent prediction of the power demand on an hourly basis for the day ahead forecast instead of the fixed demand of 40 MW for each EAF was tested for the two exemplary production days shown in Figure 60. The result is shown in Figure 63.

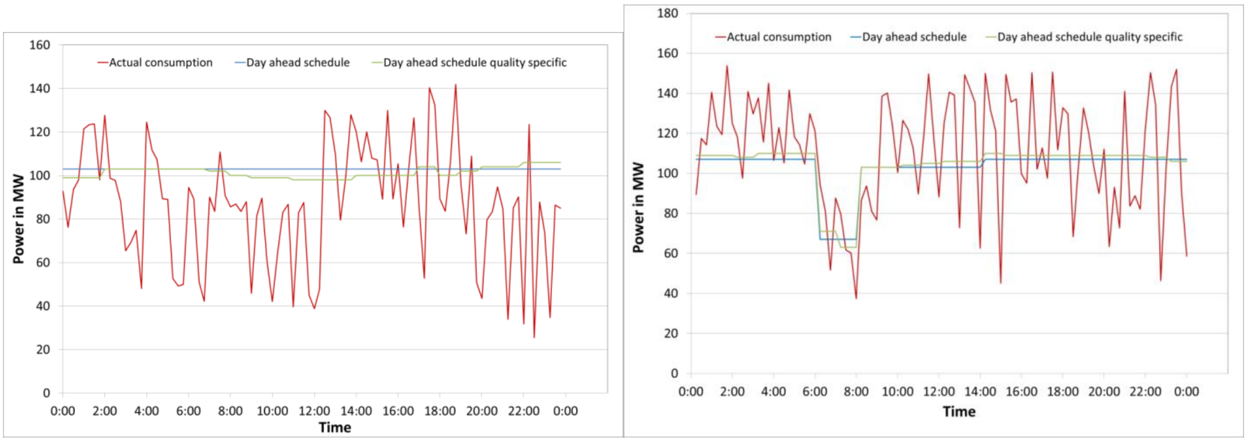


Figure 63: Deviation between quality dependent schedule of power demand and actual energy consumption for two exemplary production days at LSW

It can be seen that quality specific day ahead schedule is in both cases closer to the actual consumption, which results in lower absolute costs at the balancing market. For the production day on the left hand side, this would have resulted in a lower refund, but for the production day on the right hand side the extra costs would have been lower by a higher amount. The actually achievable savings by using this quality specific day ahead forecast would have to be evaluated for a longer time period, in order to decide if this procedure can be used in daily operation for the day ahead forecast at LSW. However, as unpredictable stoppages of the EAF operation and also short term changes in the production plan would overrule a more detailed, quality specific day ahead planning, it was decided at LSW to stay with the existing, more schematic day ahead schedule.

The analysis on AST EAFs data shows that an appreciable difference can be seen only in the differentiation between austenitic and ferritic steel. Within these classes the variation are very small and therefore is reasonable to use these classes and the relative mean value in the plant electricity needs calculation.

Moreover to calculate the energy profiles on different time scales a software application has been developed which allows simulating the energy demand by combining the demand of different sub processes, utilising detailed profiles or just average values to a total profile.

For the simplified user interaction it has been decided to organise the profile database for the sub processes by a CSV (Comma-Separated Values) file which can be loaded by the simulation system and within Excel for manual review. The CSV file is organised as shown in Table 14.

Table 14: Example of profile database

Type	Version	MaterialID	Plant	Profile		
NUMERIC	0	600_505_2,3	HRM	7439,75703	7843,43731	8247,11758
NUMERIC	base	600_505_2,3	BaseLoad	4074,40122		
NUMERIC	0	600_495_2,5	HRM	7701,55594	9308,80167	10786,4875
NUMERIC	base	600_495_2,5	BaseLoad	3378,90555		
NUMERIC	0	569_406_2	HRM	5683,51388	7343,4135	8906,88495
NUMERIC	base	569_406_2	BaseLoad	3184,47589		

The column "Type" defines the type of the profile. Foreseen are currently:

- NUMERIC: means that the profile is based on numeric sample points, which are then stretched according to the time interval. Giving only one value, allows modelling of a constant profile (e.g. average value).
- EQUATION: allows providing a model based on equation. This possibility has been foreseen in the concept, but was not implemented yet because at the moment no equation based models are used in the project. But this can be easily extended.

The column "Version" allows differentiating between different versions of the same product profile for the same process. This has been foreseen for cases when for example the same product is treated slightly different in the same process producing different energy profiles, but where the separation of the distinctions is not possible due to e.g. missing measurements.

The column "MaterialID" defines the product type. The column "Plant" defines the part of the process or machinery which is assigned with the given profile. The column "Profile" provides the samples of the energy profile for NUMERIC type or equation for EQUATION type.

The profile database in combination with schedule information allows us to simulate the total energy demand. In order to manage the schedule information also an CSV file has been introduced with a format as shown in Table 15

Table 15: Example of schedule data

ProductID	MaterialID	ProfileVersion	Plant	StartTime	EndTime
600_505_2,3	600_505_2,3	0	HRM	14.12.2016 18:51	14.12.2016 18:53
600_495_2,5	600_495_2,5	base	BaseLoad	14.12.2016 19:10	14.12.2016 19:11
569_406_2	569_406_2	0	HRM	14.12.2016 19:11	14.12.2016 19:13
569_406_2	569_406_2	base	BaseLoad	14.12.2016 19:13	14.12.2016 19:13

The column "ProductID" identifies the product, the "MaterialID" refers to the product type, the "ProfileVersion" refers to the profile type as described in previous sections. "Plant" defines the corresponding process or machinery and "StartTime", "EndTime" define the start and end time of the given process. As described before the profile course is stretched according to the duration of the process step within the schedule.

Figure 64 shows the screenshot of the of developed software module which calculates the total energy profile according to the schedule and the energy profiles of single processes and products. In the presented example two products has been defined which pass the process route from SCRAPYARD to HRM. The energy values and times in this example are artificial and are not corresponding to the real profiles. But the simple representation allows an easy understanding of the function of this software application.

By selecting the products and/or plants it is possible to analyse a subset of the whole simulation. Further the Aggregation slider in the toolbar allows to set the time base of the result, which means that the result will be aggregated e.g. to 15 min. scale building an average value over the chosen time period. This allows to create forecasts on different time frames as requested within this Task.

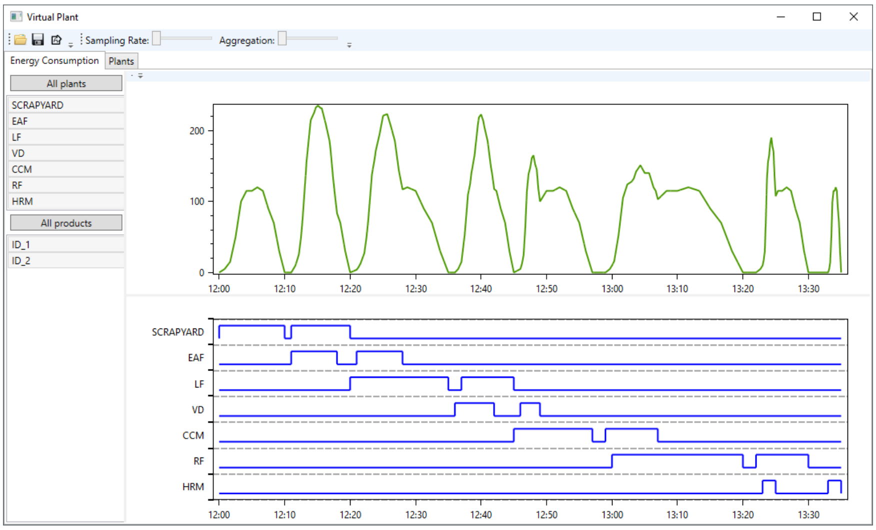


Figure 64: Example of a simulation

The software solution has been designed in such a way, that it can run as standalone application or be integrated in the agent system cp. WP6.

For the short (for the next 90 minutes) and very short (for the next 15 minutes) in particular and based on the experience on the AST plant a model able to foresee the melting progresses have been set up. The on-line model is based on an off-line model calibrated for each type of steel using the data of several heats. The calibration process is done based on Steel grade with similar charge and Operative Practices. This process is continuously updatable using the log data during the on-line running. The parameters correctness is checked based on the melting status according to the schema reported in Figure 65.

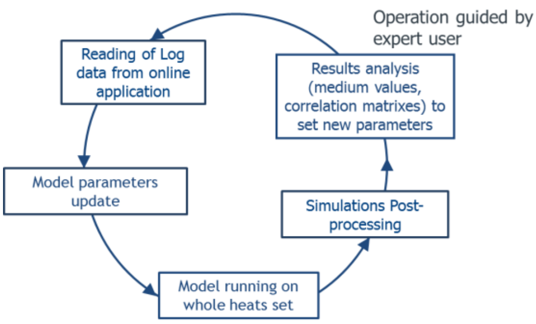


Figure 65: EAF model calibration process

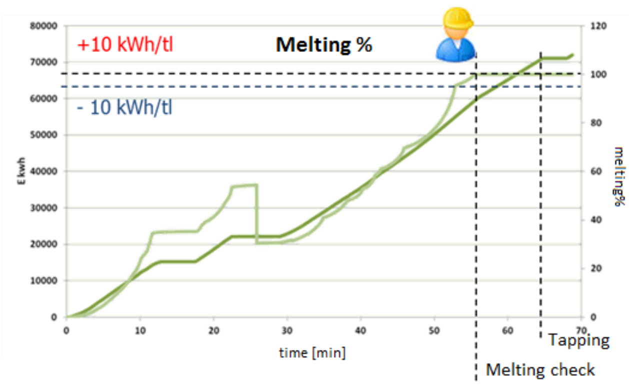


Figure 66: EAF On-line model validation

If the operator acknowledge for a complete melting the model predictions are correct. In Figure 66 a typical behavior of energy and melting progress is shown together with the foresee interaction with the operator.

2.2.3.4 Task 3.4: Methods and control-loops to adjust the power engagement according to events

The activities carried out in this task have the objective to identify control loop methods and to realize them. The goal is to modify the loads in order to adjust the power engagement according to the request.

The focus in this task is on the reduction of power load in EAF process at the industrial partners plant where EAF is present while the control concept for increasing power load is described in task 4.5.

The aims of controlling the melting power engagement of the EAFs is to reduce power peak load within the 15 min time interval reducing consequently costs for power supply. This can be achieved by:

- controlling the maximum load, avoiding to exceed the power peak load limit within the 15 min time interval
- shifting the load to the next time slot, e.g. by delaying the start of a furnace, in order to avoid exceeding the peak load

while:

- avoiding process interruptions as much as possible, to keep the productivity high
- realizing an energy demand profile as regular as possible

At LSW the automatic control of the electrical energy consumption via reduction of the power demand of the two EAFs has been realised by installation of a smart power load control software, called Smart-LKA (**L**ast-**K**ontroll-**A**nlage). The software manages the power load of the two EAFs in the current and the following 15 min time interval. The smart power load control has been implemented according to the following strategy:

- An adjustable delay of 1-5 minutes regarding the start of power-on of an EAF after charging of the first and the second scrap basket is inserted. This shall allow to shift the power demand to the next 15 min interval. The duration of the delay for one EAF is calculated automatically depending on an analysis of the current process status of the second EAF. By this the power-on mode of each EAF may be postponed by up to 10 minutes per heat. This gives the opportunity to smoothen the power load of the EAFs in each 15 min interval easily.
- In addition, a reduced power demand by automatic step-down of the transformer voltage steps of the EAFs is induced, when the peak load limit in a time interval is expected to be exceeded.
- Only if unavoidable, a complete shut down of an EAF will be applied.

This closed loop control concept applied at LSW is shown in Figure 67.

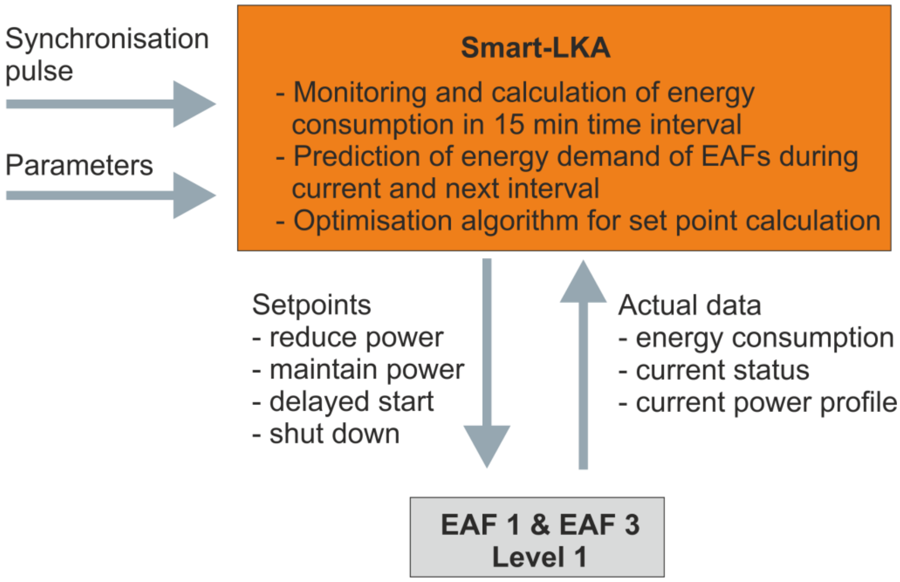


Figure 67: Closed loop control concept for power demand control (Smart-LKA) at the LSW steel plant

The described concept for closed loop power engagement control was be implemented online in the steel plant of LSW by the plant supplier company Primetals in May 2017. Although also BFI worked on this topic within the project, it was decided to purchase a commercial solution of Primetals, as this was expected to be more robust. Also this commercial solution includes a 24 hour 7 day service, which is crucial for this closed loop power engagement control system, being in permanent operation at the LSW plant. The system and is currently in a test and validation phase. It will be put in full operation after finalisation of the DynergySteel project.

At AST a control loop with the aim to limit the 15 min peak has been implemented In each 15 min interval the energy used by whole plant and the specific machine involved are continuously monitored. When the overall energy demand approach the set limit actions on plasma and EAFs are taken. Depending on the status of the two EAFs and following a predefined priority, the plasma is stopped for a predefined time interval and, if necessary, one or both EAFs. Different combinations of time interval length, priority and time between two stops were tested in order to identify the configuration that has the biggest impact on power reduction while less impacting the production.

At ORI for each 15 min interval the whole plant power and the main machines energy demand are monitored in order to forecast the mean power needed till the end of the interval. When the foreseen power is over the set limit the EAF is stooped and, if necessary the two LF in order to reach exactly the set limit. If in the meantime the rest of the plant lower its energy demand the stopped machines are restarted before the end of the interval.

2.2.3.5 Task 3.5 Scenario analysis to define possible improvements aimed at increasing power engagement flexibility

The following paragraph represents the Deliverable *D3.3.*

An analysis of the flexible disconnectable loads in steel plants has been carried out taking into consideration the specificity of the industrial partners but aiming to have general remarks for the steel companies participation in energy markets.

In Sept. 2015 a preliminary analysis of flexible disconnectable loads has been performed at LSW together with the company of Entelios (former ENERNOC) as a possible provider of flexible energy. The results of this analysis can be easily applied to all the other steel plants. Figure 68 shows the characteristics of different electrical power consumers and their possibilities to be used as flexible load.

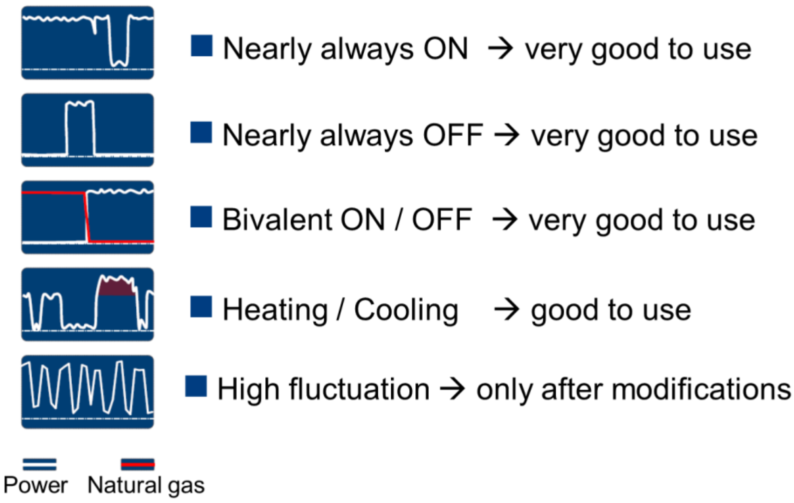


Figure 68 Characteristics of disconnectable loads

In general the output of a steel plant must not be affected by flexible loads at all. Only a few plants or machines of a steel mill have a reserve capacity and may be used as a flexible load. This has to be considered in detail at the relevant plant.

The following flexible loads were in principle identified:

- Electric Arc Furnaces
- pressurized air production
- emergency power supply
- oxygen production
- hall lighting and air conditioning including fan
- cooling towers

A) Electric Arc Furnaces

The electric arc furnaces are the main power consumers of an EAF cycle steel plant and moreover the main responsible ones for the energy fluctuations. For a precise calculation and forecast of the electricity load of the EAF it is necessary to calculate the status of each heat of the EAFs as a function of time. This is only possible for a few upcoming heats because several events may occur within the process and the sequence for quality control of the heats that influence the tap-to-tap time. When two EAFs are present they can work in a synchronized operation mode or alternatively. Therefore their total energy consumption may vary extremely if both of them, only one or none is in operation. That means that three principle process situations may occur and that this variation of the EAF status creates an extremely high change of the power load.

In principle the load of an EAF is adjustable depending on the phase of the process. In any case a reduction of the voltage of an EAF will also reduce the output of the steel melting shop. This might be possible for a short time if the capacity of the EAFs is still high enough to satisfy the overall need of the continuous casters in any case without the risk of a shortfall of the production chain. Therefore the priority and possible sequence of the production chain has to be evaluated case by case with respect to changing situations of the quality management of the heats and possible stops of the process because of unplanned maintenance.

In Italy EAFs participate normally in the Interruptible Load market. The plant is automatically shut down when TSO needs. Normally it last for less than 5 minutes and therefore the impact on the overall process is acceptable. Moreover it happens only few times a year. The difficulty is that the rest of the plant should not increment the energy use and therefore it needs to be appropriately managed.

B) Pressurized Air

The production of pressurized air is an auxiliary process with high energy consumption. The compressors are operated in an on/off-mode. Vessels for pressurized air are used to store the air at a pressure level of usually 6 bar, the tolerable variance of the pressure is about +/- 1 bar. Due to the fact that the use of pressurized air is not predetermined and follows a more or less stochastic flow this grid system cannot really be used as a disconnectable load.

C) Emergency Power Supply

In every steel mill some emergency power supply units are used as a stand-by unit. These emergency power supply units may be used as an aggregate to generate positive control energy on demand to support the grid.

D) Oxygen production

Oxygen can be both produced internally (AST, LSW) or bought from an external company (ORI, HHO). There are different processes for the oxygen production having different characteristics. The two big categories are cryogenic and not cryogenic. AST Oxygen production is of the first type while LSW is of the second.

The main difference with regards to participation in energy markets is the start-up time. Cryogenic processes need hours while non cryogenic need only minutes [34]. At AST the two Oxygen production plants belong to the cryogenic type and are therefore not suitable to participate in energy markets, while LSW uses the non-cryogenic type which is suitable to participate in energy markets.

Pressurized Vacuum Swing Adsorption (PVSA)

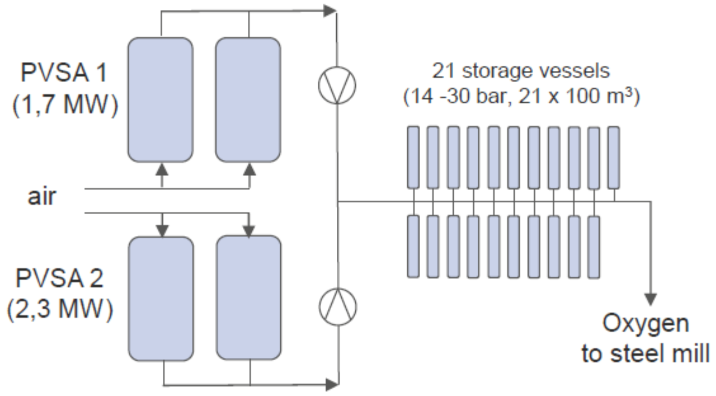


Figure 69: Flow chart of the LSW oxygen plant

Lech-Stahlwerke operates two non-cryogenic oxygen plants for the production of oxygen. Usually 30 m^3 of oxygen are used per t of liquid steel including oxygen as additive for burners. Figure 69 shows the flow chart of this plant.

The oxygen plants have an installed capacity of 2.800 and 3.400 m^3/h. The installed power sums up to 1,7 MW respectively 2,3 MW, in total 4 MW. The oxygen plants have an overall utilization factor of about 77 %. The produced oxygen is stored at a pressure level of about 12 to 30 bar in 21 vessels with a storage capacity of each 100 m^3. The two oxygen plants may be operated in an on/off-mode, considering the status of the oxygen storage (pressure up to 30 bar) and the oxygen demand of the consumers in the steel plant (EAFs, Ladle preheating, pressure 12 bar). Figure 70 shows exemplarily the flow rate of oxygen that is needed within one heat produced at the EAF No. 1 of LSW.

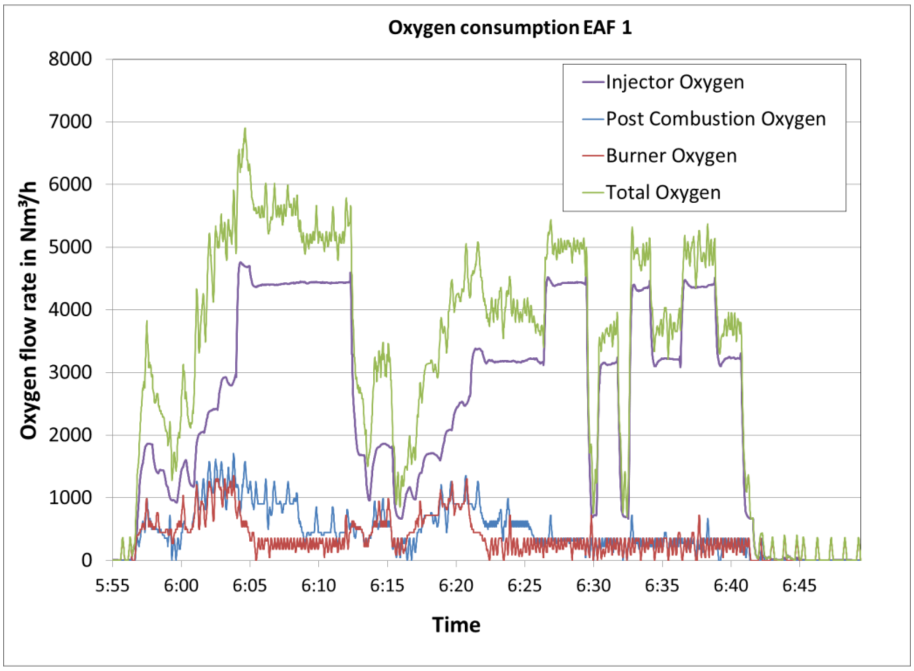


Figure 70: Example for the use of oxygen at the electric arc furnace within one heat

The specific use of oxygen per heat is nearly proportional to the production of steel and correlates directly with the output of the steel plant. Therefore the methods to forecast these two material flows are nearly the same.

These basic conditions enable the flexible mode of operation of the oxygen plant and the use as a disconnectable load depending on the status of the oxygen storage. If a lack of oxygen might occur, additional liquid oxygen is available at LSW in a separate storage tank. This liquid oxygen may be delivered on demand by external suppliers. That means that several flexible measures are available in order to assure the needed oxygen supply.

LSW decided to go ahead and to use the high flexibility of the oxygen plant as a flexible disconnectable load.

In 2017 PVSA-plant 1 was not in full operation because the filling material (granulate) was damaged. A revamp of plant no. 1 took place in April 2017 within a downtime at that time. Therefore LSW decided to operate plant no. 2 as a flexible load. A prequalification of plant no. 2 was performed together with Entelios (former ENERNOC) as a provider. The operation of the plant as a switchable load was realized in January to June 2017.

E) hall lighting and air conditioning included fan, cooling towers, filters cycles

These loads have been analysed as flexible loads mainly for the purpose of increasing the energy demand. Please refer to WP4 for more details.

2.2.4 Work package 4: Development of online devices to react on electric grid events

Currently the energy market in Europe is passing through a transition period. The expansion of renewables in European energy market needs new flexible peak load technologies and a demand side management (see Annex 2). New flexible mechanisms and technologies have to be developed in order to contribute to the balancing and security of the power grids.

The objective of work package 4 is to improve the power load flexibility and control capabilities through the implementation of suitable aggregates to increase (on time) instantaneous electric energy demand in order to react on grid signals or to switch between gas and electrical energy.

Initially the activity has been focused in the analysis of the compensation of natural gas by electricity acquired from the secondary control market. For this purpose large investment was planned for the development of additional loads in order to optimize energy consumption and increase the flexibility of the use of these additional loads during the production. Due to the lowering of the revenues for negative control energy and in order to maintain the profitability of the investment while contributing to the stability of the growing fluctuant renewable energy in Europe like wind and solar energy, the second foreseen solution, i.e. implementation of suitable existing aggregates, has been analysed and chosen for this purpose. This means that necessary investment are significantly lower.

2.2.4.1 Task 4.1: Determination of most suitable process stages for enhancing electric loads

The following paragraph represents the Deliverable *D4.1.*

The overall aim of the task is to find suitable aggregates for enhancing the energy demand flexibility at HHO by analysing and eventually revamping suitable aggregates. This newly gained flexibility can be commercialized. This commercialization is the main topic of Task 1.3 and also influences the subsequent feasibility study in task 4.2.

In Europe is emerging the "power to heat"-concept (P2H) that represent a possible and cost efficient solution in order to react on grid peaks. P2H is useful if additional negative control energy is required. The regenerative power that is produced as a peak by renewables is free of CO2 and therefore it might be useful to use power for the production of heat as well and to substitute fossil fuels.

P2H has been installed in Germany mainly by power plants that use a combined heat and power process for district heating systems. The P2H installations may extend the operation flexibility of these plants and may produce heat if a surplus of power is produced in the grid. In this way negative control energy may also be used for a production of heat. This concept is called a hybrid heating system if fossil fuels are used alternately. Within this project it has to be investigated if this kind of hybrid heat generation is useful for a steel mill as well.

The following step have been carried out:

- HHO and BFI had several meetings and a factory visit of HHO's production facilities
- Take account of HHO major request that suitable aggregates have no direct influence on the production process and therefore focus on the auxiliaries of the plant (Batch annealing and air pre-heating of acid regeneration no option)
- Several aggregates have been inspected as suitable for enhancing the electric energy demand flexibility of HHO
- Economic evaluation of elaborated aggregates

First ideas for enhancing electric loads, already formulated within the proposal of the project, have been the additional heating of the batch annealing (see Figure 71) and the additional generation and storage of compressed air. Another aggregate which has been discussed was the air pre-heating of the acid regeneration (Figure 72).

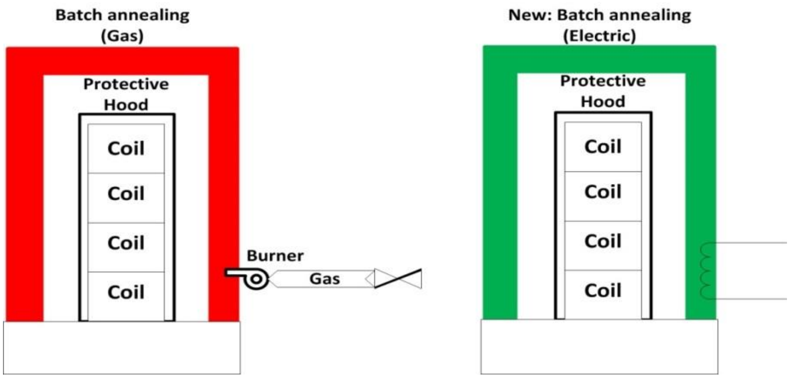


Figure 71: Concept for electrically heating batch annealing

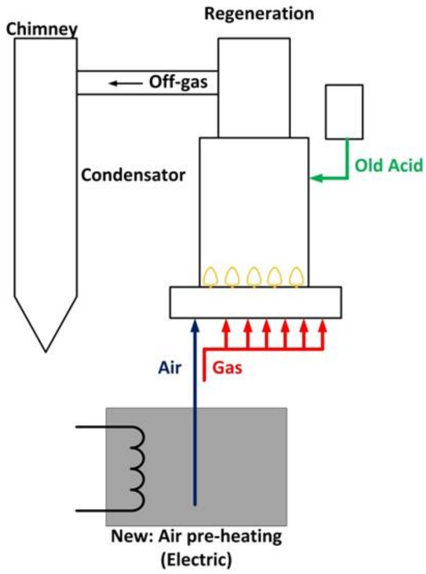


Figure 72: Concept for additionally pre-heating the air for acid regeneration

In the first discussions it became obvious that HHO will be more satisfied with a solution not directly involved within the production process. Thus, during the inspection of the plant the focus areas have been the auxiliary aggregates which offer potential for the envisaged enhancements as well.

Several potentially interesting aggregates have been inspected and were taken into closer consideration and analysis. These comprise:

- Compressed air network
- Feed water preheating
- Energy distribution station cooling
- Enhanced cooling power of cooling tower
- Increased flow rate into the cooling tower via pumps
- Hall lighting
- Hot water preparation

The decision to mainly analyse auxiliary aggregates meant also to bury the concepts for the batch annealing and the acid regeneration. The batch annealing did not seem to have the capability of being used in conventional production which diminished the usefulness of this solution. Furthermore, the integration and development of a new batch annealing has been found to be too expensive considering its usage and the risks going together with it. The concept for the air pre-heating of the acid regeneration has been rejected due to implementation risks and limitations. The process itself cannot be rapidly and easily adapted or held in a continuous state when switching between electrical air pre-heating and the heating by gas. Thereby, unexpected process failures can occur and process safety cannot be guaranteed.

Figure 73 shows the result of the feasibility analysis of several possible aggregates. The second row represents the category of the load (V – load shifting, E-energy carrier surrogate and Z-additional load). The third row represents the basic energy carrier (Gas, Steam and Electricity). The fourth row the process and the last rows represent the results of the feasibility (easy, medium and difficult) and the potential electricity consumption (small, medium and high). This lead to a list of the possible aggregates to be further evaluated.

	V= Load Shifting			1 = difficult	1=small
	E=energy carrier surrogate			2=medium	2=medium
	Z=additional load			3=easy	3=high
Number of Aggregate	Category	Basic Energy carrier		Feasibility	Potential Electricity Consumption
1	E	Gas	Generate Steam from Electricity	difficult	high
2	V	Electricity	Decrease temperature in server room	easy	small
3	V	Electricity	Prepone scavenging process	easy	small
4	E	Gas /Steam	Hall-heating	medium	small
5	E	Gas	Additional pre-heating of batch-annea	difficult	high
6	E	Steam	Pre-heating of air for acid regeneratio	difficult	high
7	E	Steam	Feedwater pre-heating	medium	high
8	E	Steam	Cooling of transformer house	easy	high
9	V	Electricity	Increasing cooling capacity of cooling t	easy	high
10	V	Electricity	Storage of compressed air	difficult	medium
11	V	Electricity	Increasing flow rate of cooling tower	easy	medium
12	Z	Electricity	Hall lighting	easy	high
13	E	Steam	Hot water treatment	medium	medium

Figure 73: Development of online devices to react on electric grid events

2.2.4.2 Task 4.2: Feasibility study of enhanced electrical load for the most promising process stage and estimation of economic benefits

The following paragraph represents the Deliverable *D4.2.*

Several process stages have been defined in the Task 4.1 for further evaluation taking into account:

- Potential for load flexibility in kW
- Practicality and applicability of adaptations (Process boundary conditions, KO-criteria)
- Economic assessment of necessary aggregate adaptions (Budget for adaptations)
- Overall potential estimation

To refine this analysis several subtasks have been carried out by HHO and BFI concerning contacting in-house experts to facilitate a more accurate estimation of these parameters, especially for economic ratings.

The level of the revenues for negative secondary control had increased from 2008 to 2010, then decreased in 2011 and stayed at constant level in 2012 at 100T€/MW·a (see Figure 74) with the constantly increasing of the amount of volatile renewable energy (Figure 75). In 2013, when the proposal was written, the preliminary economical evaluation showed a possible profitability when participating in the negative secondary power control (that means additional use of electrical load) constructing new aggregates.

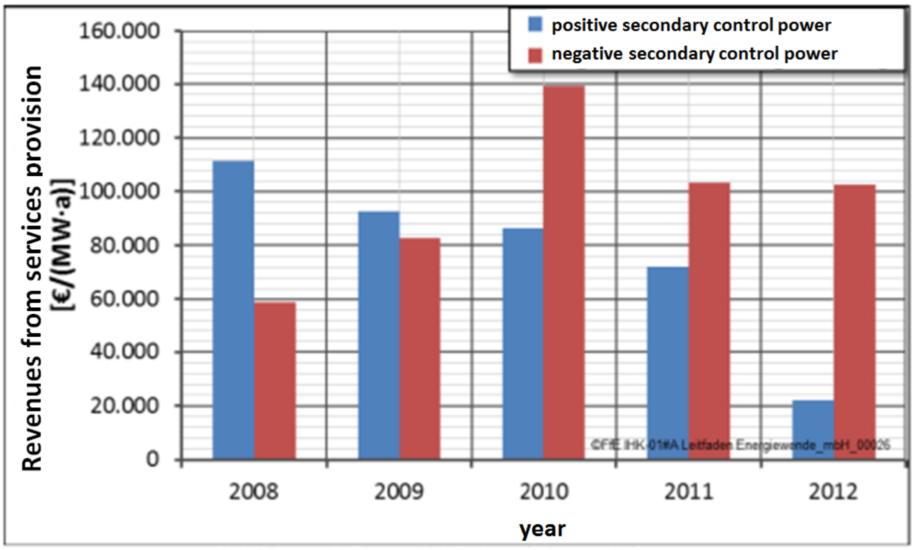


Figure 74: Potential of the revenues for the secondary control power from 2008 to 2012

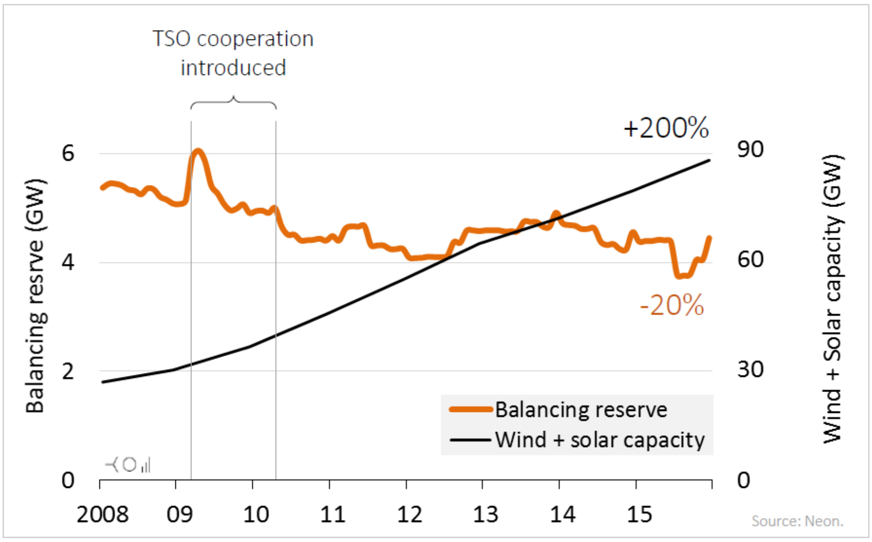


Figure 75: comparison Balancing reserve and renewable Energy capacity (wind and solar energy)

The construction of the new aggregates was evaluated asking offers to suppliers. Meanwhile the number of companies prequalified to supply secondary balancing power has consistently increased (see Figure 76), consequently the profitability for the negative secondary control power, which was at the beginning of the project around 100T€/MW·a in the year 2012 (see Figure 74) decrease significantly up to 60% of the average of secondary control power (positive and negative) between a year 2009 and 2015 (approximatively from 82000 €/MW·a in 2009 to 33000 €/MW·a in the year 2015, see Figure 74, Figure 77 and Figure 78.

In 2009 an average revenues of secondary control power (positive and negative balancing) was evaluated as 82000 €/MW while in 2015 it decrease to 33000 €/MW.

A detailed economical investigation of revenues and necessary investments costs has been carried out.

The payback period of a total investment of € 200,000, required for the purchase of two loads units each with a capacity of 588 kW to achieve the goal of 1 MW, considering an annual profit of about € 100,000 is 2 year. The falling back of the yearly revenues increased the payback period to more than 5 years, which was no longer attractive to HHO. The cancellation of this big investment caused the reductions in overall project costs for equipment, maintenance and staff.

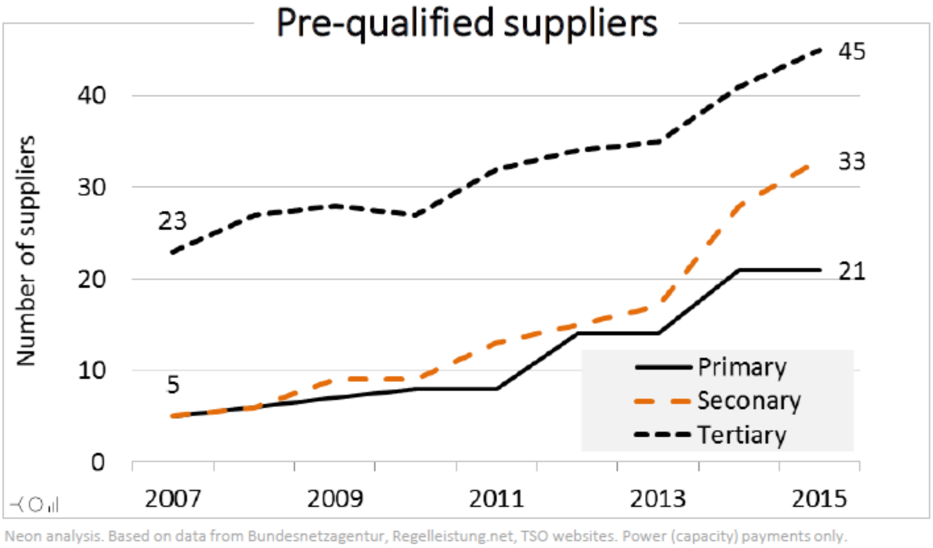


Figure 76: Number of pre-qualified suppliers of secondary balancing power increased from 2007 up to 2015

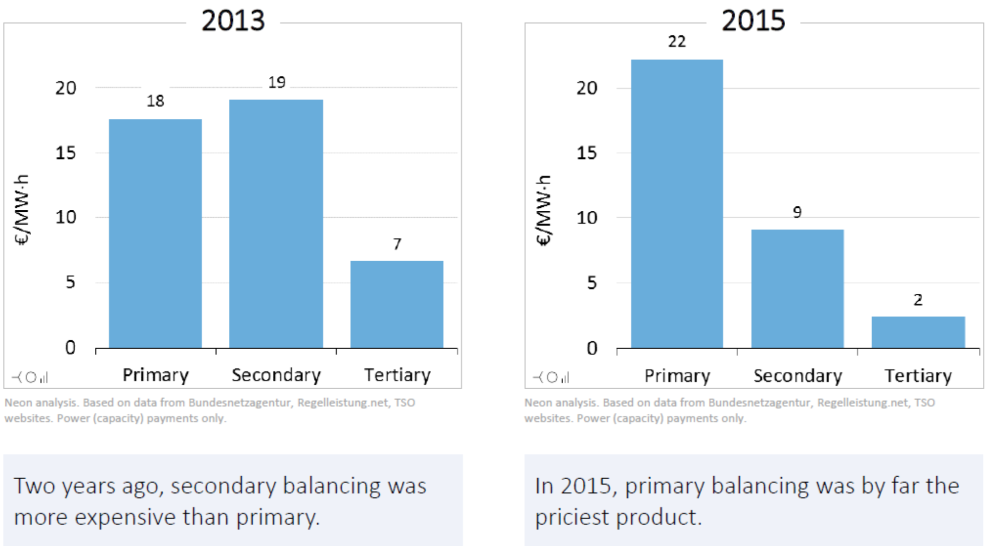


Figure 77: Revenues of average prices (positive and negative balancing) in secondary are reduced about 53% between 2013 and 2015

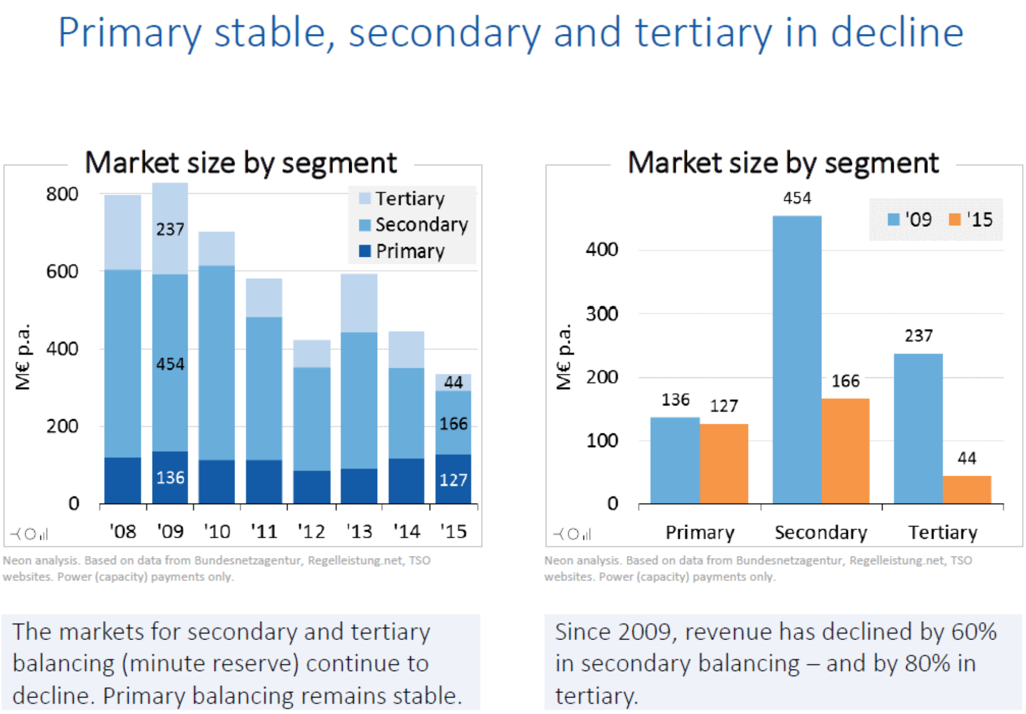


Figure 78: Market size by segment from 2008 to 2015 and comparison of the revenues from 2009 to 2015 (since 2009, revenue has declined by 60% in secondary balancing)

Because of these unpredictable changes of the revenues the final choice is to extend with additional automation possibilities several smaller already existing aggregates as initially foreseen in the proposal as one of the possibilities.

The following aggregates have been selected as suitable loads for this purpose.

- Hall lighting (160 kW)
- Air conditioning included fan (150 kW)
- Cooling towers (up to 1 MW)
- Filters cycles (about 100-200 kW)

Investment is necessary for each aggregate in order to connect it to the LAN and to allow a remote control of the device. Moreover a flexible load control station dedicated to the overall management inside HHO plant of all the connected aggregate should be installed. This control station will be used also for managing the information exchange between HHO and the intermediaries (i.e. EnerNoc or RWE).

The solution foreseen is furthermore easier to apply to other plants in Europe due to lower investments while assuring the possibility to actively participate in the balancing market through an intermediary and increase efficiency of the energy consumption inside the plant.

2.2.4.3 Task 4.3: Development, construction and implementation of additional electric loads

Figure 79 shows the schema of the planned connections of the aggregates and the management computers in order to enable the participation of HHO on the balancing market (both negative and positive). The virtual machine in Figure 79 has been installed and put in operation for this purpose at HHO. The aggregates manager software is implemented in the virtual machine to ensure the availability of the power demand, which will come from the intermediary.

For the Hardware side the availability loads of the aggregates are ensured by communication modules through TCP/IP as depicted in Figure 80: Connections between the High load Calculator (left) and the additional aggregates (right) and the conditions of the availabilities are derived from the Table 16.

As depicted in Figure 79 all the available loads will be summed and the total sum of loads must satisfy the power demand of the intermediary.

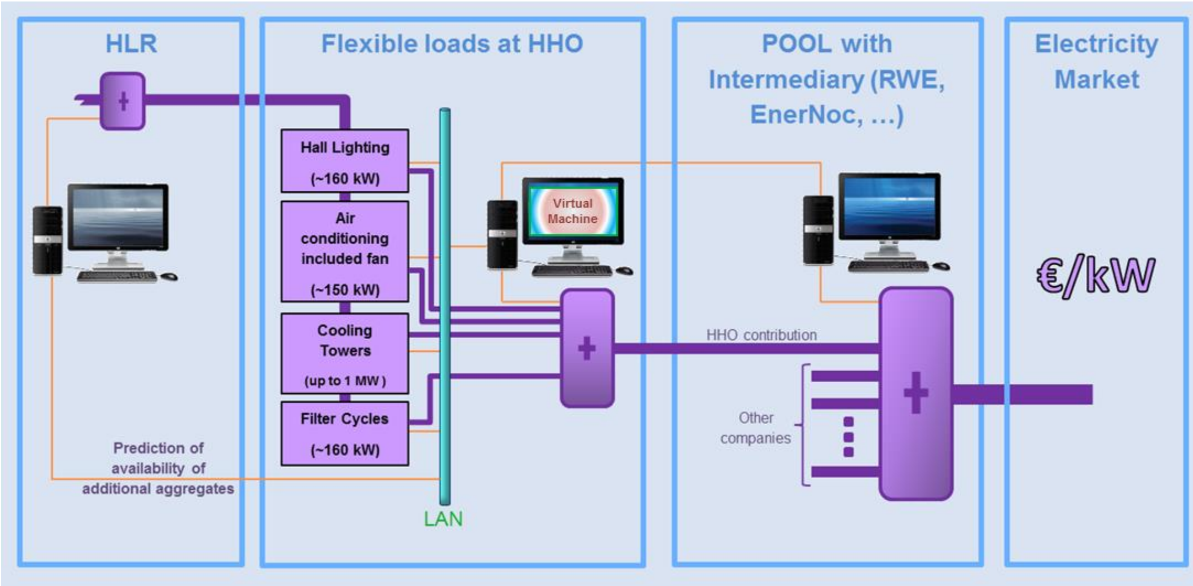


Figure 79: Planning of connections between additional loads and management computers for participation in the electricity market

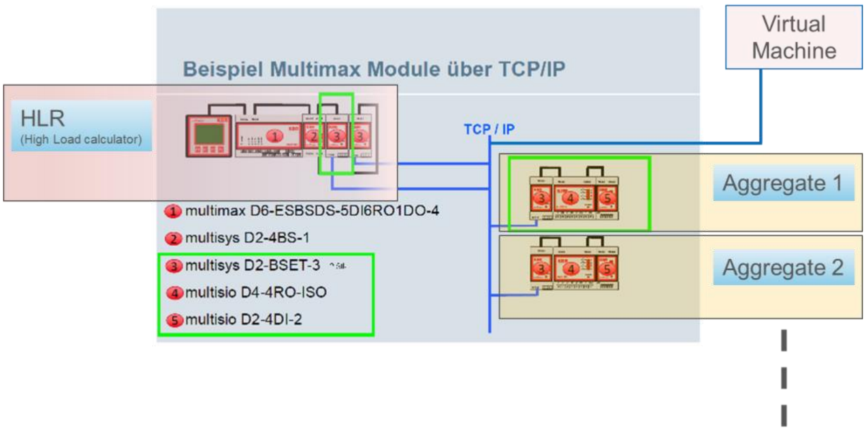


Figure 80: Connections between the High load Calculator (left) and the additional aggregates (right)

For each aggregate Table 16 gives the installed capacity, the flexibility of the load to be connected or disconnected, the type of the connection and needed hardware for his enabling or disabling, the number of needed interfaces for this realization and the conditions of load availability at HHO.

List of the additional flexible loads and their availability constraints at HHO							
Additional Loads		**Installed Capacity (kW)**	**Connection**	**Disconnection**	**Connection art**	**Number of interfaces**	**Conditions of additional load availability**
Air conditioning HV-Lenne	(If feasible) **setpoints can be raised / lowered**	100	YES	YES	Coupling HLC -external I / O level -> **coupling relay**	1	Of which approx. 60 kW of cooling and 40 kW of ventilation / cooling is controlled by the speed control Disconnecting when P > 50% of the install capacity What condition data can be supplied by the air conditioning system?
Air conditioning offices cooling tower	(If feasible) **setpoints can be raised / lowered**	20	YES	YES	Coupling HLC -external I / O level -> **coupling relay**	1	15-20 kW of cold production is speed-regulated Abschalaten, if p> 50% Which condition data can the air-conditioner supply?
Air conditioners generally with fan	(If feasible) setpoints can be raised / lowered (Is only roughly estimated)	-	YES	YES	Coupling HLC -external I / O level -> coupling		
Air conditioning Switch house Beize	(If feasible) **setpoints can be lowered**	25	YES	No	Coupling HLC -External I / O level -> **SPS**	3	Setpoint reduction is possible. Possible setpoint adjustment is not possible, since in high load phases corresponding waste heat in the switch rooms is established
Air Conditioning Switch House Miba	(If feasible) **setpoints can be lowered**	160	YES	No	Coupling HLC -External I / O level -> **SPS**	1	Setpoint reduction is possible. Possible setpoint adjustment is not possible, since in high load phases corresponding waste heat in the switch rooms is established
Cooling towers	**Setpoints can be lowered.** The potential can only be determined in practical tests and **is strongly dependent on the weather conditions (temperature / humidity)**	800	YES	No	Coupling HLC -External I / O level -> **SPS**	3	Setpoint reduction is possible Setpoint adjustment is not possible, since high heat loads can cause corresponding waste heat Interfaces to cooling tower (old + new) rolling mill and pump control
Filter cycles	**7 filters are provided here**, the start cycles of which are to be shifted into the next period segment with correspondingly present load prognoses. Potential depending on the active filter approx. 100,200 kW average value of 140 kW flushing time about 30 minutes	140	YES	temporary	Coupling HLC -External I / O level -> **SPS**	1	Advance the rinsing process is possible Delaying of a rinsing cycle which has not yet been started is possible Interruption of an already running rinsing process is not possible The limit value of the minimum duration in the settling tank has to be clarified Control unit in SPS must be adapted
Hall lighting	4 halls at 40 kW -> potential approx. 160 kW Ensure the connection of lighting / work safety	160	YES	No	Coupling HLC -external I / O level -> **coupling**	4	Can only take place during the day with sufficient daylight
	Total Power Consumption	**1305**	**kW**		**Total number of interfaces**	**14**	**Interface modules**
					Number of Modules	**7**	**logical modules**

Table 16: List of the flexible additional loads and their constraints for the participation for the Electricity Balancing Market at HHO

Due to the decision to use only the existing loads, the problem of the position and secure installation and of the robust process-integration of a new aggregate is no longer relevant. For this reason only the equipment alteration costs and boundary conditions for construction have been considered.

In order to enable the communication among the HLC, the virtual machine and the participating aggregates, 14 Hardware module are needed (see Table 16). The main parts of this hardware are multimax modules (see Figure 80 and Table 16), The and the accessory parts are the LAN-connection cables.

2.2.4.4 Task 4.4: Modelling of electric load availability

The following paragraph represents the Deliverable *D4.3.*

The modelling of the additional loads is essentially based on the load constraints and their cost functions. Each cost function must take into account all the load constraints in Table 16 and evaluate the optimal decision for the enabling or disabling weighting the contributions according to the cost of each constraint. Furthermore, due to the different characteristics of each load, the agent based modelling lead to optimal use of these characteristics of each aggregate (more details about the Agent-Based modelling are depicted in the deliverable D4.5 in the task 4.5).

For this reason each additional load module gives his availability to the load Manager (Agent Additional Loads Manager in Figure 82 related to deliverable D4.5.) based on its own calculated cost function independently from the other loads.

The precise formulation of each cost function will be done in task 4.6 before the implementation of the control system in order to ensure that all possible constraints are considered in the overall method implementation in WP6; an easier method could be considered (i.e.: the sum of all minimal actual available load of each aggregate) to react to the energy demand.

Figure 81 shows one example of parameter extraction for the Agent-Based modelling of cooling towers.

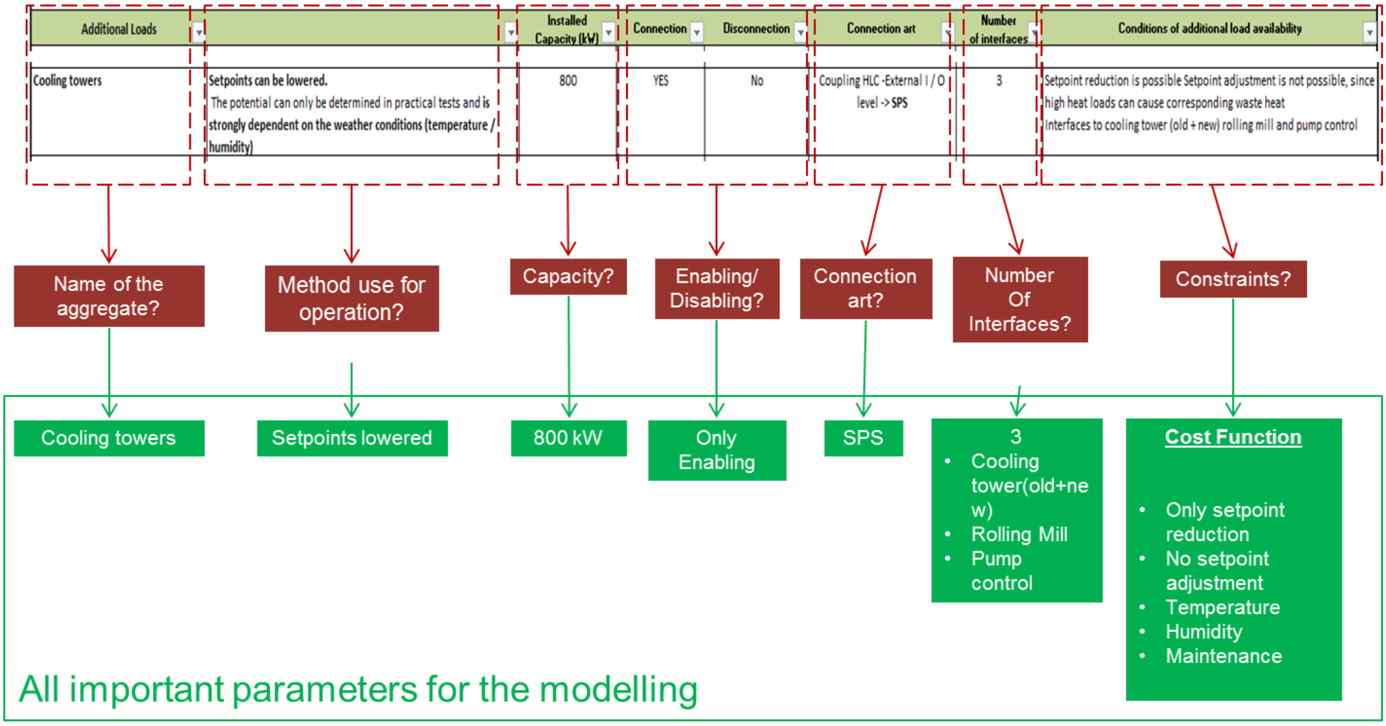


Figure 81: Example of the extraction of the modelling parameter from the table of loads availabilities and constraints

2.2.4.5 Task 4.5: Development of control concepts

The following paragraph represents the Deliverable *D4.4.*

Each additional load is firstly considered as an independent entity able to be controlled individually due to e.g. the difference in capacity. All the loads are then integrated in a controlling system in order to be able to participate in the electricity market. The agent based control has been individuated as a suitable technology to manage all the involved aggregates and efficiently ensure the availability of the asked load.

Figure 82 shows the Agent-Based control to be implemented at HHO. For this realization two types of agent were identified. The Aggregate Agent whose task is the internal management of each aggregate constraints, the evaluation of the cost function, and the communication to Manager Agent of its load availability.

The Manager Agent manages the overall loads availabilities integrating the information received from each aggregate agent. Furthermore it receives the information about the energy demand (Power demand, availability demand, prediction period) and use them as constraints to his own cost function to ensure the availability of the load demand.

The Manager Agent has then the duty to calculate the new optimal scheduling for the production planning. The production scheduling closes the control loop by giving the new 15 min forecast.

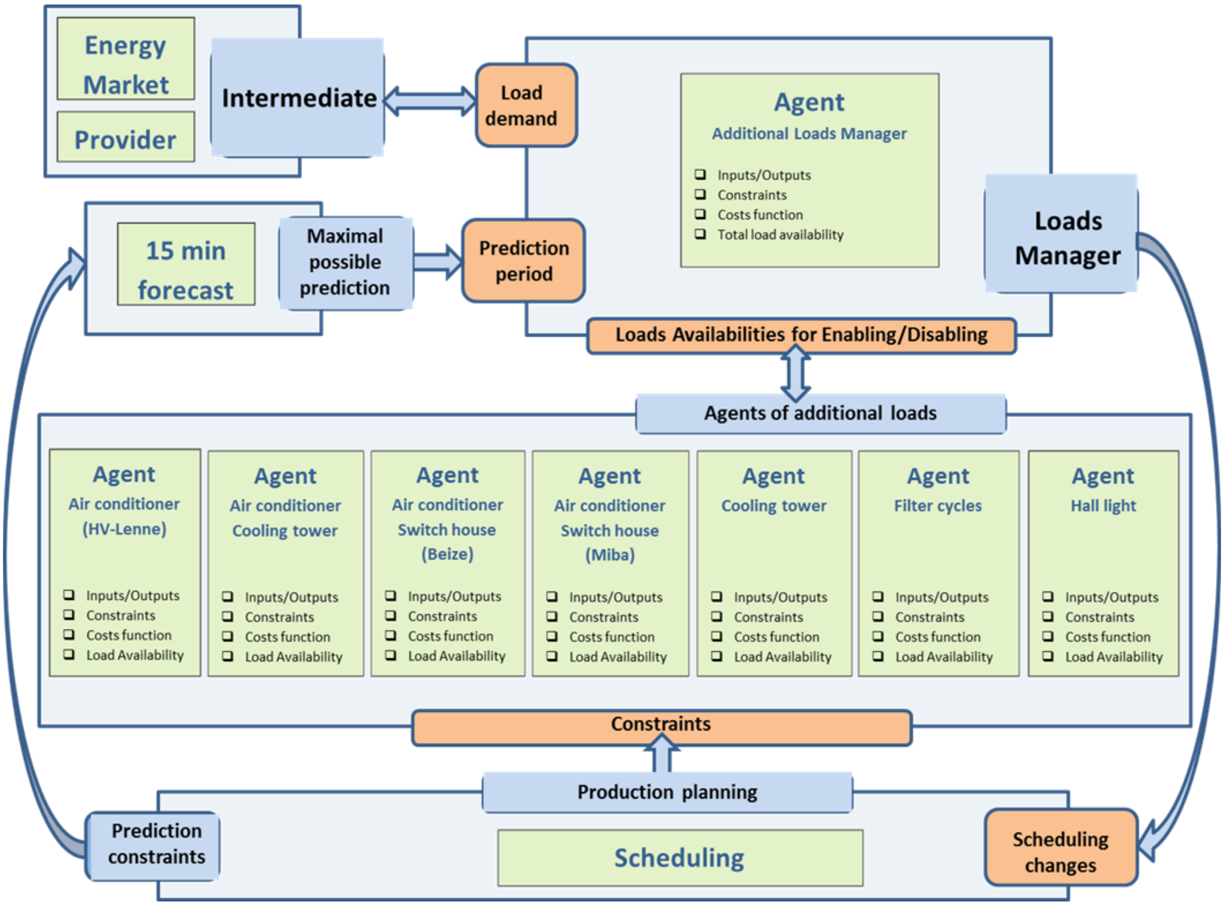


Figure 82: Agent based control concept to react on the electricity market

2.2.4.6 *Task 4.6: Implementation and evaluation of developed concept for additional electrical loads*

The following paragraphs represent the Deliverable 4.5.

<u>Commissioning of the developed control concept</u>

For the commissioning of the developed control concept at HHO two aggregates have been considered. The first are the cooling towers with a capacity of 800 kW (cooling towers, Pumps, fans). The second is the air conditioning switch House Miba with the capacity of 160 kW (see Figure 83).

For security and reliability reasons, the additional load management software was installed a few months before the commissioning. The purpose was to collect the data for the offline examinations in order to improve the software robustness.

Once this phase has been validated, a software commissioning test has been carried out at HHO. For this purpose it was important to consider the constraints of each device particularly those cooling towers which have two levels of adding loads. The first level for the pumps and the second level for cooling tower fans (see Figure 84).

Figure 85 shows the cooling towers at HHO during the production.

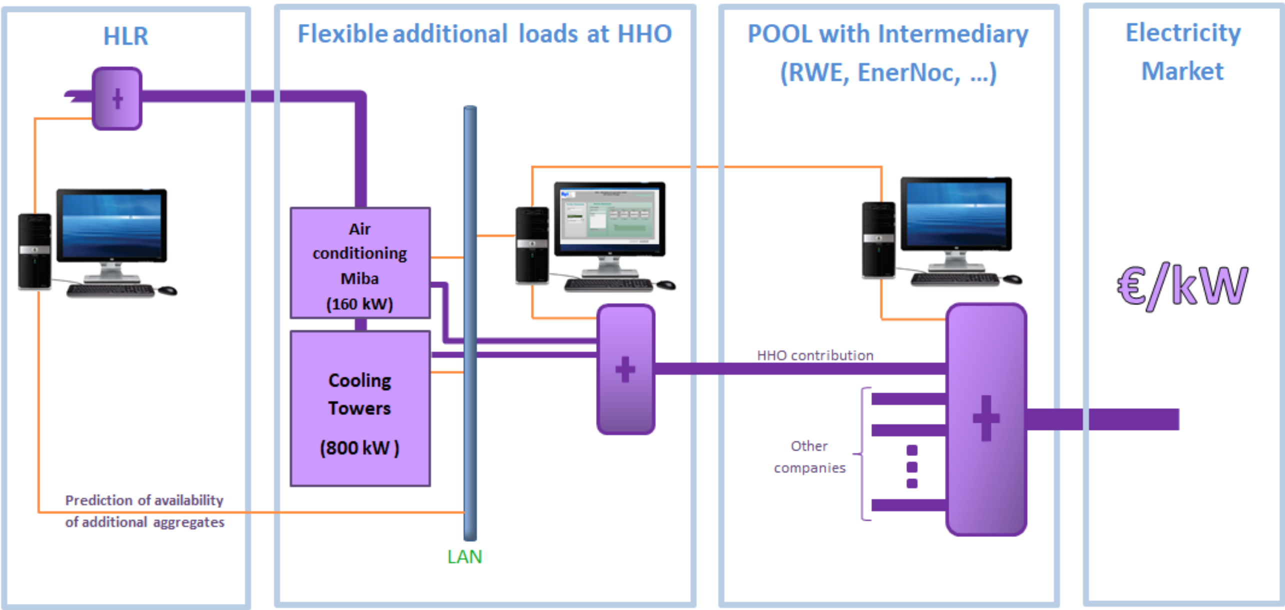


Figure 83: implemented solution at HHO with two devices (Air conditioning, Cooling Towers)

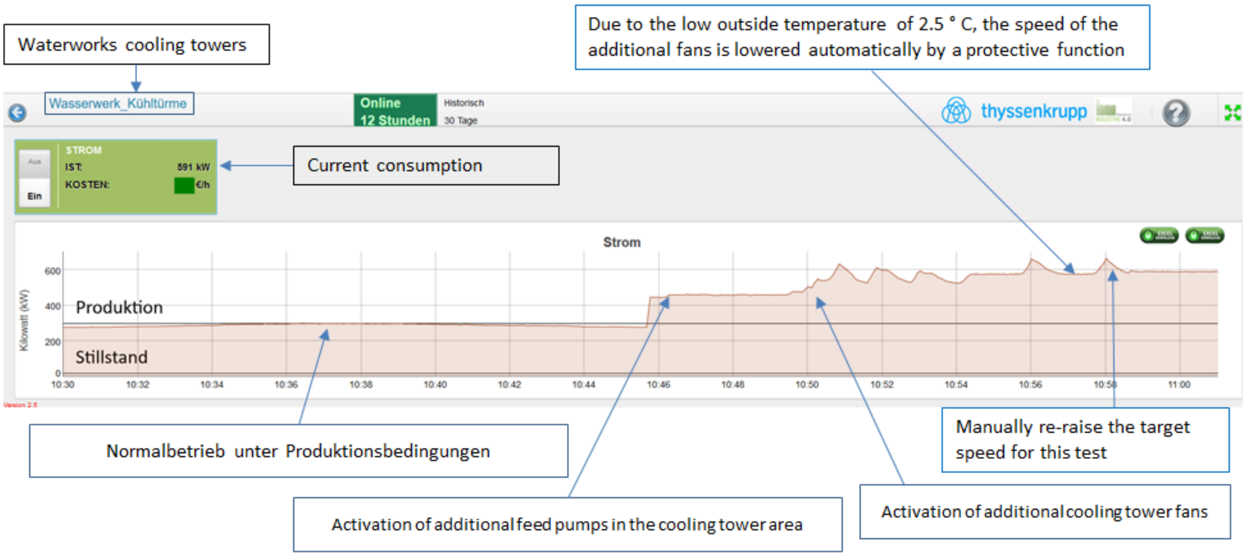


Figure 84: Switching stage of the cooling towers at HHO

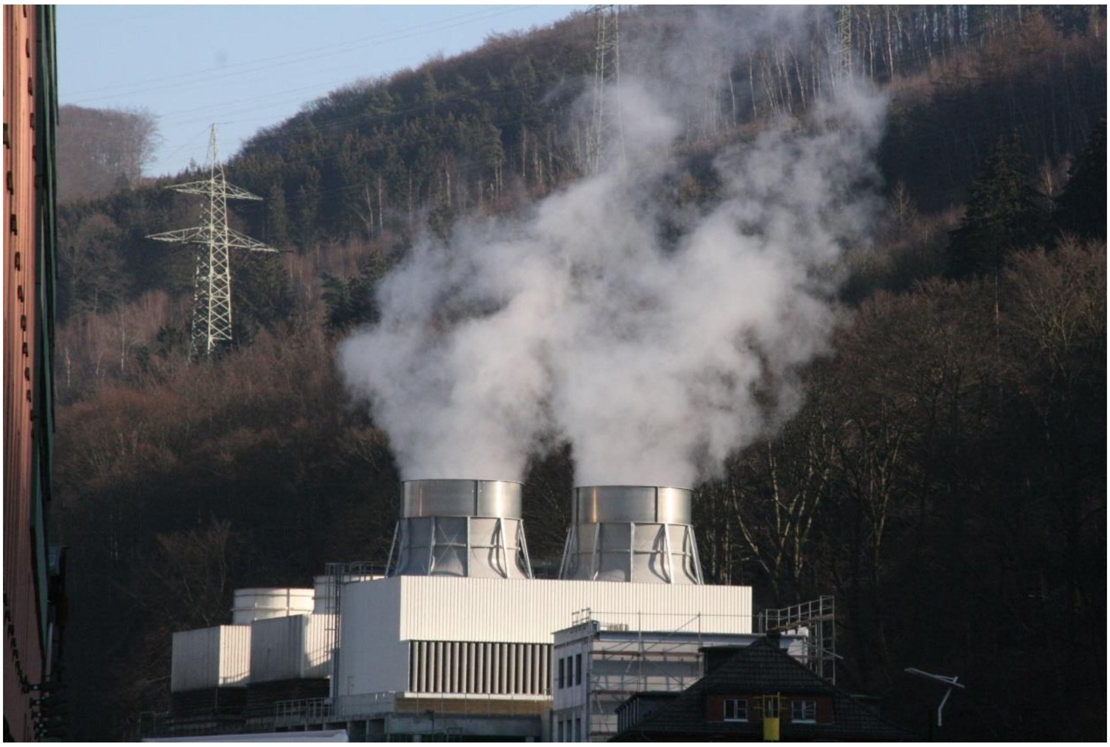


Figure 85: Cooling towers during the production at HHO

Implemented component system approach for the additional loads management with Labview

Figure 86 shows the interactions between the provider, the additional load control software, the database and the additional loads at HHO. This interaction works as follows. At the beginning of the chain we have the provider that sends to the component system approach (Devices Manager) a load request. Once the request is made, the software will be responsible for finding the cheapest combination to satisfy the demand based on the information received from the additional charges on their availability. Once the best combination found the Device Manager will write in the database the commands for activation or deactivation of additional loads.

As shows in Figure 87 and Figure 88 the implemented component system approach (Software agent based at HHO) for the management of the available additional loads at HHO is composed by two Agents. The first one is the main agent for the management of additional loads and the second is the load agent (each load is responsible for evaluating and transmitting its availability). To satisfy the load demand of the provider each load agent evaluates his availability and gives his current capacity to the loads manager for the overall availabilities evaluation. Figure 87, Figure 88 and Figure 89 shows the Human Machine Interface (HMI) of the implemented agent based control of the additional load at HHO.

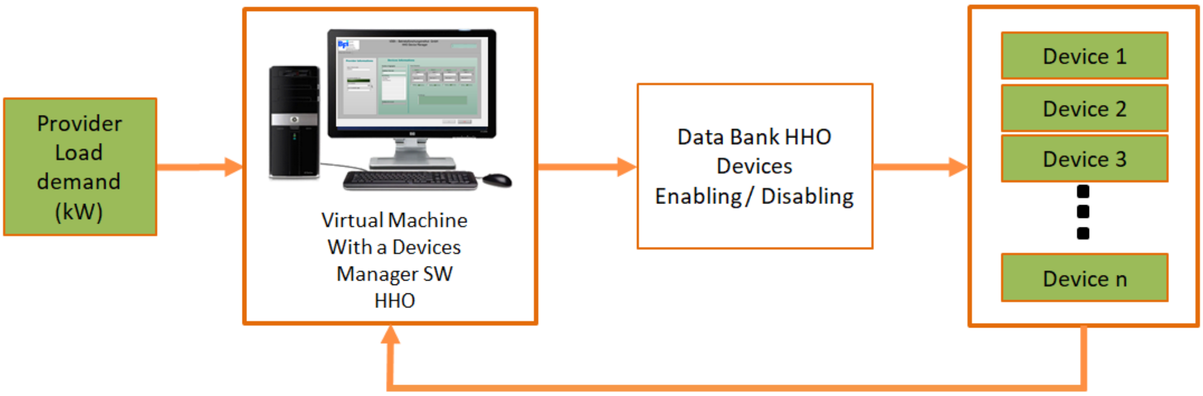


Figure 86: simplified diagram implementation of the Devices Manager Software at HHO

Agent loads manager

As shown in the Figure 87 the load management agent can be divided into two parts. The first part concerns the provider (Provider Informations) and the second part concerns the additional charges (Devices Informations).

For the provider information we have the name of the provider, a manual button to simulate the load request of the provider, an input value of the load required in kW, an input value to define the duration of the availability of the load, a light indicator that turns lime-green when the load request is validated and the load availability condition is filled, otherwise the light remains gray (load required not available).

Devices Informations allows you to enter the potential loads to satisfy the provider's request (name, power consumption) and a light indicating the active (lime-green) or inactive (dark green) state of the load.

Cost function

Once the different potential loads have sent their availabilities, the costs function choose the most appropriate combination for the provider demand based on the additional loads availabilities to avoid unnecessary energy consumption.

The production planning does not affect at the moment the cost function calculation since at HHO only the additional loads are planned not to disturb the operation of the production and to increase the required reliability of availability. But for a higher profitability including the optimization of the planning of the use of the loads during the production the software developed in the task 6.4 (WP6) can be associated to the cost function of the devices manager in order to give the 15min constraints feedback of the production planning (see Figure 82).

Agent additional load

Figure 88 shows the availability of each additional load agent online and the Figure 89 shows the sum of the available loads which allows the agent load manager to find the best combination to satisfy optimally the requirement of the provider.

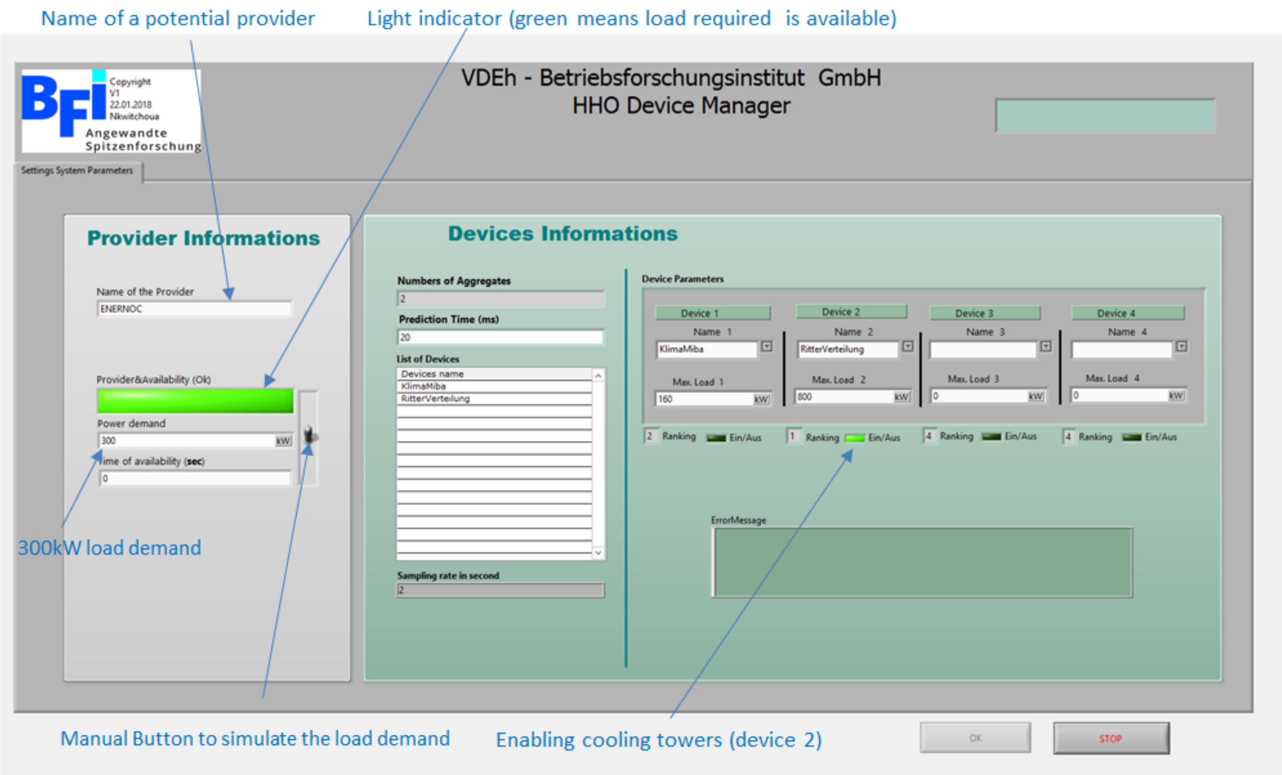


Figure 87: implemented loads manager (Main Agent) at HHO

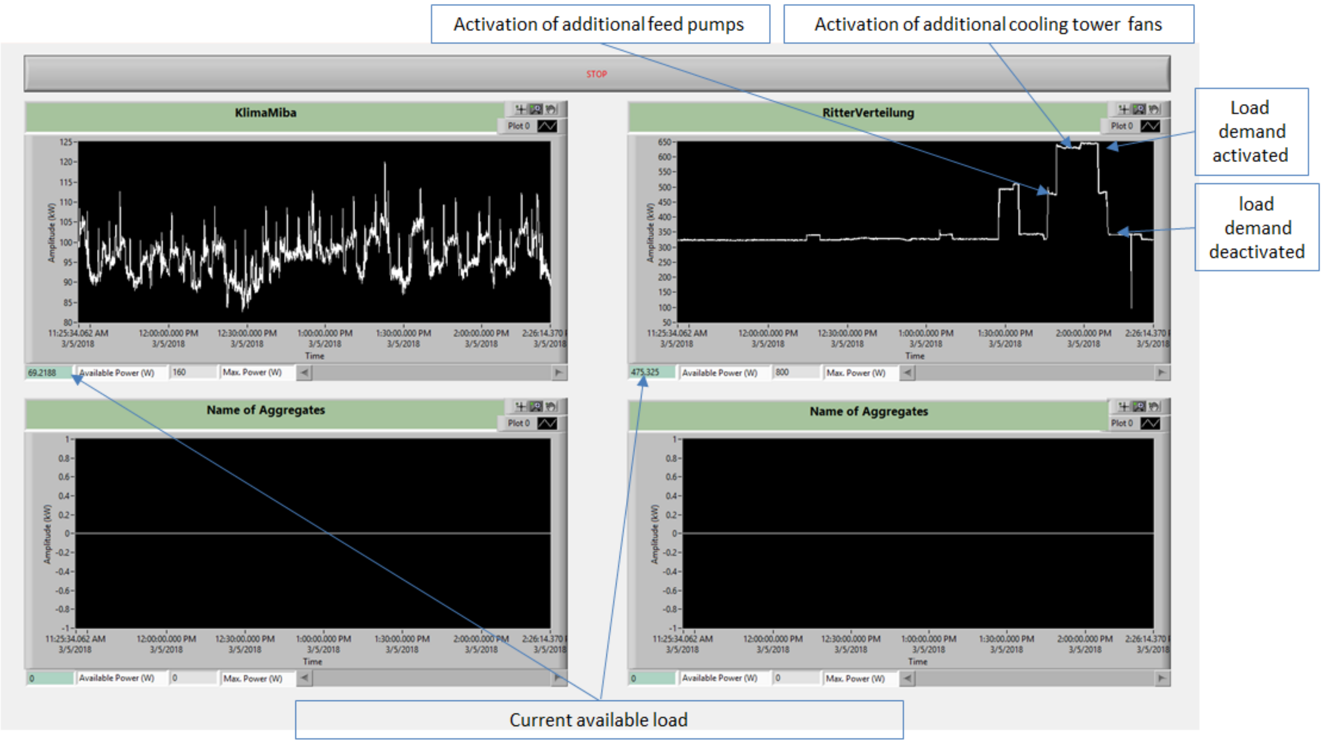


Figure 88: Implemented agents of additional loads with a sampling rate of 2s with the enabling and disabling of the cooling towers

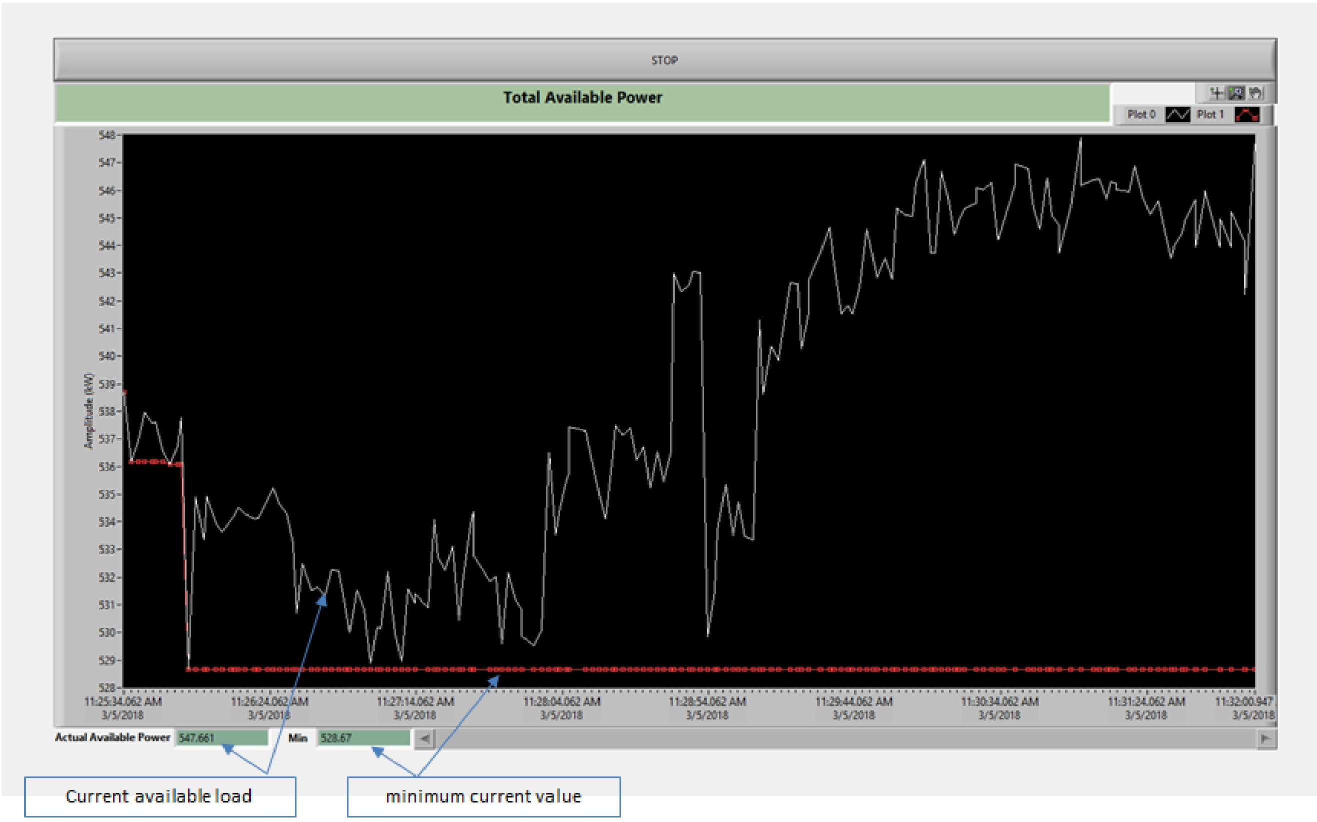


Figure 89: Total available load for the additional devices at HHO with a sampling rate of 2s

Since the current income for participation in the energy market is considered from HHO unattractive for the moment (25000 € / MW per year according to HHO), HHO has postpone to put the software into service once the revenues will become more attractive.

2.2.5 Work package 5: Strategies for production redefinition to align and re-align actual power engagement with the forecast

2.2.5.1 Task 5.1: Analysis of the actual procedures and methodologies used in the steel companies to calculate and re-schedule a "day-ahead"-forecast of the production

The forecast of needed power is provided to the intermediator on an hour basis, while for the calculation a shift or an hour is taken into consideration depending on the variability of the processes, the detail of the production plan taken into consideration or the fact of being part of a consortium for the electricity purchase that acts as a pre-balancing before accessing the external electricity market.

At LSW, currently a weekly production plan for the two lines in the electric steelmaking plant is defined and broken down to the three shifts of each production day. For each shift it is indicated if quality steel grades (QST) or structural steel grades (BST) shall be produced. Planned maintenance shifts are indicated separately (e.g. 'Gefäß' for EAF vessel change or 'SGA' for the continuous casting plant). Further planned downtimes are indicated for each of the two production lines separately. Figure 90 shows a typical example of such a weekly production plan.

KW 36	01.09.2014			02.09.2014			03.09.2014			04.09.2014			05.09.2014			06.09.2014			07.09.2014		
	Montag			Dienstag			Mittwoch			Donnerstag			Freitag			Samstag			Sonntag		
	FS	MS	NS	FS	MS	NS	FS	MS	NS	FS	MS	NS	FS	MS	NS	FS	MS	NS	FS	MS	NS
Linie 1 (EAF1)	QST	QST	QST	Gefäß	Gefäß	BST	BST	BST	BST	BST	BST	BST	BST	BST	BST	BST	BST	QST	QST	QST	QST
	178	178	178	130	130	130	130	130	130	130	130	130	130	130	130	130	130	178	178	178	178
Linie 2 (EAF3)	QST	QST	QST	QST	QST	QST	QST	QST	QST	SGA	QST	QST	QST	QST	QST	QST	QST	QST	QST	QST	QST
	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
ggf.: Stillstandszeit Linie 1																2 h					
ggf.: Stillstandszeit Linie 2										8 h											

Figure 90: Weekly production plan of Lech-Stahlwerke

From the production plan, a day-ahead forecast of the electrical energy demand with the expected peak load per 60 min intervals for one day is derived. The influences of the different steel grades to be produced, the quality of the scrap or process interruptions cause deviations, are not yet considered within the forecast.

Figure 91 shows step by step the development of the method for predicting the electrical energy consumption by HHO.

The working layer allocation and the average energy needs of all involved units are recorded in an Excel table (monthly/weekly/15 min.). This Excel table gives the energy profile of the forecast, which is transmitted in a standardized interface to energy purchase planning.

Figure 92 presents an example of the inputs of working layer allocation with the average Energy needs of all involved aggregates in one month in HHO. Each column have three workgroups per day (the first one in the morning "Früh", The second one in the afternoon "Spät" and the last one in the evening "Nacht"). The "X" in the table means that the aggregate "M" (in total 8 aggregates from M01 to M08) will be activated for the corresponding workgroup. The "H" and "X1" are special programs that are different to the normal program. Based on all active aggregates per day the average consumption need can be calculated. The result of this calculation is the profile which is presented in the Figure 93, which shows the forecast profile of a month in HHO.

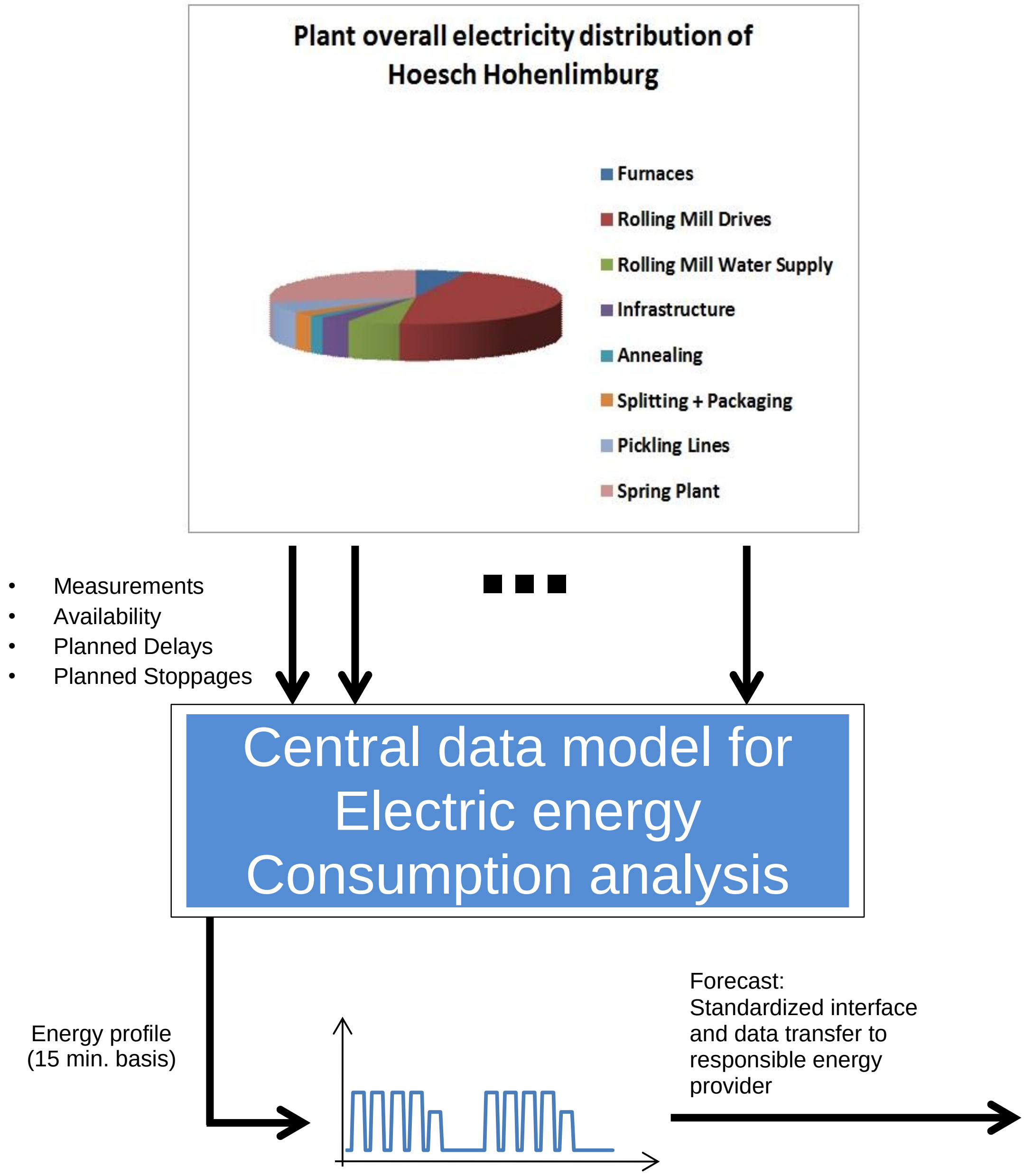


Figure 91: Method of calculation of energy consumption profile for the forecast

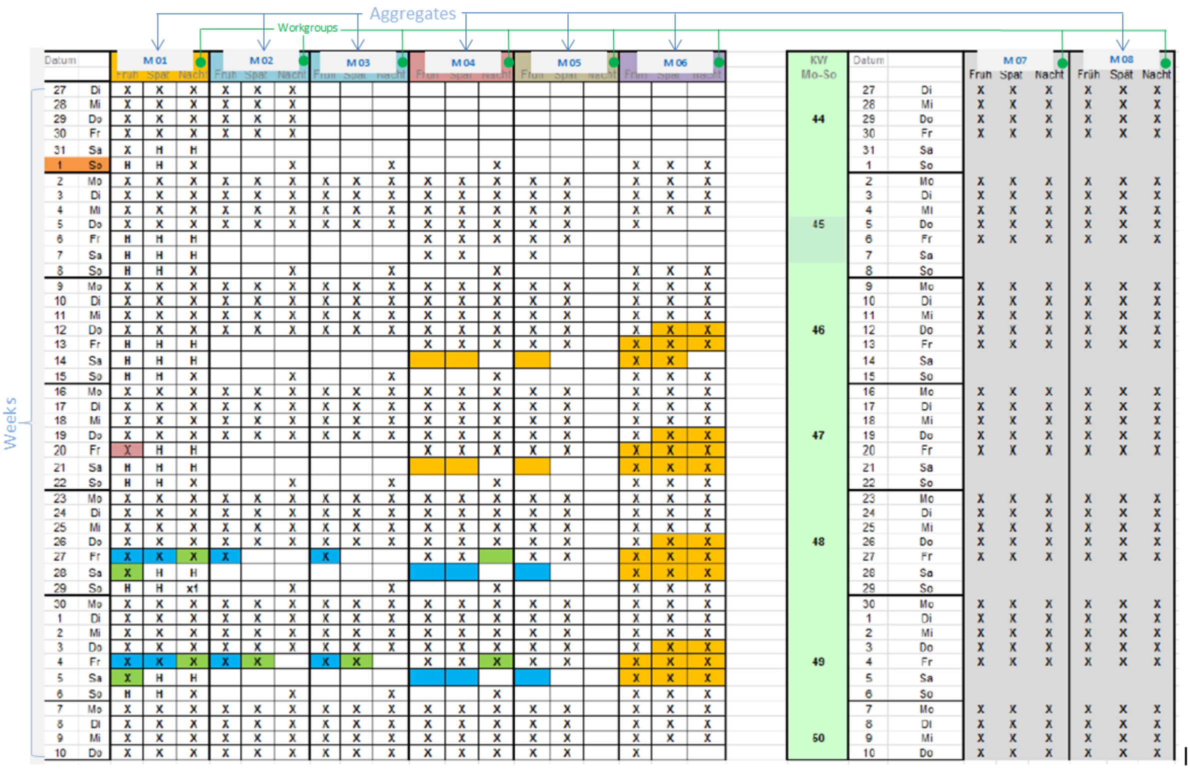


Figure 92: Forecast tool for all working layer with each aggregate in HHO

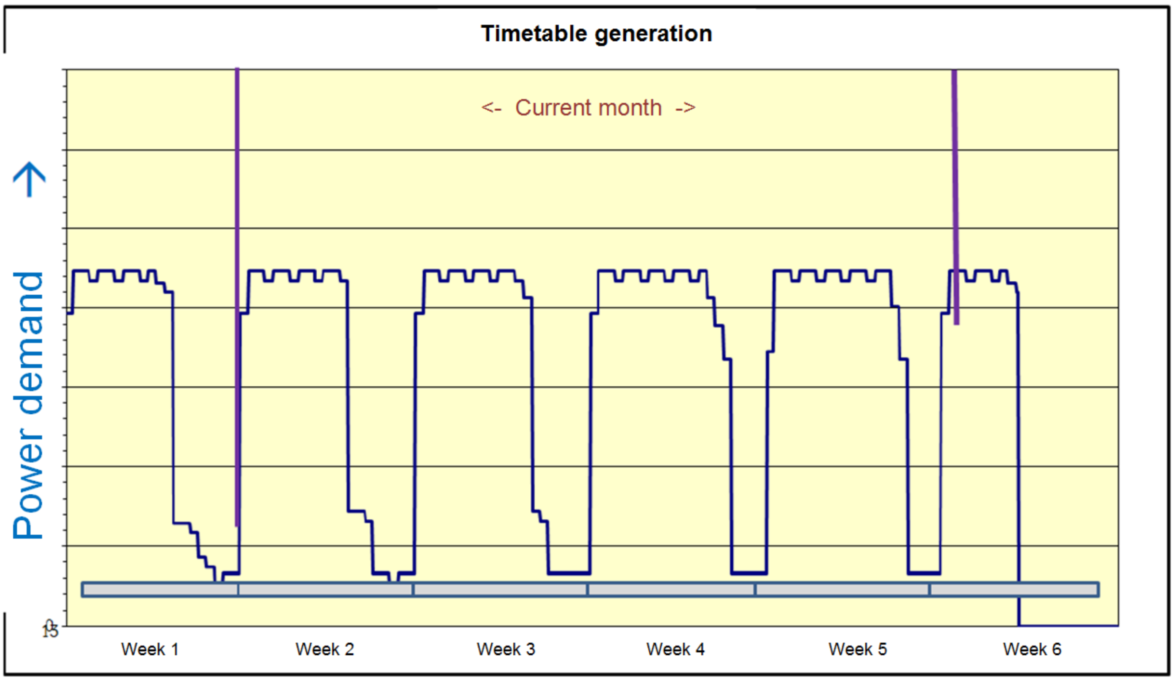


Figure 93: forecast profile of a month in HHO

ORI is part of a buying electricity consortium established among more than 20 steel factories located a few kilometres away from each other. The foreseen electricity needs are communicated to the consortium very early mainly considering flat profile a part from process downtime and the changes are communicated whenever they happen. The modifications are mainly due to the foreseen activities for maintenance or other stopping activities with a duration between 4 and 8 hours and the holidays (see Figure 94). The participation of several plant in a pool lead to a natural balancing of the overall energy demand and therefore no accurate profile was requested by the aggregator. The planning is done using an Excel file based on hours slots and for each of them the booked MW are indicated. In case of variation a flag for each hour indicate that a modification exists and which is the new value.

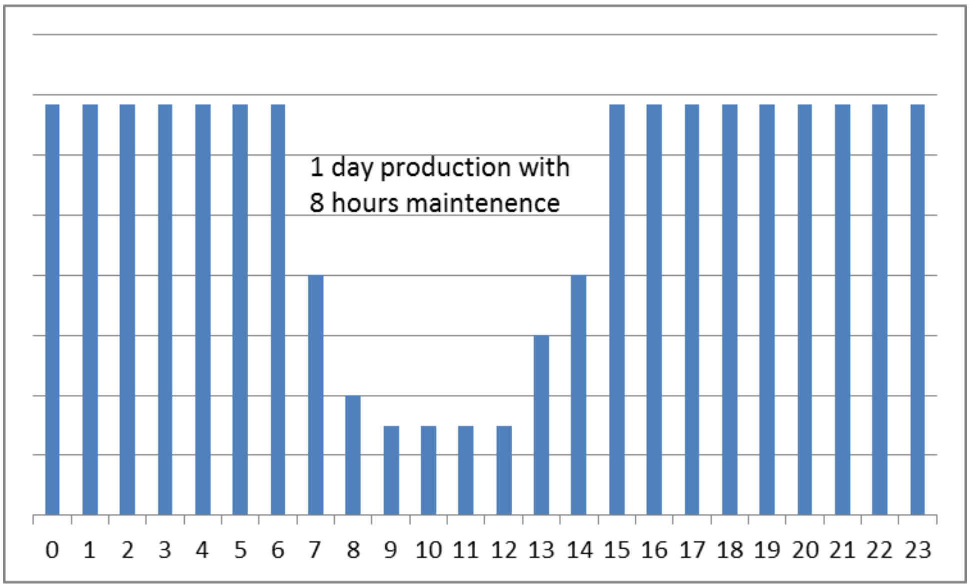


Figure 94: Booked electricity at ORI when a 8 hours maintenance is foreseen

At AST a detailed production plan for the steel shop is prepared (see Figure 95). The profile of electricity needed is then calculated on this basis adding the contribution from the rest of the plant. A profile of one week production is shown in Figure 96. The profile is based on the sum of the electricity needed for each process. In particular for EAF and HSM a profile is used based on the evaluation of historical data. For the other processes a flat contribution is considered.

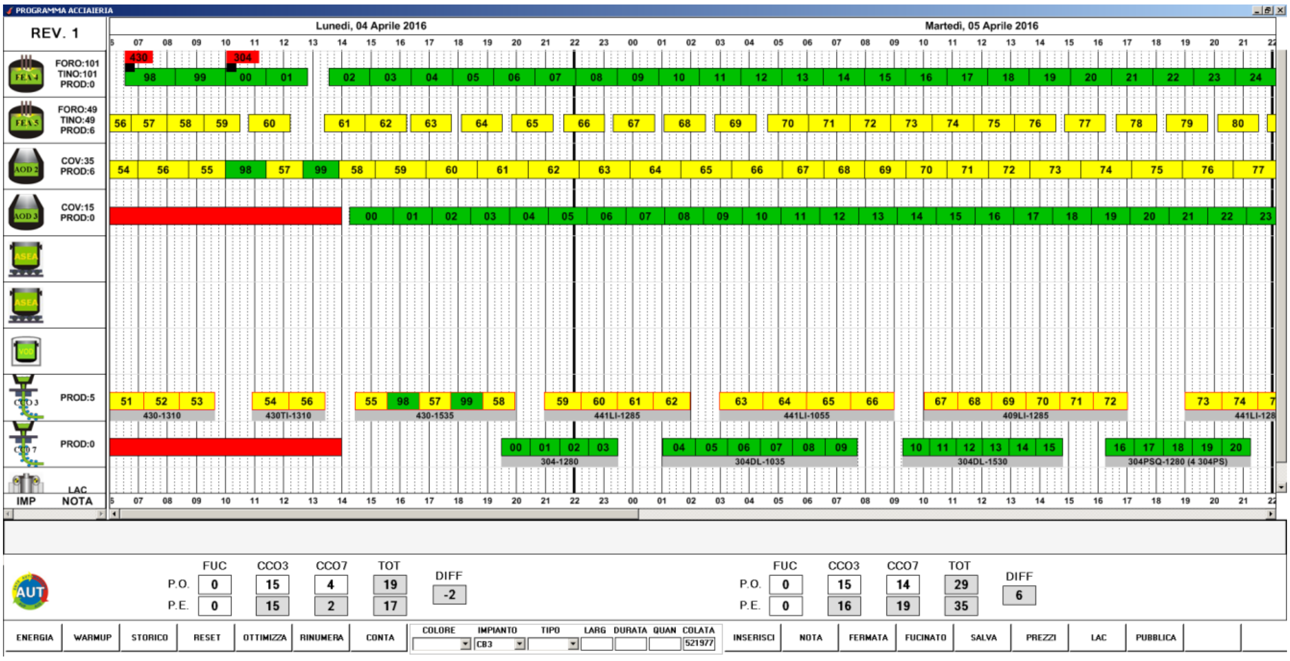


Figure 95: Example of AST steel shop production plan

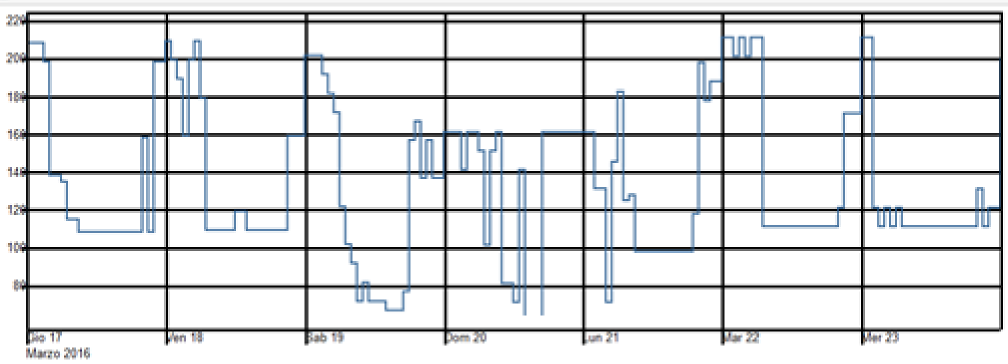
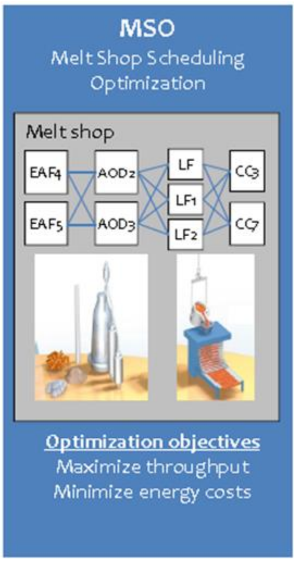


Figure 96: Example of foreseen electricity needs



In order to perform a substantial step ahead, energy constraints must be included dynamically into the optimization procedure, coming within the scope of the multi-objective optimization procedures. This way, continuous re-scheduling becoming possible, reaching to the following expected benefits:

- Optimal grouping, assignment, sequencing and timing of heats ensure continuous caster feed, better integration and coordination between different production processes.
- Minimize make span and waiting times, thus energy losses too.
- Maintenance planning.
- Energy aware scheduling.
- Possible integration and coordination with the hot rolling mill scheduling in order to increase ratio of hot charged slabs and thus reduce natural gas consumption in reheating furnace.

In the next tasks of this Work package, methods, algorithms and procedures will be realized and tested to reach this objective.

2.2.5.2 Task 5.2: Definition of metrics to measure and estimate the deviations between booked and consumed electrical energy

The following paragraph represents the Deliverable *D5.1.*

A deep discussion has been developed among the partners on the suitable ways to quantify both the deviations between the forecasted (i.e. the energy bought at the day-ahead market) and actual consumption (which is derived from the current production plan and from the flowsheet model developed in WP3), and the potential effects that such deviations can lead, taking into account the different regulations and opportunities provided by the Italian and German electricity markets.

Figure 97: Melt Shop Scheduling Optimizatin Schema

Also the need to have indexes [35], which are suitable to validate the proposed method on historical data, has been faced, taking into account that, when processing historical data, some information on the network status could be available, which are normally not available when the system runs on-line.

At Lech-Stahlwerke, AST and ORI the costs for the operation of the distribution grid and balancing the power network are calculated for each day and every time slot of 15 minutes (in Germany) or 1 hour (in Italy) retrospectively at the end of each month. The steel mill will be charged with a fee for the operation of the balancing work that is done by the grid operator. Figure 98, Figure 99 and Figure 37 shows an example of the deviations between used and booked power load at LSW, AST and ORI respectively. Table 17 shows the possible balance situations that might occur each day. During last year the situation in Italy for the quantification of the revenues/fees is changed as reported in WP1.

Table 17: Balancing costs for operating the grid at Lech-Stahlwerke

Situation of the steel mill	Situation of the grid	
	1 (-) The grid has to sell power in order to be balanced.	**2 (+)** The grid has to buy power in order to be balanced.
A (-) The power load is lower than ordered (the day before). The steel mill does not need the ordered energy.	**A1 (-/-)** The steel mill gets a negative balance fee for not using the ordered energy.	**A2 (-/+)** The steel mill gets a positive balance fee for not using the ordered energy.
B (+) The power load is higher than ordered (the day before). The steel mill needs additional energy.	**B1 (+/-)** The steel mill gets a positive balance fee for using more energy than ordered.	**B2 (+/+)** The steel mill gets a negative balance fee for using more energy than ordered.

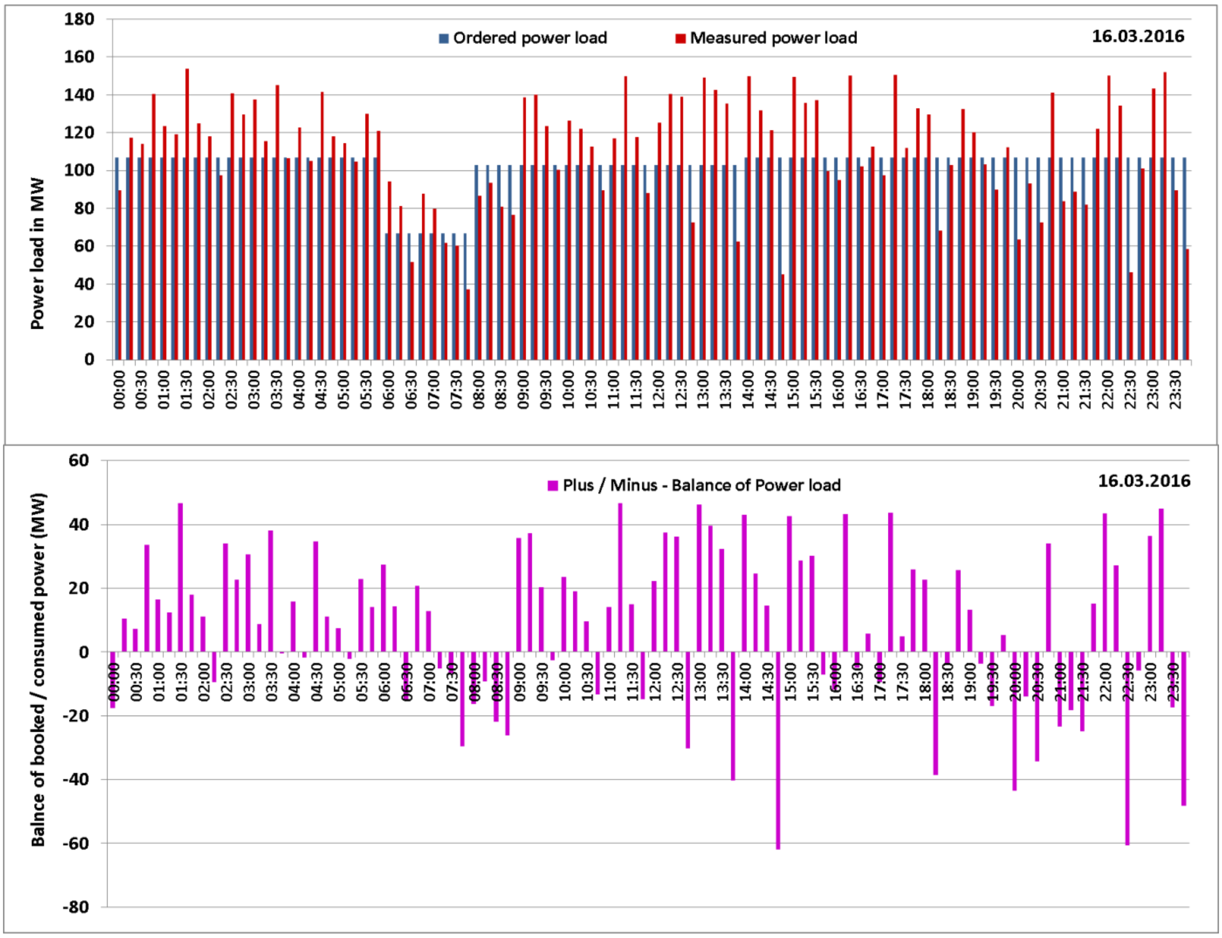


Figure 98: Example of Lech-Stahlwerke showing the balance deviations of the booked power load to the measured power load for 15 min intervals of one day (16.03.2016)

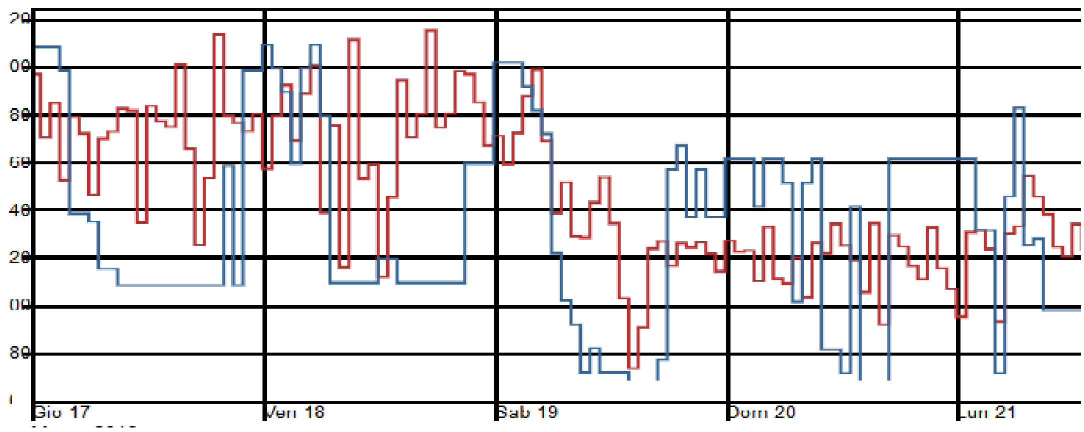


Figure 99: Example of AST showing the balance deviations of the booked power load (blue line) to the measured power load (read line) of five days

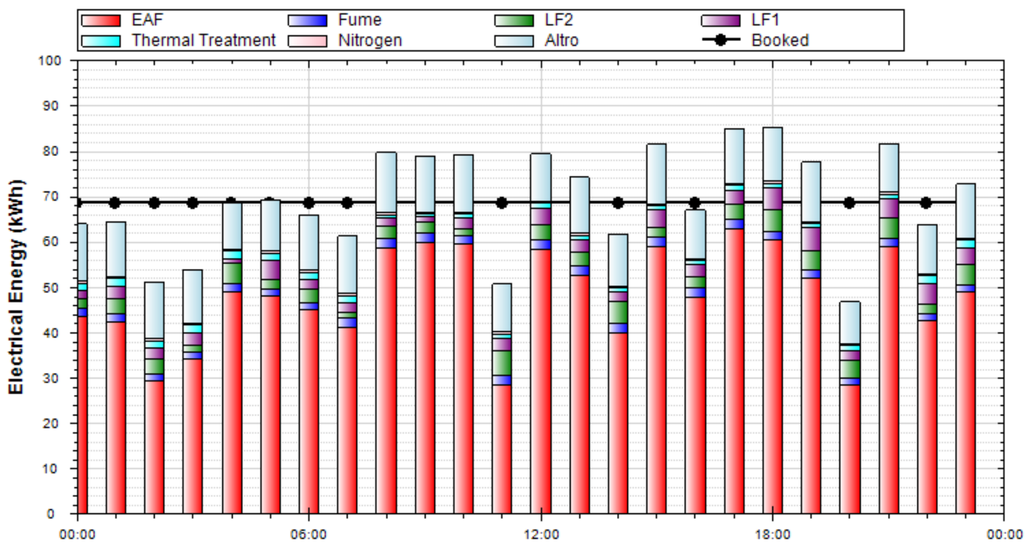


Figure 100: Effective electricity demand compared to booked one in a day at ORI

The simplest way to quantify the deviation in a given time period is a sort of weighted error between the forecasted consumption and actual consumption derived from the current production plan. Let us define ΔT the typical time interval which represents the basis for the Energy market (typically $\Delta T=1h$, $\Delta T=15min$). Any period of time comprised between an initial and a final time instant, named respectively T_0 and T_f (e.g. 1 day, 6 hours, etc..), can be divided into N time slots of identical duration, where obviously $N=(T_f-T_0)/\Delta T$. Let us indicate with C_i and $\widehat{C_\iota}$, respectively, the consumptions of electrical energy that are computed according to the flowsheet model and the ones that have been forecasted in the past for the i-th time slot. One can then define on this time slot an absolute error e_i and a relative error ε_i as follows:

$$e_i = \left|\widehat{C_\iota} - C_i\right| \qquad \varepsilon_i = \frac{\left|\widehat{C_\iota} - C_i\right|}{C_i}$$

A first trivial way to quantify the deviation between actual (or derived from production plan) and forecasted (or bought at the day-ahead market) consumption values is provided by the average of the absolute or relative errors, which are computed as follows [36]:

$$M_1 = \frac{\sum_{i=1}^{N} e_i}{T_f - T_0} = \frac{\sum_{i=1}^{N} e_i}{N} \qquad\qquad M_2 = \frac{\sum_{i=1}^{N} \varepsilon_i}{T_f - T_0} = \frac{\sum_{i=1}^{N} \varepsilon_i}{N}$$

The reason for keeping both these indexes lies in the different purposes by which they can be applied. M_2 is supposed to be more suitable in the validation and development phases, in order, for instance, to evaluate the accuracy of the models, as it weights in a different way the error depending on its percentage value with respect to the real consumption. M_1 is more suitable for optimization purposes, e.g. when adjustments of the production schedule are searched, in order to match at best the actual consumption values with the consumption plan that has been prepared the day before and on the basis of which interventions on the market have been made.

In order to evaluate the effect of the deviations between estimated and actual consumptions, one can also evaluate the “cost” or possible revenues associated to such deviations [37]. In effect, it has been already underlined that, if the deviation between actual and estimated consumptions allows to partly recover an imbalanced situation of the network, such deviation, although heavy, can have a null or even a positive economic effect.

For instance, when the network suffers a lack of supply with respect to the demand of energy and the company is consuming less energy than forecasted or when, in the case of a positive imbalance of the network (i.e. an excess of energy), the company can increase the load, economic consequences for the company could be low or null, or they might even result in a chance for a profit (according to the specific imbalance regulation in force). This also depends on the sell/buy price, which must be compared to the price that has been previously sustained for purchasing that amount of energy. If no sale of excess energy is possible, in any case the availability to “devolve” some amount of the acquired energy to counteract and compensate the network imbalance can receive an award, that must be always compared to the cost sustained to have that amount of energy available. On the other hand, if the network suffers for an excessive availability of energy, offering a further amount of energy is penalizing for the company. On the contrary, if the company has a further demand for energy, such energy can be much cheaper than in standard conditions and the company can produce at a lower cost.

The general policy of the company with respect to the energy availability can also affect the importance attributed to the deviations between estimated and actual consumption: e.g. a company that always prefers to guarantee that enough energy is available for the production, tends to attribute a greater importance to negative values of the deviation, as they refer to the conditions where there is a lack of energy compared to the demand of the production. This can also be related to the flexibility of the production cycle and the time of reaction, the time by which the potential countermeasures are expected to have an effect.

To sum up, in order to evaluate the effect of the deviations between estimated and actual consumption, the sign of the deviation s_e=sgn$(\hat{C}_i - C_i)$, is relevant as well as the sign s_n of the network imbalance. In the following s_n=+ refers to the situation where there is a surplus of energy production on the local network while s_n=- refers to the situation where there is a demand of energy which exceeds the energy supply. If these two signs are equal, the imbalance has heavier consequences with respect to the opposite case. Clearly, when evaluating the effect of the deviations, also its absolute value is relevant.

Therefore, a further measure for the deviation between actual and forecasted consumption values can thus be depicted as a weighted sum of the absolute deviations on each considered time interval, as follows:

$$M_3 = \frac{\sum_{i=1}^{N} w_i \cdot e_i}{T_f - T_0} = \frac{\sum_{i=1}^{N} w_i \cdot e_i}{N}$$

where w_i is a weighting factor that is computed according to the regulation of each country. An example is provided in the following matrix ***W***, shown in Figure 101, referring to the current Italian regulation.

s_n \ s_e	**+**	**-**
+	w_{++}	w_{+-}
-	w_{-+}	w_{--}

Figure 101: Weight matrix ***W***

The matrix *W* exemplifies four possible cases:

- *Case ++: the network has a surplus of energy and the company is consuming less energy than the forecasted.* Therefore, the not consumed energy *that has been bought at the day-ahead market (MGP), is sold by the company at the* Dispatching Services Market (MSD) at the mean purchase price, which is lower than the MGP price, being paid.
- Case +-: *the network has a surplus of energy and the company is consuming more energy than the forecasted. Therefore, the company buys the missing energy at the* Dispatching Services

Market (MSD) at the mean purchase price, which is lower than the MGP price, that the company would have paid the day ahead.

- Case -+: *the network has a lack of energy and the company is consuming less energy than the forecasted.* Therefore, the not consumed energy *that has been bought at the day-ahead market (MGP), is sold by the company at the* Dispatching Services Market (MSD) at the mean selling price, which is greater than the MGP price, being paid.
- Case --: *the network has a lack of energy and the company is consuming more energy than the forecasted. Therefore, the company buys the missing energy at the* Dispatching Services Market (MSD) at the mean selling price, which is greater than the MGP price, that the company would have paid the day ahead.

The cases ++ and --, where s_n and s_e are both positive or both negative, are indeed the worst cases and represent loss cases. Vice versa, the case -+ is a case where the company could make profits, while the case +- is a case where the company could have savings with respect to the MGP.

The basic idea is that M3 should represent a profit indicator, with the following meaning:

- $M_3 > 0$ indicates a profit situation; the greater is the indicator, the greater the profit is.
- $M_3 = 0$ indicates a balanced situation.
- $M_3 < 0$ indicates a loss situation.

The elements of matrix W have been evaluated in terms of the average selling and purchase prices (from TERNA) at the Dispatching Services Market and of the average price at day-ahead market.

The average MGP price in the period from January 2014 to December 2015 is about 52 €/MWh.

The average selling and purchase prices have been computed for each macro zone, North and South, and are shown in Figure 102.

Avg MSD Price / S_n	**Selling**	**Purchase**
+	*21.22*	*21.22*
-	*106.56*	*106.56*

(a)

Avg MSD Price / S_n	**Selling**	**Purchase**
+	*10.45*	*10.45*
-	*112.32*	*112.32*

(b)

Figure 102: Mean selling and purchase prices related to the North (a) and South (b) macro zone

The weight elements of matrix *W* have been evaluated with the following formula:

$$\boldsymbol{w_{**}} = \frac{(\boldsymbol{Selling\_Price} - \boldsymbol{Purchase\_Price})}{\textbf{Average MGP}}$$

Selling_Price is the selling price of energy at MSD, which appears only when S_e is positive.

Purchase_Price is the purchase price of energy at MSD or MGP, which appears only when S_e is negative.

An example of the calculations for the north macro zone is as follows:

$w_{++} = \frac{(21.22-52)}{52} = -0.6$

$w_{+-} = \frac{(0-21.22)}{52} = -0.4$

$w_{-+} = \frac{(106.56-52)}{52} = 1.0$

$w_{--} = \frac{(0-106.56)}{52} = -2.0$

The matrix W has been evaluated for each macro zone, North and South, and both of them are shown in Figure 103.

S_n \ S_e	+	-
+	-0.6	-0.4
-	1	-2

(a)

S_n \ S_e	+	-
+	-0.8	-0.2
-	1.16	-2.16

(b)

*Figure 103: Matrix **W** related to the North (a) and South (b) macro zone*

When training the whole system by processing historical data, both the s_n and some average information on costs, prices and penalties can be available in order to compile the above reported matrix. When an optimization strategy for the future must be elaborated, s_n is not known. In this case, a worst case philosophy can be adopted, by assuming s_n=-. As an alternative, one can use a model to attribute a probability to the two signs of s_n based e.g. the Markov model or some historical data. The main limit of KPI_3 (M_3) lies in the fact that the sign of imbalance of the network is unknown in real time and for this reason another KPI has been introduced which takes into account the economic aspects.

KPI_4 (M_4) is defined in formula (1). It is composed by the sum of two terms: the first term quantifies the deviation between booked consumptions and actual consumptions in a given time period, the second one takes into account the maximum load for the *i-th* slot. The slots where actual consumption is near to the maximum load, with a threshold of τ, are penalized.

In practice, minimizing this KPI we want on one hand to ensure that the energy consumed is as close as possible to the booked energy and on the other hand to penalize those consumptions that are near to the *virtual* peak load. The regulations for the Italian market provide that the monthly bill is calculated on the basis of maximum consumption reached during the month. Therefore, the purpose of the second term of the KPI is to penalize the slot whose consumption is near or exceeds the highest peak had during that month before the current time slot. Of course, the penalty is higher if such a peak is exceeded. Thus, the second term represents an estimation of the cost of the fee due to exceeding the peak so far reached: it has been built so that only the highest slot consumption near or exceeding the peak load is considered, by means of the max function.

$$M_4 = \frac{\sum_{i=1}^{N} MGPPrice_i * \left|\widehat{C_i} - C_i\right|}{N} + \max_{i=1..,N} \mu\left(C_i\right) \qquad (1)$$

$$\mu(x) = \begin{cases} 0, & x < ML_i - \tau \\ fee * ML_i, & ML_i - \tau \le x \le ML_i \\ fee * x, & x \ge ML_i \end{cases}$$

where $MGPPrice_i$ is the price at the MGP (Day-Ahead Market) for the i-th slot and it is measured in *MWh*, N represents the number of time slots of identical duration (typically 15 minutes), C_i is the consumption of electrical energy computed according to the flowsheet model (Actual) for the i-th time slot and $\widehat{C_i}$ is the forecasted consumption of electrical energy, that is the booked at the Day-Ahead Market for the i-th time slot. Both consumptions are measured in *MWh*.

ML_i is the maximum Load over all time slots of the current month previous to the i-th time slot, while τ is the threshold on the maximum load depending on consumption models accuracy for the time slot. Both ML_i and τ are measured in *MWh*.

Finally the parameter fee is the penalty due to exceeding the maximum reached peak and its measure unit is *€/MWh*. Therefore, the unit measure of the KPI_4 is euro and this KPI defines an economic index that should be minimized in order to optimize the control of energy consumption.

2.2.5.3 *Task 5.3: Implementation of KPIs to be used within a calculation algorithm*

The four proposed KPIs have been implemented. The first two KPIs take into account only the deviation between actual and forecasted consumption values. The third KPI should be suitable to the market representation but until now it is not usable for scheduling optimization because the imbalance sign is actually unknown in real time. The last KPI, composed by the sum of two terms quantifying the deviation between booked consumptions and actual consumptions in a given time period, and taking into account the maximum load for the *actual* slot, is the most appropriate one because it is able to express in terms of euro the effectiveness of the production plan and it will be used also for the optimization of the production re-scheduling. The implemented KPI will be validated later when they will be embedded into the Agent System.

2.2.5.4 *Task 5.4: Production Re-scheduling Criteria and relevant validation*

The following paragraph represents the Deliverable *D5.2*

The objective of this task is to find an optimal production schedule of a part of a steel making process that minimizes the KPI4 described above while satisfying production constraints. The developed model has been inspired from the work of Hadera et al. [38] using mathematical programing with Mixed-Integer Linear Programing (MILP) and implemented in MATLAB environment. In this work, it is assumed that the electricity consumption of any production task is constant over the time span of the task: it is a reasonable assumption since exact modelling would increase the complexity without obtaining significant benefits as demonstrated in [39][40][41].

The inputs of the model are the set of stages (e.g. EAF, AOD, LF, CCM …), the set of machines at each stage (e.g. EAF1, EAF2, EAF3 for stage EAF…), the list of products to be processed and some timing parameters needed by the scheduling constraints. A general situation is modelled, where any number of machines is possible at each stage, so for example there might be one EAF, two AOD, two LF and four CC.

The scheduling model should satisfy several production constraints deriving from the steel making process, starting from the melting phase in the EAF stage and ending with the heat casting in the CCM stage. Moreover, the process passes through intermediate stages, such as AOD, in order to reduce the carbon content of the molten steel, and LF, in order to adjust the chemistry and the temperature before the final stage of casting.

Some considerations on the steel making process are given in order to introduce the nature of the scheduling constraints.

There is a certain time $t_{m,m'}$ needed to transport products from machine m to machine m'. In order to avoid a too large decrease of the temperature of the molten steel, the waiting time spent by a heat p after stage st is restricted by a maximum allowed delay time $t_{p,st}^{max}$. Specific rules about the sequences of heats are applied in the continuous-casting stage. Heats are divided in groups and all the heats of the same group need to be assigned to the same continuous cast and are casted subsequently without waiting times. For all stages, except for CC, a machine specific setup t_m^{setup} has to be performed in advance in order to carry out the processing of the next heat. On the other hand, for the continuous casting, a setup is needed only for the first heat of the sequence or group of heats. The processing duration $\theta_{p,m}$ depends both on the product p and on the machine m where it is processed. Among input parameters there is the power consumption $h_{p,m}$, which is specific of products and machines.

Task start times variables are related to the energy part of the model, leading to the computation of the total electricity consumption within a given time interval.

These variables are used to find the contribution of a task to the electricity consumption within a given time interval by considering four possible cases:

- Case 1: a task is processed entirely within the time slot.
- Case 2: a task starts before and finishes within the time slot.
- Case 3: a task starts within and finishes after the time slot.
- Case 4: a task over-spans the full time slot.

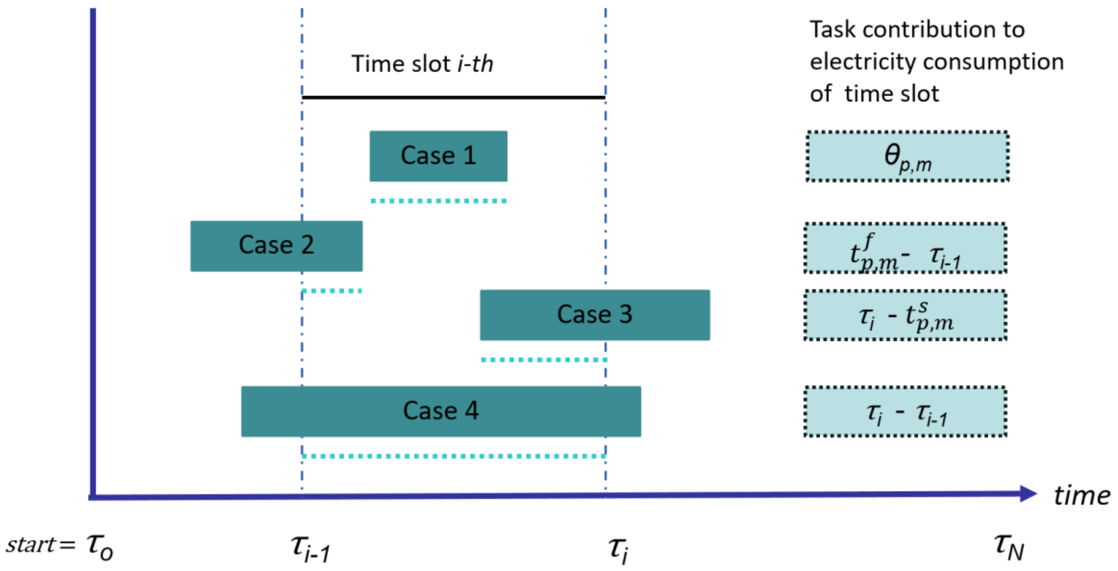


Figure 104: Task contribution to electricity consumption of a time slot

Figure 104 describes the four possible cases considered to compute a task consumption of energy in a time slot: in the light blue boxes the process duration within the time slot s-th is indicated, by putting into relation the starting or final time of a heat p on machine m with the lower, τ_{s-1}, and upper bound, τ_s, of the time slot. For example, when the task is entirely processed within the time slot, as in case 1, the complete process duration of the heat on the machine $\theta_{p,m}$ is accounted for.

The overall electricity consumption q_s within the s-th time interval can be computed by summing the contributions of all tasks in the interval. The total electricity consumption q_s is needed for the evaluation and optimization of KPI.

The specific electricity consumption $h_{p,m}$ of process p on machine m is known for every process and for every machine. This consumption is assumed to be constant over time, introducing an approximation that creates an acceptable error.

Using the variables a, b, c, d (see Annex 4) is possible to calculate the electricity consumption q_s of each time slot s as follows

$$q_s = \frac{1}{60} \cdot \sum_{p,st,m \in M(st)} h_{p,m} \cdot (a_{p,m,st,s} \cdot \theta_{p,m} + b_{p,m,st,s} + c_{p,m,st,s} + d_{p,m,st,s})$$

where the sum is divided by the number of minutes in a the time slots, which in our case is 60.

Having defined the electricity consumption q_s it is possible to compute the objective function, which is a combination of the function M_4 defined before and a function that penalizes the scheduling delay, namely the sum of all starting times. Therefore the objective function f is as follows

$$f = k \cdot \sum_{p,m} t^s_{p,m} + \frac{\sum_s MGPPrice_s \cdot |\hat{q}_s - q_s|}{|SL|} + \max_s \gamma(q_s)$$

Where |SL| is the number of times slot and

$$\gamma(q_s) = \begin{cases} 0 & q_s < ML_s \\ \phi * q_s & q_s \geq ML_s \end{cases}$$

The parameter ϕ is the fee for exceeding the maximum peak as described in the previous section. Moreover k is a parameter that tunes the tradeoff between the total scheduling time and the quality of the solution in terms of the KPI.

This expression of the objective function f is nonlinear as it contains modules and a maximum calculation. In order to obtain a linear expression of the objective function, further equations are needed. To linearize modules $|\hat{q}_s - q_s|$, real variables μ_s are introduced, so that $\mu_s = |\hat{q}_s - q_s|$.

The max over the cases function can be linearized by introducing the variable M representing the max of the electricity consumption over all the time slots. If this maximum is bigger than the maximum load ML, then the real variable $\Gamma = M * \phi$, otherwise, $\Gamma = 0$.

The objective function becomes thus

$$f = k \cdot \sum_{p,m} t_{p,m}^{s} + \frac{\sum_s MGP_s \cdot \mu_s}{|SL|} + \Gamma$$

In order to account for the possibility of machines of the same type having different consumption $h_{p,m}$ another term is added to the objective function, namely the total consumption. Therefore the final objective function is

$$f = k \cdot \sum_{p,m} t_{p,m}^{s} + \frac{\sum_s MGP_s \cdot \mu_s}{|SL|} + h \cdot \sum_{s} q_s + \Gamma$$

The number of variables and constraints in the formulation is sensibly high, and therefore the problem cannot be solved in an acceptable running time if the input is too big. An iterative algorithm is designed to overcome this problem, when the set of products too large.

The set of products is divided into smaller subsets, which are iteratively processed: the reduced products set is given as input to the MILP described above. The solution is stored and the booked consumptions vector is updated to account for the consumptions q_s^1 of the first iterations. Hence $\hat{q}_s$ becomes $\hat{q}_s - q_s^1$. Moreover the maximum assigned start time L(m) of each machine m is used as a lower bound for the start times on m in the next iteration by adding further constraints .

A new solution is found and the process is repeated until all orders are assigned (or until there is no more time available for the scheduling).

Recall that the model selects the machines to be used by each heat and outputs the starting time of all the input heats on the associated machines in order to minimize the KPI.

Examples of input data to the model are shown next. A schema example of the melt section for stainless-steel is represented in Figure 105, where stages and corresponding machines are represented.

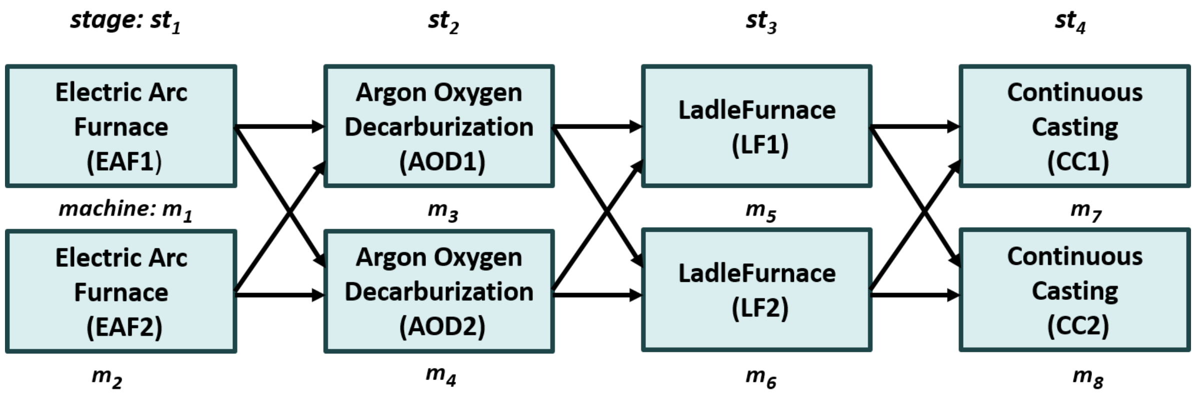


Figure 105: Melt section for stainless-steel production process

Table 18 shows the list of products to be processed, while Table 19 defines the processing times and electricity consumption for each machine. Table 20, Table 21, and Table 22 contain timing parameters needed by the scheduling constraints, respectively setup times, transportation times and maximum waiting times after stages. All data tables are taken from literature [38].

Group	Heat (product)
HG1	P1-P3
HG2	P4-P7
HG3	P8-P12
HG4	P13-P16
HG5	P17-P20

Table 18: Heat group definition

	EAF1, EAF2	AOD1, AOD2	LF1, LF2	CC1, CC2
P1-P20	85 [min] 85 [MW]	8 [min] 2 [MW]	45 [min] 2 [MW]	60 [min] 7 [MW]

Table 19: Processing times and electricity consumption

Machine	Setup time
EAF1, EAF2	9
AOD1, AOD2	5
LF1	15
LF2	5
CC1	50
CC2	70

Table 20: Setup times [min]

	AOD1	AOD2	LF1	LF2	CC1	CC2
EAF1	10	25				
EAF2	25	10				
AOD1			4	20		
AOD2			20	4		
LF1					20	45
LF2					45	20

Table 21: Transportation times [min]

	ST1	ST2	ST3
P1-P20	60	90	60

Table 22: Maximum waiting times after stages

A number of tests have been performed using the parameters in the previous tables in order to evaluate the algorithm performances and tune the parameters for the multi-objective function.

The chosen solver for the MILP is a freeware program lp_solve. It is the best performing software among the free of license software and performs better than the inbuilt Matlab solvers too.

The MGP price chosen is constant over all time slots and equals 123€ per consumed MW. The chosen maximum load is 133 MW. The fee for exceeding the maximum load is chosen as Φ=1528€ per extra MW.

For all the tests the maximum allowed running time has been set to around 30 minutes. In this situation not all the 20 heats from the previous tables can be scheduled in one day if the KPI has a high weight in the objective function: therefore the value of k in (30) is chosen bigger to increase the weight of the total scheduling time (namely the first term of the objective function). This yields a solutions scheduling all the heats in one day and provides relatively good quality solutions in terms of the KPI.

Table 23 shows the starting process time of the products on the assigned machines

	EAF1	EAF2	AOD1	AOD2	LF1	LF2	CC1	CC2
P1	189		284		324		429	
P2	283		378		390		489	
P3	377		472		484		549	
P4	0		95		127			232
P5	95		190		202			292
P6		4		149		247		352
P7		99		209		307		412
P8	556		661		759		864	
P9	650		745		819		924	
P10	744		839		879		984	
P11	838		933		945		1044	
P12	932		1027		1039		1104	
P13	462		557		569			659
P14		371		516		614		719
P15		465		576		674		779
P16		559		659,9		734		839
P17	1017		1112		1124		1197	
P18		980	1125		1184		1257	
P19	1111		1206		1244		1317	
P20	1205		1300		1312		1377	

Table 23: Processing time schedule

Table 24 shows for each time slot the booked and consumed energy and the market price

	Booked	*Consumed*	*Difference*	*Market Price*
S1	73,09	164,05	-90,95	123,1
S2	72,70	141,84	-69,13	122
S3	64,49	171,76	-107,27	199
S4	80,86	80,86	0	129
S5	81,39	81,25	0,13	111
S6	84,83	94,69	-9,85	139
S7	113,26	150,09	-36,83	122
S8	71,53	170,03	-98,50	123,1
S9	113,36	178,77	-65,40	111
S10	91,64	153,06	-61,41	124
S11	84,04	137,86	-53,81	142
S12	127,75	94,03	33,72	133
S13	96,56	81,71	14,84	135
S14	105,30	80,78	24,52	109
S15	120,27	97,82	22,45	109
S16	97,02	80,81	16,21	190
S17	111,03	149,52	-38,49	133
S18	111,76	157,52	-45,75	122
S19	104,11	80,45	23,66	120
S20	120,81	84,12	36,68	199
S21	131,77	86,54	45,22	118
S22	100,12	51,14	48,97	110
S23	132,89	8,23	124,65	123,1
S24	108,61	6,66	101,95	123,1

Table 24: Energy consumption

Even though this are solutions of a relatively good quality, it is possible to achieve better solutions quality with faster and more stable optimizing software, such as the MILP optimizer Gurobi. This better software does not have a free industrial license though.

2.2.5.5 Task 5.5: Short term power scheduling on line model development and relevant validation

The developed model is general enough to deal with extraordinary events, such as a machine failure during the daily process. In this case, to obtain a rescheduling, it is possible to restrict the inputs of the model to the remaining products (not yet processed), taking into account only the available machines and the remaining time slots of the time production range. The algorithm is run again with this restricted input and outputs a new schedule of products.

2.2.6 Work package 6: Dynamical access to the power market through an Agent System aimed to support the Decision Makers

This WP aims to develop an integrated system based on the concept of multi-agents enabling a more flexible system which gives the possibility to better exchange information between processes and energy markets in order to build the basis for a continuous adaptation of the production based on the opportunity offered from the market and the state of the processes.

2.2.6.1 Task 6.1: System requirements and automation landscape

This chapter represents the D6.1.

The aim of this task is to define the requirements originated from point of view of a steel producer. Starting from the analysis of the automation systems and the database infrastructure different possible application scenarios have been investigated in order to identify broad spectrum of requirements for the system to be developed.

Due to security reasons (from both perspectives IT security and confidentiality with respect to competitors) the low level details of the configuration are accessible only to the partners involved in the corresponding use case and are not presented within the report. In order to enable the common development and interchange between project partners the description is made on abstract and generalised level.

The automation landscape found in the plants is in line with Figure 106 where the different level of the automation systems, both related to processes and electricity management, are reported. As already described in the previous chapters the electricity part have been (or will be in 2016) enhanced by the acquisition of new smart meters to be integrated in the overall architecture.

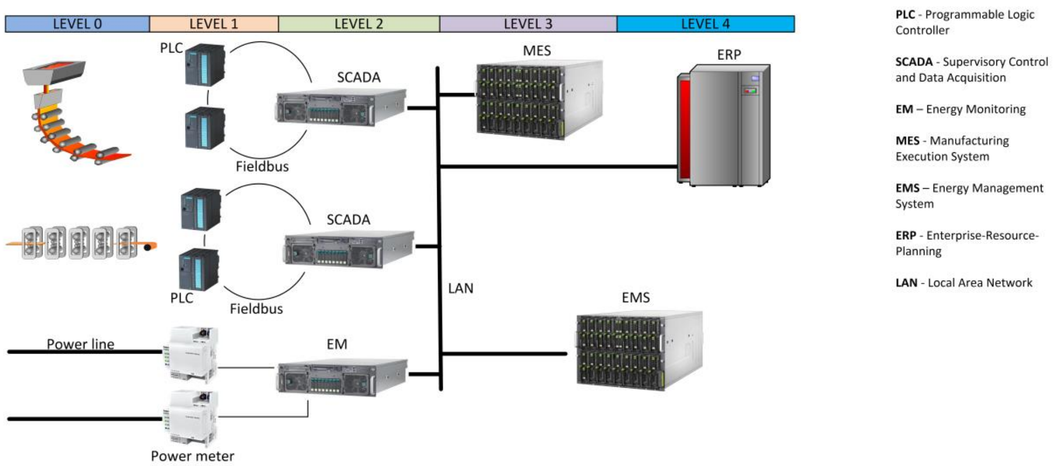


Figure 106: Automation landscape

From the databases point of view the founded situation was more heterogeneous due to the several processes that should be taken into consideration, the dimension of the plants and the level of implementation. In fact, as shown in the previous chapters, the level of data details available vary from one plant to another and therefore a special attention will be put during implementation phase in order to realize the more general approach as possible. Both BFI and CSM have already developed in other projects a general approach to the management of heterogeneous data sources and this knowhow will be applied in this project.

In Figure 107 the general schema for the integration of electricity data with process data is shown highlighting the necessary brick for the integration. The Level2 Databases are considered as input to the system and, as depicted above, specific software module will be developed in order to decouple DYNERGYSteel from the specific installation.

One fundamental point is the synchronization of data time stamp coming from different sources and therefore it is necessary to add an NTP server (where not available). Moreover available data have several time frames depending whether are part of automation, monitoring or planning systems. For the purpose of the project and depending on which electricity markets is approaching is necessary to maintain the same level of granularity. For the purpose of accessing the day-ahead markets it is also useful to have specific data related to products instead of times. We found that they are not available in all the plants and therefore when necessary to the specific use case the opportune elaboration will be added.

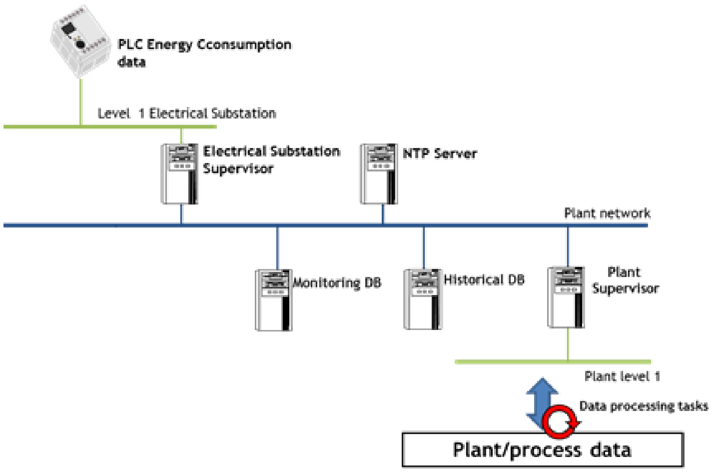


Figure 107: Data management architecture

The industrial partners identified first of all general goals for the systems covering major roadblocks in the current industrial systems. Following goals has been determined as most important:

- **Integration**: one of the major roadblocks during the development of new process optimisations is missing availability of information from different process stages and automation levels. Often such information are encapsulated within proprietary systems without open interfaces. Therefore one of the major goals within this project is to break the limitation of the information exchange by providing a flexible agent based system allowing an easy integration of different information sources within the common framework.
- **Extendibility**: a very important goal for DYNERGYSteel system is the possibility to easy extend the provided solution. In practice often occurs the situation where for a known problem a solution has been developed. After some time of usage or based on changes in the process the users gain the knowledge about additional optimisation potential for initial solution. To integrate these additional potentials usually a complete redesign of the system is required producing a high barrier for the practical realisation. Therefore one of the major goals is to provide the ability to extend the solution by new functionalities without the need of changes within the initial approach.
- **Customization**: the easiness of integration of DYNERGYSteel system within the plant is important from mainly two point of view:
  - User interface should be in line with the specific industrial habits with the aim of helping the introduction and the customer loyalty of the new system
  - interface to data should be easy to manage and independent from the core part of the system.

In addition to the global goals discussions with plant experts have been performed. The intention was to analyse the general user needs and expectations on the system with focus to problems originating from the practical experience of the users. In this context following specific goals has been identified:

- Energy cost optimization by more efficient planning with the inclusion of existing data from all the production processes.

- Comprehensive consideration of the production process by the decision for rescheduling and/or main or ancillary process conduction to catch energy markets opportunities.
- Decision-making for the production planning by means of strategies taking into account energy, resources, delivery time, throughput and costs.

Complimentary to the goals investigation we analysed different possible application scenarios in order to identify the specific requirements for the system. The scenarios have been investigated in collaboration with plant experts and refer to typical optimisation challenges. Following use cases has been considered covering different aspects of the DYNERGYSteel system.

- Production Planning evaluation: The base for the following use case is to have a clear idea of the energy necessary for the production based on the actual planning. For this purpose based on historic data and/or specific model the electricity necessary should be evaluated.
- Rescheduling: Target schedule can be modified to catch markets opportunities. Data for replanning is accessed, using material flow (rest), order situation and plant state. The system generates a new optimised schedule which is close as possible to the original one. Some possible measures are:
  - Modification of EAF conduction:
    - increase the power for complete actually production
    - decrease the power and increase the residence time without compromising the engagement in casting machine
  - Task change:
    - Select another compatible production for current heat in EAF that requires less energy to produce (ex: change steel grade)
    - Select another compatible production that requires less energy (ex: change heat routing or final product)
  - Machines switching on or off:
    - delay the scheduled tasks without affecting the quality of current production.
    - change actually production (ex: turn off VD and change final quality, turn off Mill and produce billet for stock, turn off EAF if production is started recently or if it’s possible manage the heat in LF)

The integration of such a new system necessitates the possibility to interact with several systems which works at different time scales: at the automation the time is the milliseconds, the production is in seconds and minutes, and at higher level for programming and logistics are hours and days. The system should be able to manage these different time scales with the right intercommunication services and agents.

Moreover the system will be used in Brown Field, the system should not disturb the existing system and slow down the production due to the wait.

Based on this analysis we specified the functional requirements including following aspects:

- **”Yellow pages”:** specifies the requirements for “yellow pages” functionality within the agent system. Yellow pages provide the ability to the agents to search for each other or to search for services provided by agents.
- **Software agents:** specifies the requirements for the agents themselves
- **Agent marketplace:** specifies requirements for infrastructure which regulates the agent negotiations
- **Communication with external systems:** specifies the requirements for the integration of the agent system in foreign environment
- **Communication between installations:** specifies the requirements for the collaboration of different installations of the system
- **Communication between agents and the market place:** specifies the requirements for negotiation procedure
- **Persistence:** specifies the requirements for the possibility to store data generated by the agents
- **Licensing:** specifies the requirements for ensuring the legality of the installation
- **Configuration:** specifies the requirements for the management of agent configuration
- **Logging:** specifies the requirements for the possibility to store log messages generated by agents
- **User interface:** specifies the requirements for interaction with operators
- **Debug:** specifies the requirements for the monitoring of agent communication allowing searching bugs.
- **Recovery: :** specifies the requirements for recovery of the system after a failure

For non-functional requirements we considered following aspects:

- **Performance:** the response time for the communication between agents
- **Interoperability:** the ability to run in inhomogeneous IT environment
- **Availability, Reliability, Recoverability, Robustness, Fault Tolerance:** stability of operation
- **Usability:** ability to integrate new functions in the system
- **Extendibility, Modifiability:** ability to add new agents at run-time
- **Testability:** ability to perform automated tests
- **Deployment and Commissioning:** requirements on installation procedure
- **Maintainability:** requirements on documentation and programming conventions
- **Security:** ability to encrypt the communication between external agents
- **Scalability:** ability to handle a growing demand on work

2.2.6.2 Task 6.2: System architecture and solution strategies

This chapter represents the D6.2.

The goal of this task is the development of the design for the agent software system, including the communication infrastructure, the interfaces and structural details of the solution. Additionally different approaches for the trading strategies are investigated within this task and solution strategies are developed.

A multi agent system (MAS) is a software system which consists of independent proactive entities, called agents. The objective of these agents is to find a solution for their own goals through communication with other agents. The agent based solutions are often used for complex problems which are very difficult to handle by single monolithic system. The idea behind the agent based approach is to break down a complex problem into a quantity of small problems which are easier to handle by single piece of software.

That means MAS is a paradigm of a software design which aims to subdivide complex software solutions in simple pieces of software, where the complexity arises through not coordinated communication of these pieces.

Generally a MAS consists of number of agents and their environment. An agent in a multi agent system is defined by some important characteristics:

- **Autonomy:** the agents are independent from each other and follow always their own objectives
- **Local view:** agents don't have the global view of a problem; they always try to solve their individual problems
- **Decentralisation:** there is no central instance which control the communication and activities of the agents

Further the difference is made between those types of agents:

- **Passive Agents:** agents without own goals, this type of agent provide typically some services to other agents
- **Active Agents:** agents with own goals, those agents try to find a solution for the own problem by asking the others for services, an active agent can also offer services to other agents.
- **Cognitive Agents:** agents which change their behaviour in dependence to the current situation. This type of agents have typically an internal state

As already mentioned in order to handle the communication between the different agents an agent environment is required. Within out conceptual design this environment is called Agent Management System (AMS) cp. Figure 108.

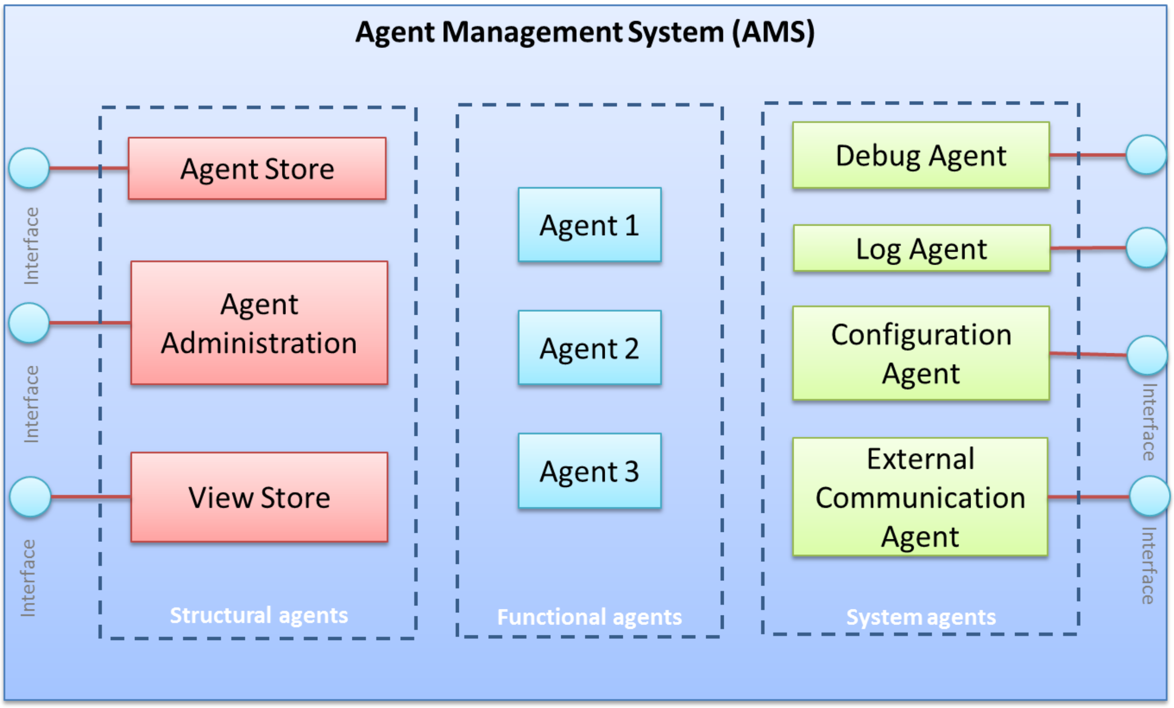


Figure 108: Scheme of the agent management system design

In our approach we followed the idea of "everything is an agent". This means that in our concept even structural components of the system are represented by dedicated agents. These agents utilize the same communication methods as the normal functional agents.

In doing so we differentiate between following types:

- **Structural agents:** This type of agents represents the structural components of the system. To this type belong following agents:
  - **Agent store:** this is an agent which manages the available agents inside the system. The goal of this agent is to analyze the existing libraries and to collect the information about the availability of the agents. This agent is also responsible for the creation of the other agents.
  - **Agent administration:** is an agent which manages the living agents. That means after the creation of an agent it is registered within agent administration and is consequently findable by other agents. Additionally the agent administration provides the communication interface allowing existing agents to exchange messages between each other's. Furthermore agent administration provides the functionality of "yellow pages" allowing the agent to search for available services and for existing agents.
  - **View store:** is an agent which manages visual components of the agents. That mean each agent can have different GUI (graphical user interface) components which represent the state of an agent. "View store" collects automatically the information about the available user interfaces and is responsible for their administration.
- **System Agents:** This type of agents represents some special system relevant functionalities. To this type belong following agents:
  - **Debug agent:** This agent provides the possibility to analyze the communication between other agents. Once it is started it collects the information about messages exchanged between the different agents and shows this information graphically allowing users to analyze and to debug the function of the other agents.
  - **Log agent:** provides the logging capability to other agents. It receives the log messages of other agents and takes care for their storage.
  - **Configuration agent:** This agent manages the configuration of other agents. It is responsible for the storage of the configuration during the shutdown phase and for loading of the configuration during startup phase.

- **External communication agent:** This agent provides an interface for external application, which can be either external agent or a coupled agent system. It manages the communication between the external systems and internal agents including the communication protocols and data coding.

- **Functional Agents:** represent the user defined agents which provide the functional scope of the system according to the usage scenario.

For the realization of structural and system agents dedicated interfaces are foreseen inside the AMS. These interfaces allow the structural and system agents to couple with the AMS and to offer the desired functionalities. This concept provides a high flexibility as far through this loose coupling the system relevant agents can be easily replaced when new functionalities are required.

Besides the conceptual design of the agent system also some trading strategies has been investigated within this task. This project aims to utilize the trading strategies of virtual markets in order to optimize or to balance the usage of the electrical power according to the situation on electrical power market or in dependence on requests of the power providers.

The idea behind the usage of virtual market strategies for optimization tasks is similar to the general objective of the agent system; the complexity reduction. That means the idea is to subdivide a complex optimization problem into simplified parts where the virtual market represent the platform for the combination of the different aspects. Further the market based approach is easier to understand for human users and enable people to follow the activities and decision of the market much easier than of complex algorithms.

The central mechanisms of virtual market approaches are the auctions. The market is by definition the place where the auctions are taking place. That means it is a virtual entity which will be represent by a functional agent inside our system. The auction is a process of buying and selling of goods or services.

In our concept an agent initiate an auction by asking the market place agent to establish an auction for desired good; this can be for example the release energy demand. In this case e.g. the energy consumers like lights or parts of machinery which are represented also by agents can participate on the auction by providing bids for their own energy release. Each particular agent can consider the own current situation, e.g. production state, the possible risks when disabling this parts and weight the bid with a personal factor or cost function.

Doing so at the end of the auction the initiating agent receives a list of disconnectable devices with information about costs and risks of the detaching. Based on this list the agent can calculate the optimal combination of devices to switch off.

Basically inside the virtual trading approaches different types of auctions are known providing different benefits in dependence to the requirements. In following same most popular auction types are presented:

- **Open ascending price auction:** is an auction type where participations bid openly against another, where each subsequent bid must be higher than the previous bids. The highest bid wins the auction.
- **Open descending price auction:** is an auction type where the price of the good is automatically descending based on a time scale, the first bidder wins the auction. In case of multiunit auctions the auction can continue until all units are distributed.
- **Sealed first price auction:** within this auction the participants submit simultaneously sealed bids, so no bidder knows the bid of any other participant. The highest bid wins the auction paying the submitted price.
- **Sealed bid second price auction:** is similar to the "sealed first price auction" with the difference the winner with the highest bid pays the price of the second bid.
- **Uniform price auction:** is a type of multiunit auctions, where multiple units have to be distributed to multiple bidders. Within this auction type each bidder submits the bids (multiple are also possible) designating the quantity and the price. After the end of the auction the winning bidders are selected based on the highest price and number of asked units (until all units are distributed). The price to pay per unit can then be either the highest price or the lower price of winning bids depending on the type of auction.
- **Double auction:** is type of auction where sellers and bidders simultaneously submit their offers and bids to the auctioneer (e.g. sell/ask *n* units for price *p*). Based on submitted propositions the auctioneer calculates the price per unit and serves the trades according to this price. (This auction type is typically used for stock markets)

In order to solve the optimisation problem of switchable loads in the meaning of energy balancing a type of uniform price auction is the most appropriated solution.

In general the energy management has a nature of a dynamic multi-objective problem where different events strongly influencing the production processes and changing the optimisation goals partial even in oppositional direction.

Figure 109 shows a scheme on dependencies between the influences and necessary reactions. According based on this scheme different optimisation tasks can be identified.

1. **Energy engagement:** defines the possibility to exploit the daily energy price fluctuation in order to shift the production with high energy demand to times with lower prices. In doing so a prediction of daily price profiles is necessary allowing adapting the production planning according to the price progression.
2. **Disconnection event:** describes the scenario where due to the low grid capacity production processes with high energy demand must be switched off in order to stabilise the grid. Accordingly in order to minimise the influence of the disconnection on the production processes the decision must be met disabling of which processes is more favourable. Anyway adaptation of production schedule considering the booked energy profile is necessary too.
3. **Enabling event:** due to the high volatility of the renewable energy it appears that the energy grid produces more energy than necessary. This leads to lower prices on the market up to negative prices as e.g. in Germany. In order to take an advantage of this it is necessary to be able to increase the energy consumption on demand. The idea is on one side to create buffers which can be released in high price phases but might be also used in order to shift the production of products with more energy demand in this phase. Anyway an adaptation of production schedule might be necessary.
4. **Surveillance of local limits:** The calculation of energy cost is typically done based on mean values for some time period. For example the cost can be calculated based on maximal value of 15.Min energy consumption average for the whole year as done at HHO. For the steel producer that means that they must prevent spikes in 15.Min averages. In doing so a prediction of the 15.Min average is necessary allowing meeting countermeasure e.g. by disabling of energy consumers. This also influences the production schedule.

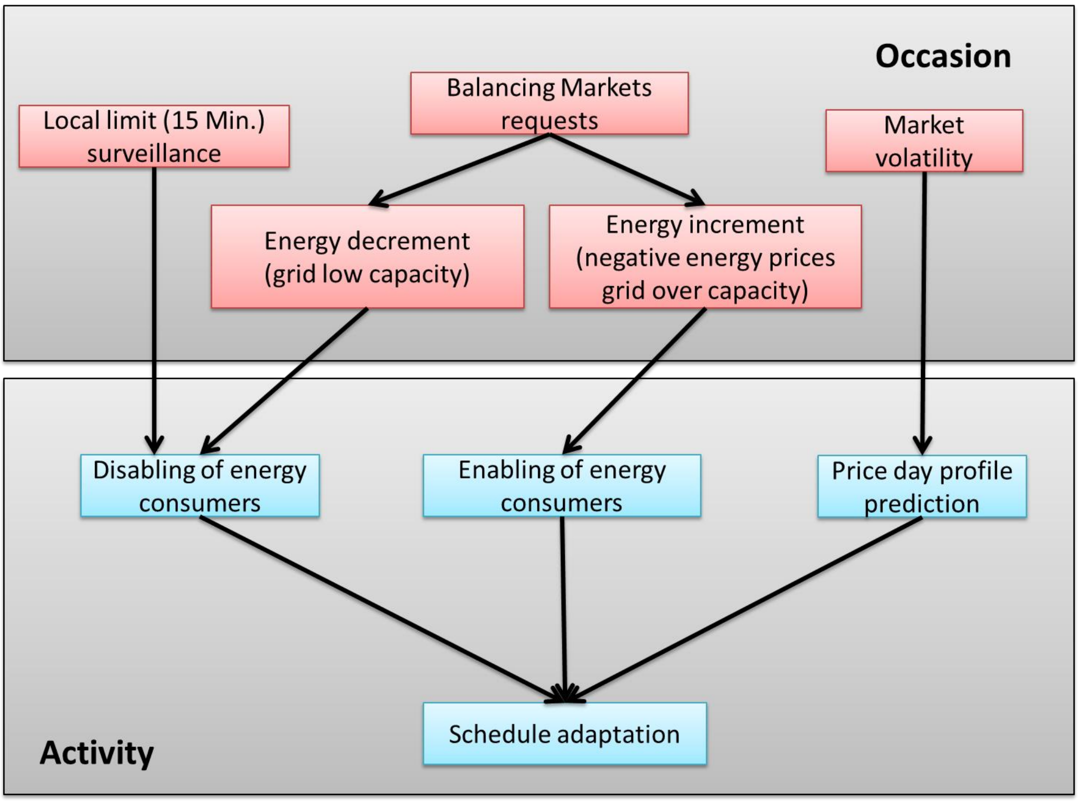


Figure 109: Influences and Reactions

As it can be seen from the Figure 109 all events have direct or indirect impact on the production schedule but with different objectives, sometimes increasing energy demand sometimes decreasing. For this reason in order to handle this optimisation problem the target function must be flexible adapted to the current situation.

Following, this optimisation problem can be seen as a global problem consisting of separated sub problems which are active or inactive depending on the given situation. This problem is perfectly suitable to be solved by an agent system. As it has been written in previous sections the main benefit of an agent system is that the agent based approach allows to separate a big problem into smaller sub-problems where the global solution is generated through the communication of the agents.

Figure 110 shows a generalised schema of the agent solution. Here different types of agents are foreseen which are responsible for various tasks. Difference is also made between active agents (blue) who act autonomously and passive agents (green) who provide only some services to other or represents the external interfaces.

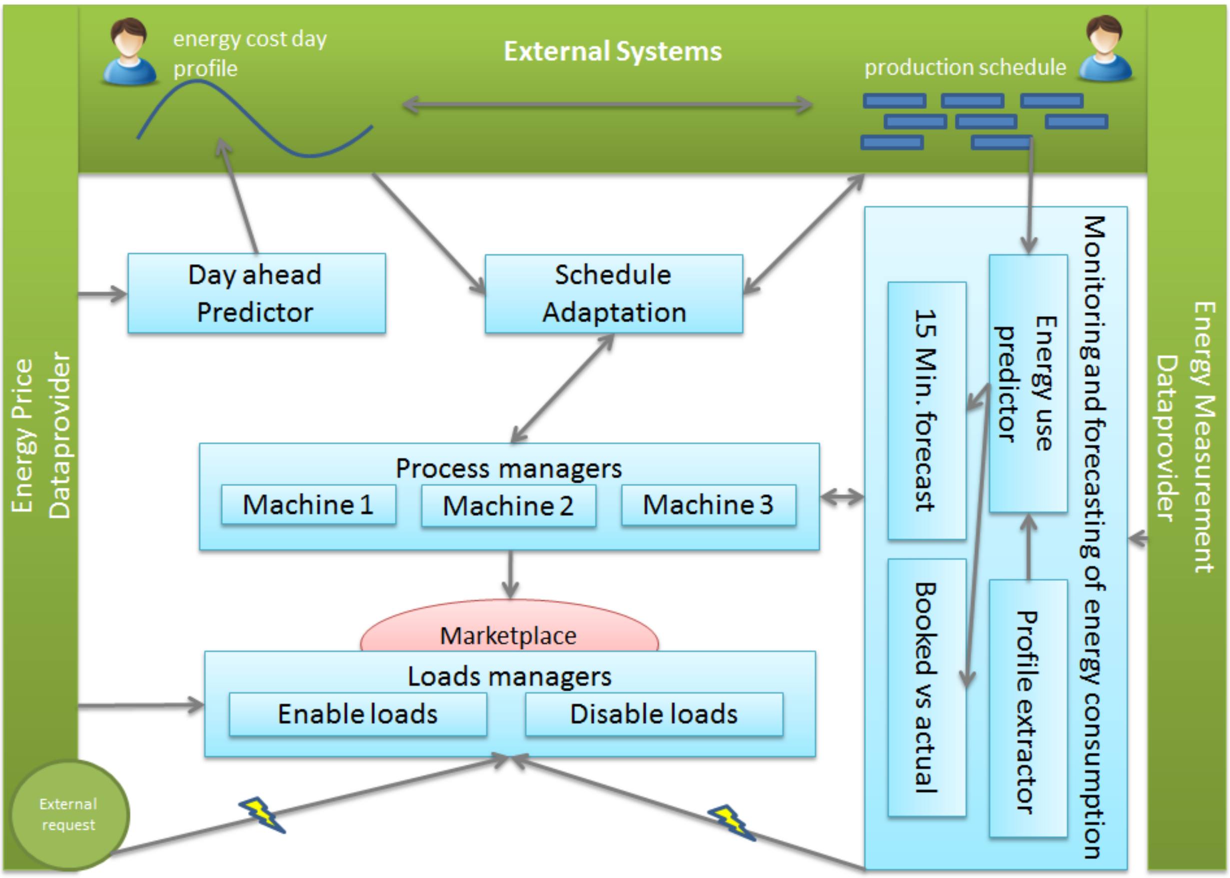


Figure 110: Scheme of agent infrastructure

The passive agents in this scheme are responsible for the communication with external systems and data management for example in order to provide price data of energy market or to provide information about energy measurements at the plant.

For the active part following types of agents are designated:

- **Day ahead predictor:** this agent analyses the historical courses of the energy price and generates a prediction of daily energy price profile. This information can be used by operators in order to make plans for the production schedule utilising the low price phases for production of products with higher energy demand.
- **Profile extractor:** is an agent who is devoted to the extraction and management of energy profiles for each type of product and each separable process based on historical data.
- **Energy use predictor:** calculates the energy demand based on a given production schedule and energy profiles (managed by profile extractor) on a daily base. The results can be used by operators in order to generate an energy demand profile to be ordered on day ahead energy market.
- **15 Min. forecast:** is an agent who is responsible for making predictions of energy consumption based on already consumed energy and foreseen energy demand defined by production schedule and product energy profiles for the current 15Min slot. This information can be used in order to avoid the 15 Min. spikes through the disabling of flexible loads or shifting of production phases.

- **Booked vs. actual:** This agent is devoted to the monitoring of booked energy profile and comparison with the actual energy consumption. In cases of bigger deviations this agent should meet countermeasures e.g. by asking for enabling or disabling of flexible loads.
- **Enable Loads / Disable Loads**: both agents have a similar functionality but with different objectives, one is responsible for enabling of loads and the other for disabling. From the functional perspective each of them utilise the marketplace in order to select the desired loads. The trigger for the activation is generated either by an external system or by another internal agent. In case of the activation the agent creates an auction on the marketplace asking the other agents (here representatives of the machines) to generate the bids for disable/enable loads providing also cost function for the utilisation of the bid.
- **The machine agents** as the representatives of the real energy consumer, knows intrinsically about the available load and are able to provide the bids to the load managers. Based on provided bids the agent is capable to select best combination of machines to be enabled or disabled.
- **Schedule Adaptation:** is an agent which is responsible for the adaptation of the production plan in cases when a change becomes necessary e.g. by disable loads event. The adaptation is performed considering the existing production plan, the relating constraints and booked energy profile for this day utilising KPI developed in Task 5.3.

2.2.6.3 Task 6.3: Software development and implementation of strategies and algorithms

This task is devoted to the implementation of agent system core components as well as adaptation of the algorithms to the different use cases. In general this task can be seen as integrative tasks which combine the results of previous work packages to a common approach, providing generic algorithms, which then are adapted to corresponding application scenarios.

Concerning the core parts of the agent system following agents has been implemented: "AgentStore", "AgentAdministration", "ViewStore", "DebugAgent", "LogAgent", "ConfigurationAgent", "ExternalCommunications" according to their description presented in previous chapter. Figure 111 shows a screenshot of the system, showing different views of the system agents which can be flexible arranged within the main window. Mentionable is here the "DebugAgent" who allows tracking the communication of other agents. In the presented example two test agents "PingAgent" and "PongAgent" has been created which just send a message to each other in order to test the communication interface. The "DebugAgent" presents a progress of the communication on a time line allowing the analysis of messages.

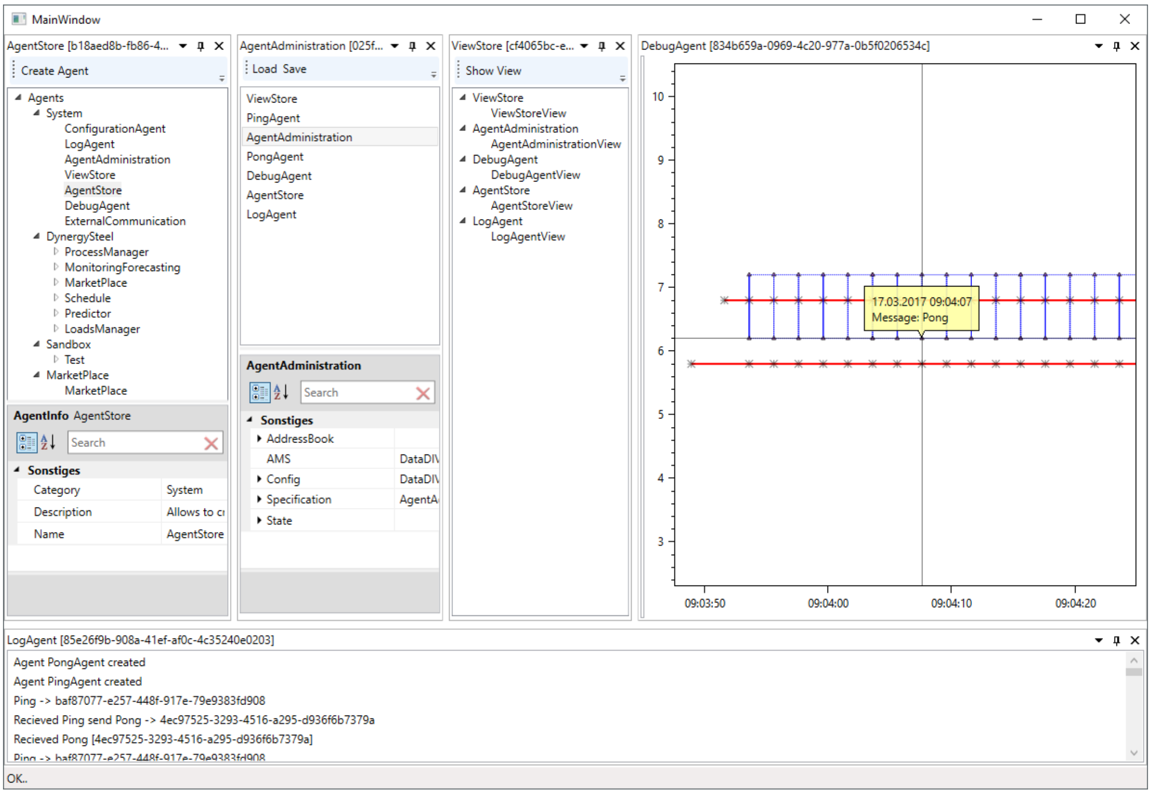


Figure 111: Screenshot Agent System "Core parts"

Referring to functional aspects of the global approach following components have been developed:

Profile Extractor (extracts energy profiles from historical data on a product and process base): This Agent is mainly used for processes, e.g. rolling mill, were the energy demand profile can be predicted with a sufficient level of reliability and is useful for the evaluation of very short time energy demand. Figure 112 shows examples of the extracted profiles from hot rolling mill process for three different products. The thin lines represent the originally measured profiles, while the thick line represents the average of the measured profiles determining the generic profile for the corresponding type of products. The administration of extracted profiles is done currently on file base that means all profiles are stored in a CSV (Comma-Separated Values) text file, which can be either imported by excel for manual review or evaluated automatically by the described agent.

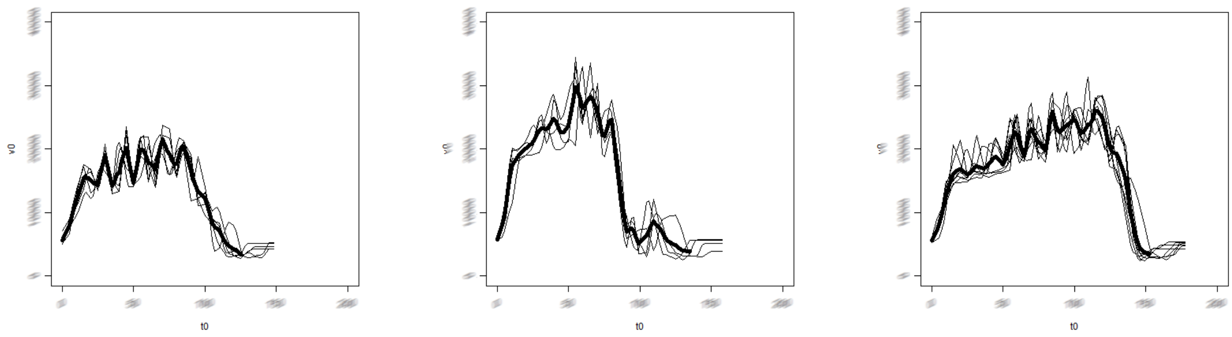


Figure 112: Examples of energy profiles for three different products from hot rolling mill

Energy demand profile calculation: The energy demand predictor utilizes the extracted profiles or a flat profile together with a given production schedule to predict the energy demand. The approach developed in Task3.3 has been integrated into the agent.

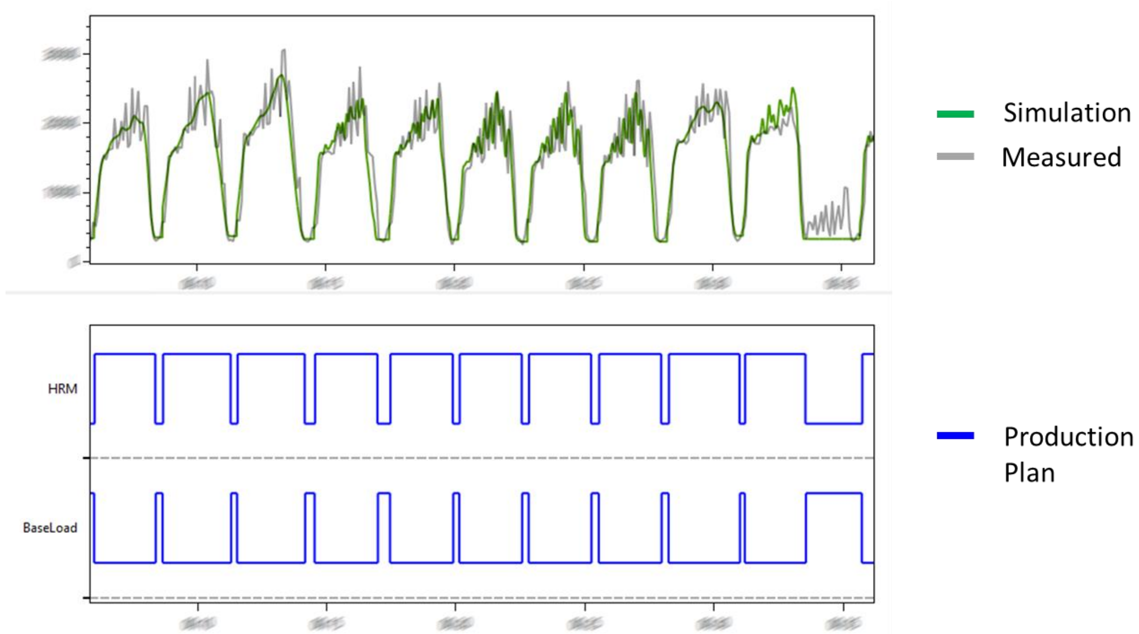


Figure 113: Example of energy demand prediction based on generic profiles and production schedule

Figure 113 shows an example of the production simulation where the green line represents the simulated result based on generic profiles while the grey line shows the real measured signal. The blue line represents the production plan for corresponding process step. The developed component is able to simulate energy profiles consisting of arbitrary amount of sub processes.

15min forecast: Calculates the already spent energy within the current 15min. slot and utilize the energy use predictor to calculate the prediction for the remaining part of the slot. In case of “fast” processes (less than 15 minutes) the production schedule is also taken into consideration.

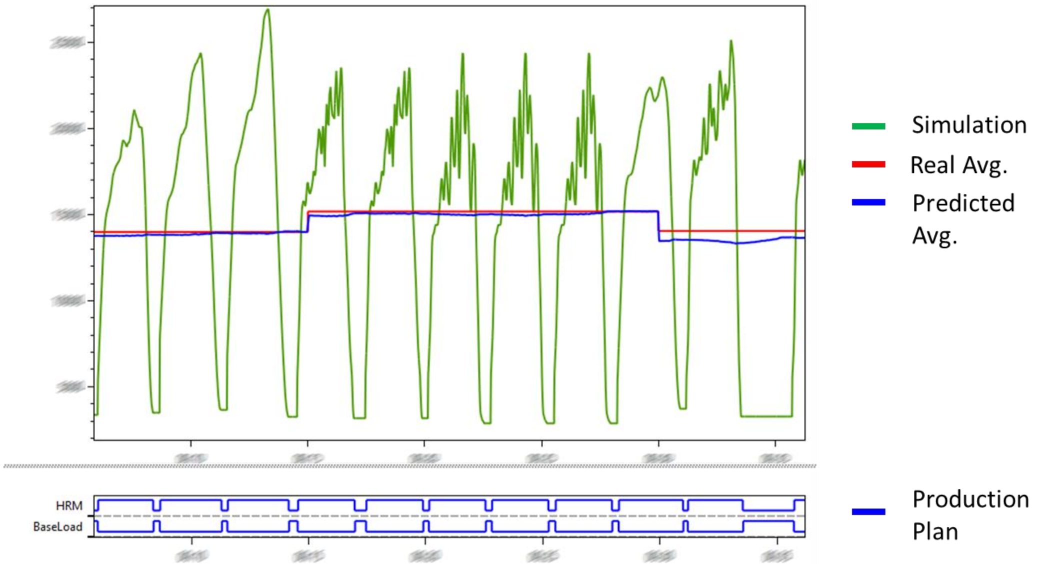


Figure 114: Example for the 15min. peak forecast

Figure 114 shows an example for 15min. peak forecast. The red line represents the real 15min peak, while the blue line shows the prediction at each time step.

Booked vs. actual: calculates the KPI based on algorithm defined in Task 5.2/5.3

Machine Agents: represents the machines participating in auctions for enabling or disabling

Loads manager: utilize the marketplace in order to select the machines to be enabled or disabled depending on request.

Day ahead predictor: represents the prediction of energy price profile based on historical market data and according to the model developed in WP2.

Schedule adaptation: represent the adaptation of the schedule in cases when a change becomes required according to model developed in Task 5.5

2.2.6.4 Task 6.4: Installation of the software tools into the plants infrastructure

Thanks to the agent architecture adopted the specific agents necessary for each plant has been integrated in the industrial infrastructure.

In particular the possibilities to limit the 15 minutes peak has been implemented on all the industrial partner site. AST and ORI have also focused on the limitation of the imbalance, while LSW and HHO tested the possibility to access the balancing market, enabling of additional loads at HHO (see Task 4.6 for more details) and disabling loads at LSW (see Task 6.5 for test results).

<u>15 Minutes peaks limitation</u>

Within this part the agent approach has been utilized in order to predict and limit the 15 Min. peaks based on energy profiles and under consideration of production schedule. The general approach has been already described in previous chapter (Task 6.3). The final solution covers following functions:

- **Collection and storage of energy consumption data.** This part implements the interfaces to the energy management systems capturing the energy consumption data in real-time regime. The data is then stored and utilized by other agents e.g. for profile extraction.
- **Extraction of energy profiles per product (coil).** This part includes the algorithms for the profile recognition as well as for the assignment of the profile to the produced product.
- **Management of profile storage.** The system stores up to 50 profiles per product type in a bunch by continuously replacing the oldest profile by the newest one. The mean profile is then automatically updated based on profiles stored within the bunch.
- **Generation of forecasts for next one or two 15Min periods.** The behavior of this agent depends on the specific installation. For rolling mill the creation of forecast is based on production schedule originated from the furnace allocation and historical profiles generated by profile extraction. In cases when a profile is unknown a standard artificial profile is utilized. For EAFs the

calculation is based on the process models implemented in WP3. For the other processes the forecast is based on a projection of the actual energy demand continuously updated.

- **Transmission of the results to the control systems.** The predictions are stored in real-time within a production database. These information are accessible to the control systems which can induce a delay in production schedule or limit the power for a process or stop a process in cases when 15Min limit may be exceed.
- **User interface,** shows the current energy consumption data as well as the predictions graphically.

In Figure 115 a screenshot of the user interface for 15 Min. peak prediction installed on a virtual computer at the IT infrastructure of HHO and connected with plant databases and energy management system is shown. Within the user interface the current energy measures are shown as well as predicated profile and corresponding forecasts for 15Min average values for both current and next 15 Min. period.

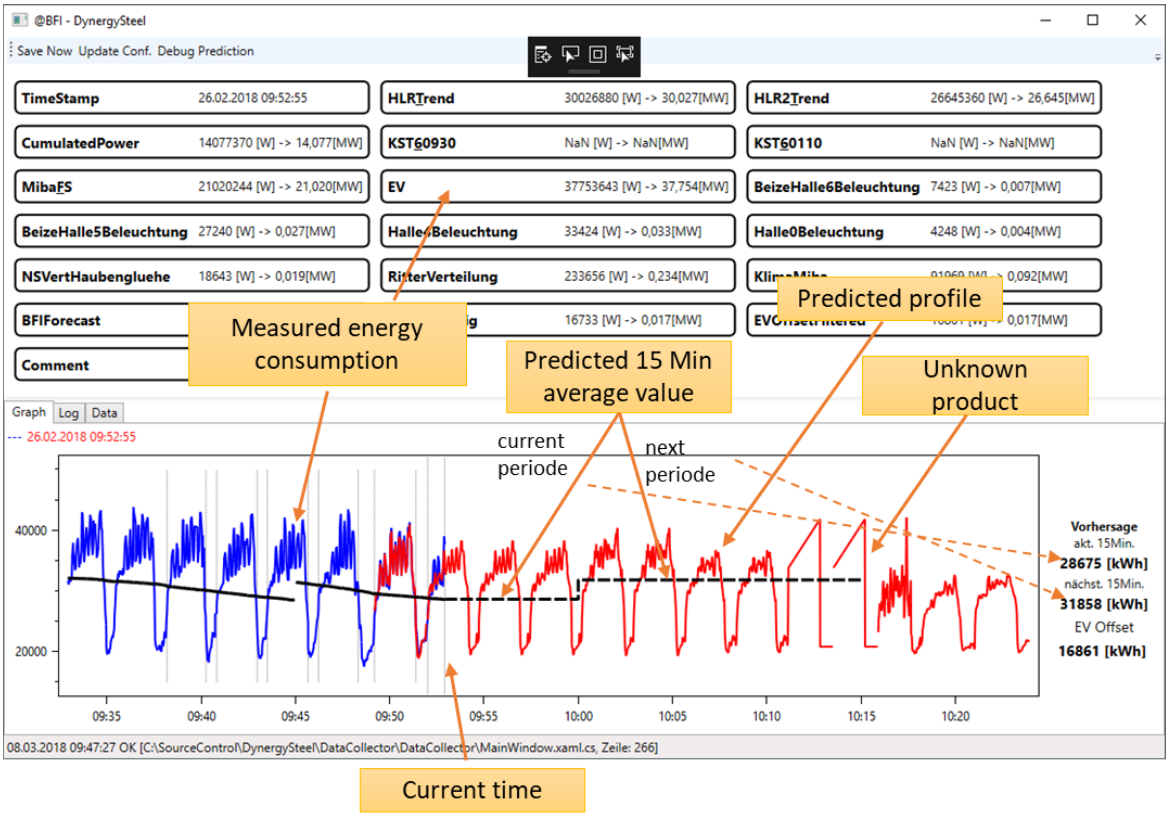


Figure 115: Screenshot of the user interface for 15 Min. peak prediction

In Figure 116 a screenshot of the user interface in AST to monitor the behavior of the system is shown in a 15 min interval where the EAF4 (F4) is stopped. The actual 15 min interval is presented where the green line represents the defined limit for the 15 min peak, the red line is the energy used in the whole plant and the yellow and light blue lines are the energy in the two EAFs that are continuously monitored.

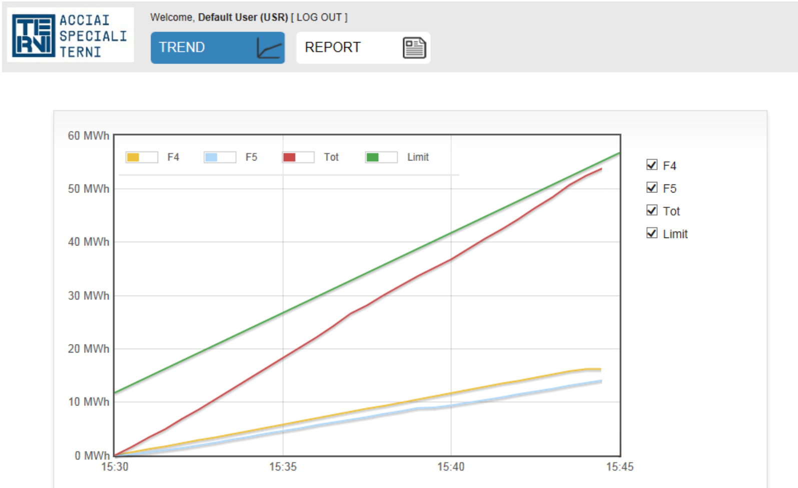


Figure 116 Example of 15 minutes peak control loop

In Figure 117 a screen shot of the user interface of the system at ORIMartin is shown. Actual and previous 15 minutes interval is shown together with energy monitoring data of the whole plant.

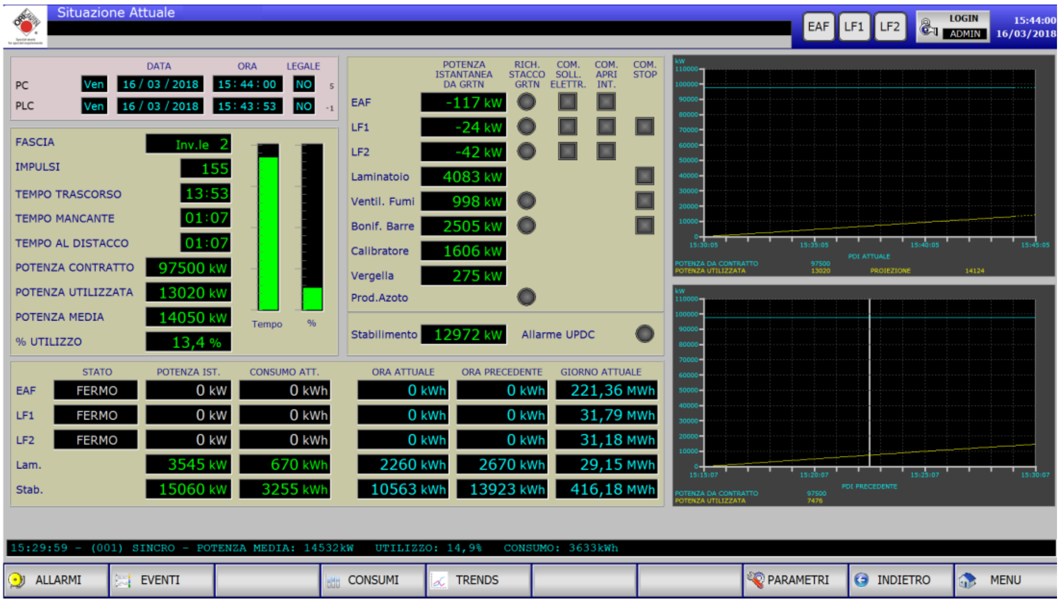


Figure 117: user interface for 15 min peak management at ORI

<u>Lowering imbalance</u>

The aim is the lowering of the imbalance between booked and actual energy profile. For this purpose the following agent are necessary.

- **Historical data elaboration.** Calculation of energy consumption related not only to the specific process but also to the characteristics of the product according to the methodologies developed in Task 3.1.
- **Day ahead predictor.** Generation of prediction of daily energy price profile
- **Energy demand profile calculation.** Calculation of the energy profile interacting with production scheduler, historical data elaboration. The calculation are based on the model developed in task 3.3. The profile is integrated with the cost profile in order to evaluate also the economic point of view.
- **Energy Monitoring.** Collects and visualize the actual energy use by all the monitored machines.
- **KPI calculation.** The generated profile is continuously monitored and compared to the actual energy demand and the KPIs are calculated according to implementation done in task 5.3.
- **User interface,** shows the current energy consumption data as well as the predictions graphically.

In Figure 118 a screenshot of AST user interface is shown where the first two lines indicating the hourly total energy demand and the energy cost calculated by the DYNERGYSteel system have been added to the steel shop planning user interface already used by the plant in order to minimize the impact on the final user. In the rest of the plant downtimes have been taken into consideration according to the planned process stops inserted by the operators. The overall plant energy profile is then prepared by the system and sent to the energy manager who are in charge of interacting with the energy provider to buy energy on the day ahead market. The user interface are web based and are accessible from any PC on the LAN. When the Intra Day (ID) auctions are opened the energy manager can rearrange the energy profile in order to minimize the imbalance. The continuous energy monitoring (Figure 119 and Figure 120) together with evaluation of the KPI helps the energy manager to decide whether to participate in the Intra Day auction.

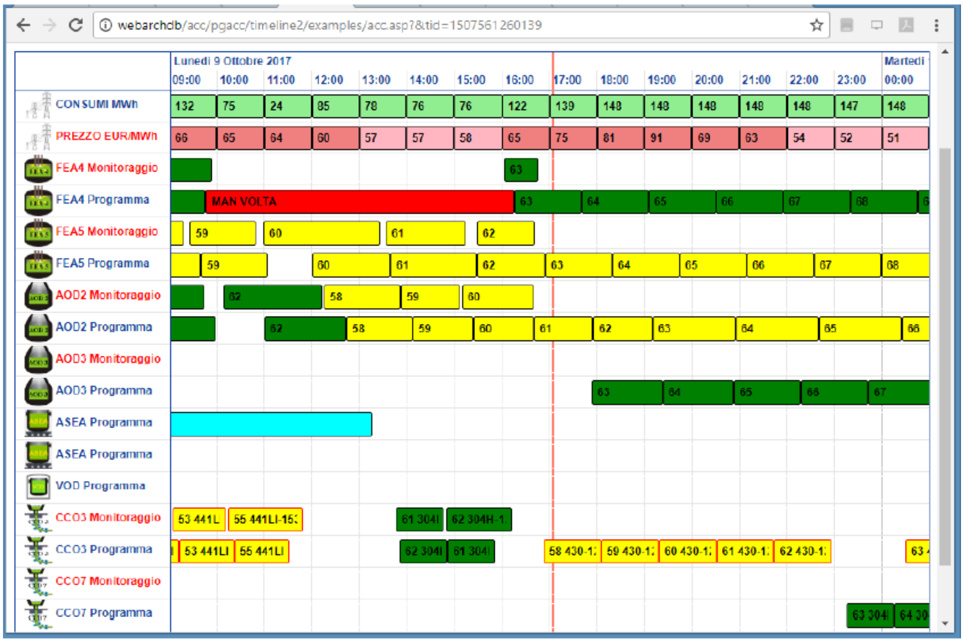


Figure 118: Forecasted AST steel shop energy cost and profile

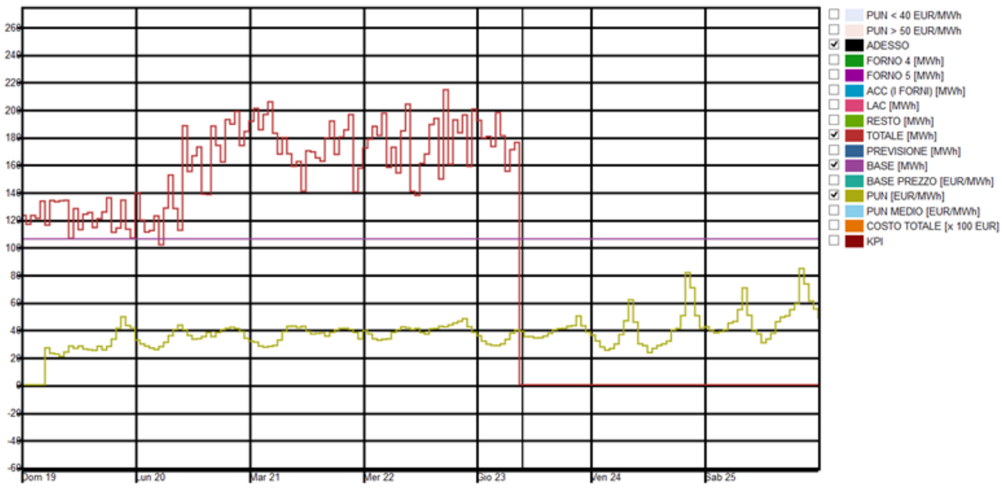


Figure 119: Energy monitoring at AST

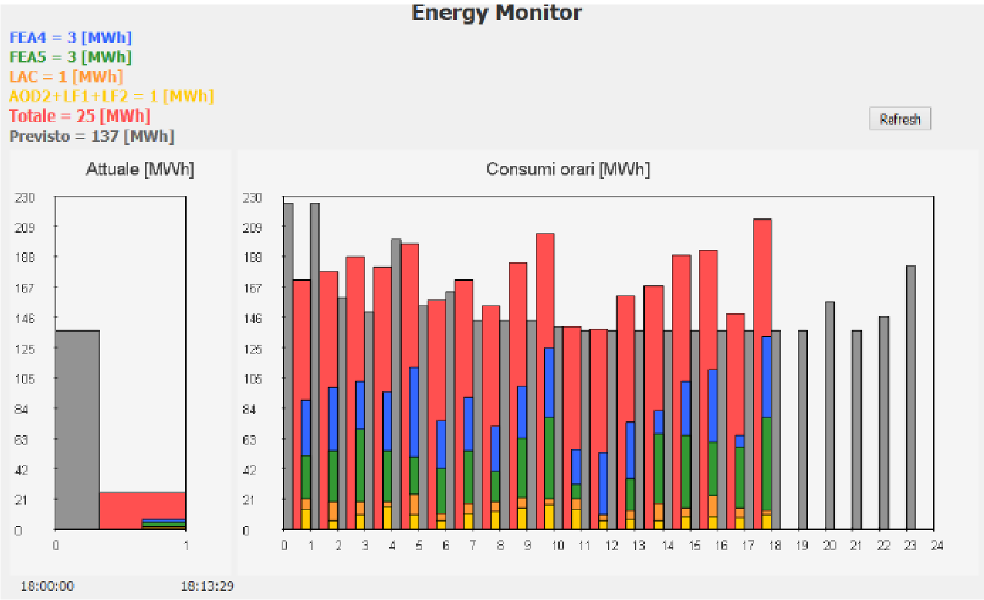


Figure 120: Steel shop energy monitoring at AST

2.2.6.5 *Task 6.5: Test and validation phase*

The developed system has been tested in the industrial partner sites according to the implemented use cases.

15 Minutes peak limitation

At HHO for the analysis of prediction quality a data set of 7 days operation has been selected. From this original dataset some of 15 [min] intervals have been removed, in particular such where the continuous production was considerably disturbed. This is for example the case when change of rolls is taking place. Such intervals would essential falsify the analysis results, because in these cases the prediction is of course very bad (because the prediction algorithm assumes continuous production). Nevertheless, from the point of view of 15 [min] Peak avoidance is this situation uncritical. The energy demand during the roll change is much lower as during the production phase, so that the probability to exceed the limits almost does not exist. Finally 403 of 15 [min] intervals have been selected for the analysis, this correspond to more then 4 days of continuous operation and a production of approx. 2400 coils.

Figure 121 shows the course of the error at each time point of 15 [min] interval for each selected interval. Looking at that graph it can be seen that the error at the beginning of interval has much higher variance as at the end. This is logical, since the prediction at time point t is made for the residual of the interval time. That means at the beginning of the interval t=0 [min] the prediction is made for 15 [min] residual time while for example at t=10 [min] the prediction is made for 5 [min] residual time. Accordingly the accumulation of error is much higher at the beginning of the interval as at the end. Nevertheless it can also be seen that the main channel of the error is between +/- 6[%].

From point of view of 15 [min] peak avoidance the prediction quality at time t=10~12 [min] is of major relevance because the remaining time of 5~3 [min] is the time frame which allows to influence the production for example to delay the production of next coil.

Looking at course of the average of relative error (see. Figure 122) it can be seen that the average error E_{AVG} at the beginning of interval t=0 [min] is equal to E_{AVG} = 5.5 [%] while at the time point t = 10 [min] E_{AVG} = 2 [%]. Also it can be seen that the standard deviation of absolute error stabilize around t = 10 [min] which positively influence the applicability of the prediction for avoidance of 15 [min] peaks.

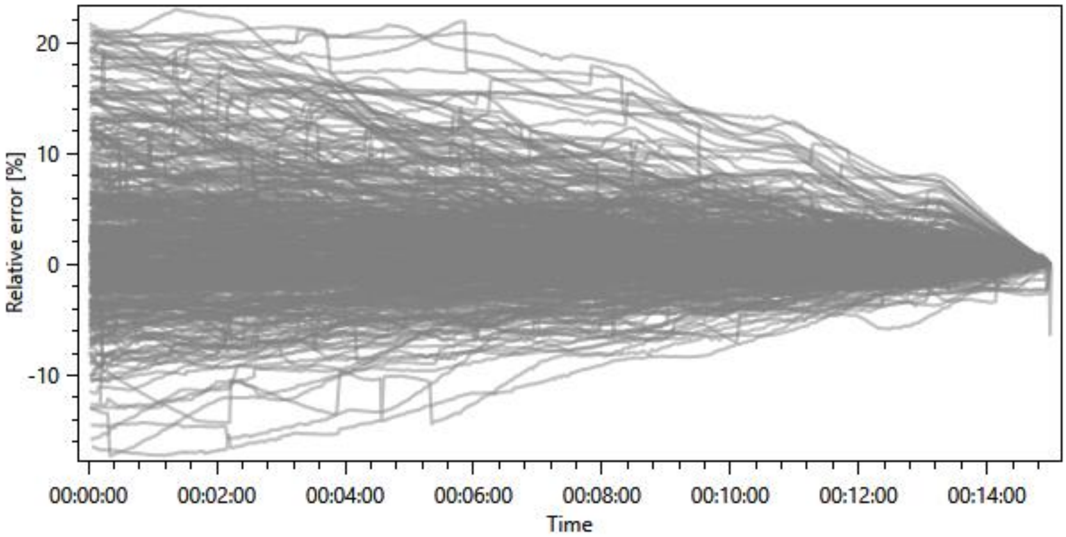


Figure 121: Error course for each selected interval

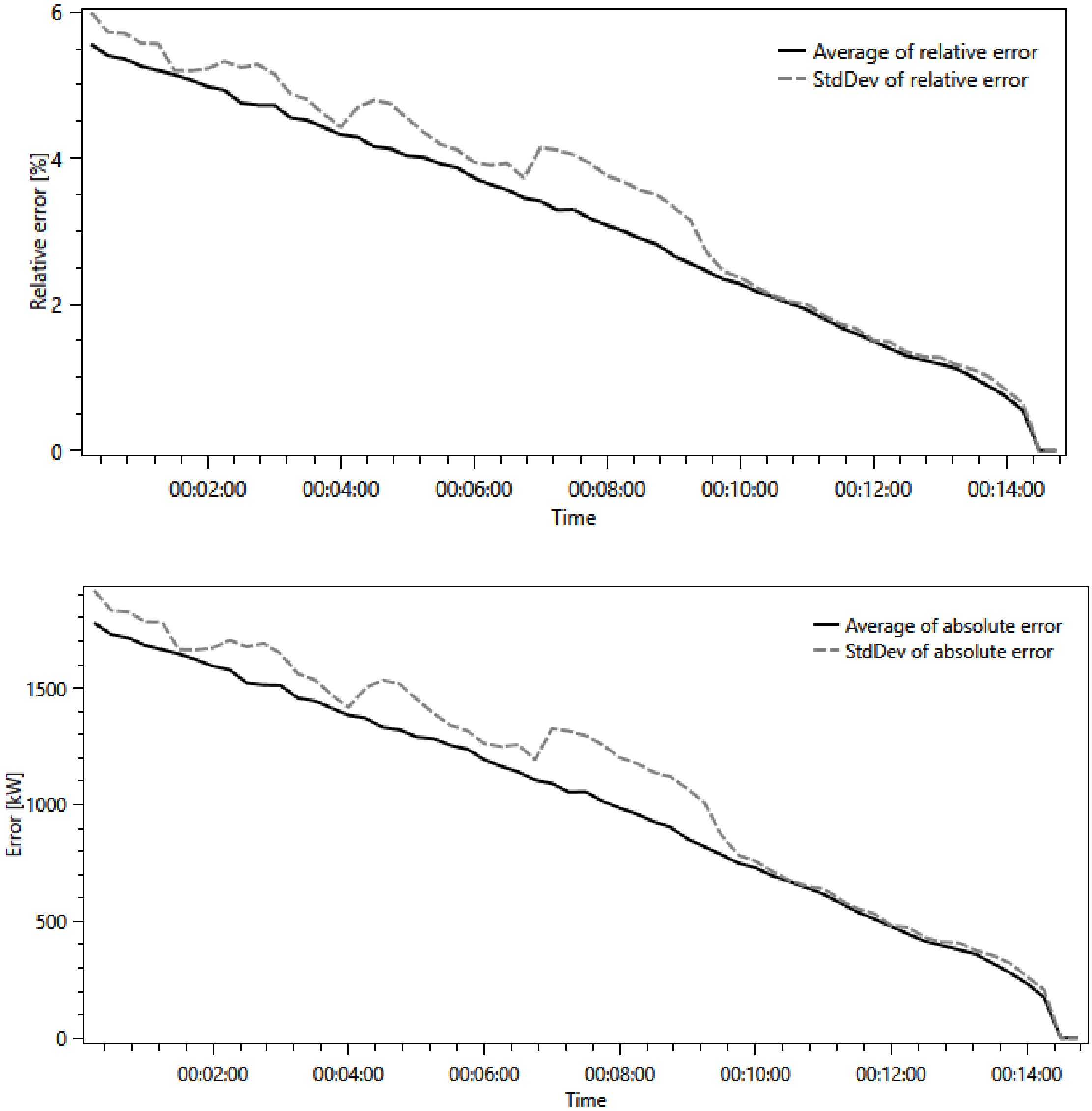


Figure 122: Average and standard deviation of relative errors

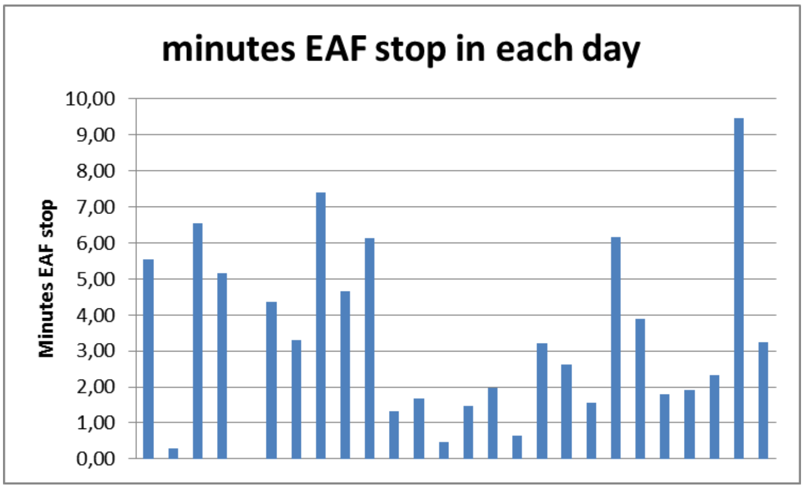


Figure 123 15 min peak result at ORI

Figure 123 shows the daily system intervention at ORI in terms of minutes of EAF interruptions during a month reaching the objective to maintain the 15 Minutes peak lower than 97.5 MW.

In Figure 124 the intervention of the system in terms of EAF4 and EAF5 stops at AST on some days of production is shown.

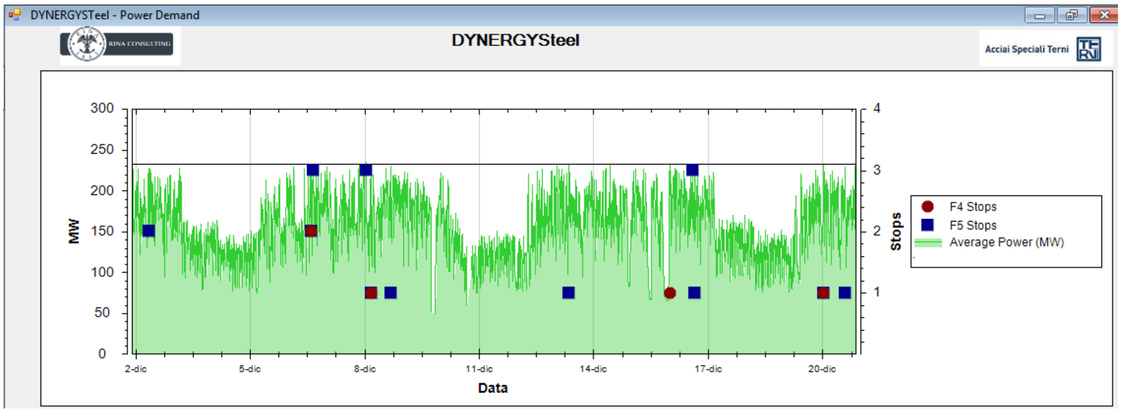


Figure 124: 15 minutes peak interventions at AST

In Figure 125 the result obtained at AST reducing the 15 min peak is shown. In particular the reduction of the peak from 268 to 226 can result on saving around 160,000.00 €/month considering 3,800.00 €/MW/month.

<u>Lowering imbalance</u>

The overall objective at ORIMartin is to maintain the imbalance lower than 15%. In such a way little money can be gained but mostly no fees will be charged from the electricity provider in the future for the imbalance. In 2017 the paid imbalance account for around 1% of the total electrical energy costs.
Initially only EAF was taken into consideration for preparing the forecasted energy profile, but the results was not convincing, therefore the focus has been put also on the rolling mill. The operators can insert the planned process stops due to strikes, unions meetings, vessel refractory lining, other foreseen maintenance and the corresponding plant energy demand. .

The overall plant energy profile is then prepared by the system and sent to the energy manager who are in charge of interacting with the energy provider. In Figure 126 the energy profiles for two examples days are shown. Around 10 o'clock on Day2 a manual downtime was inserted while the other differences between the two profiles are due to the rolling mill programme.

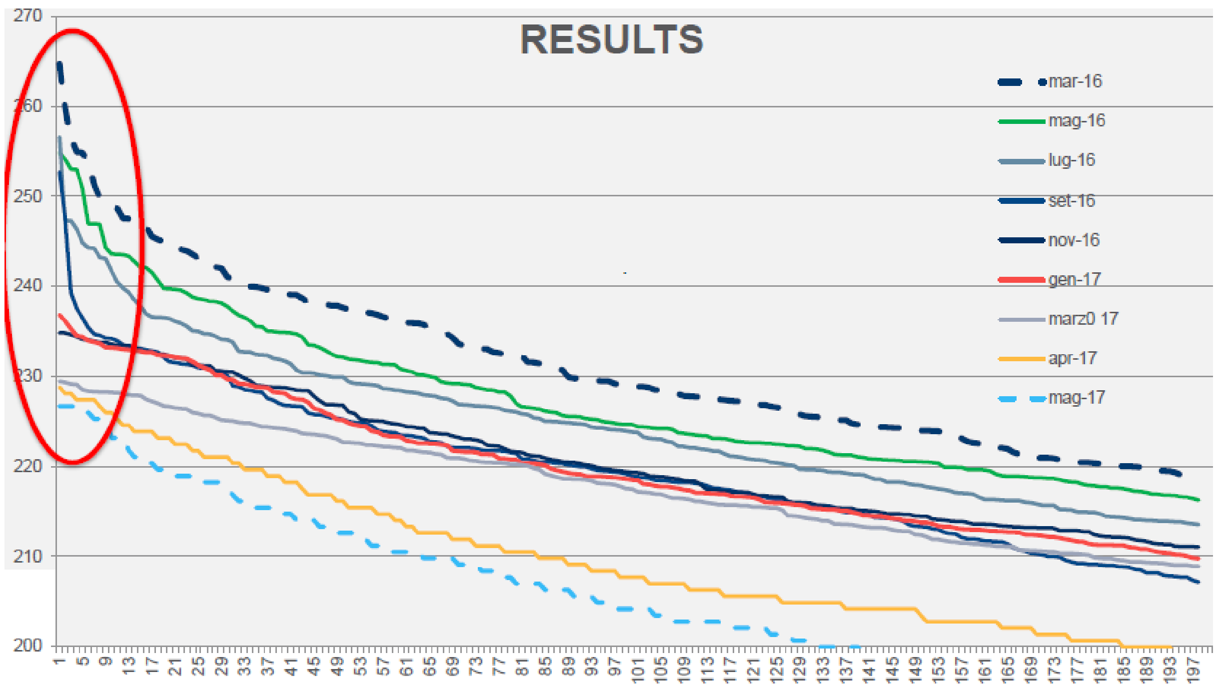


Figure 125: 15 min peak results at AST

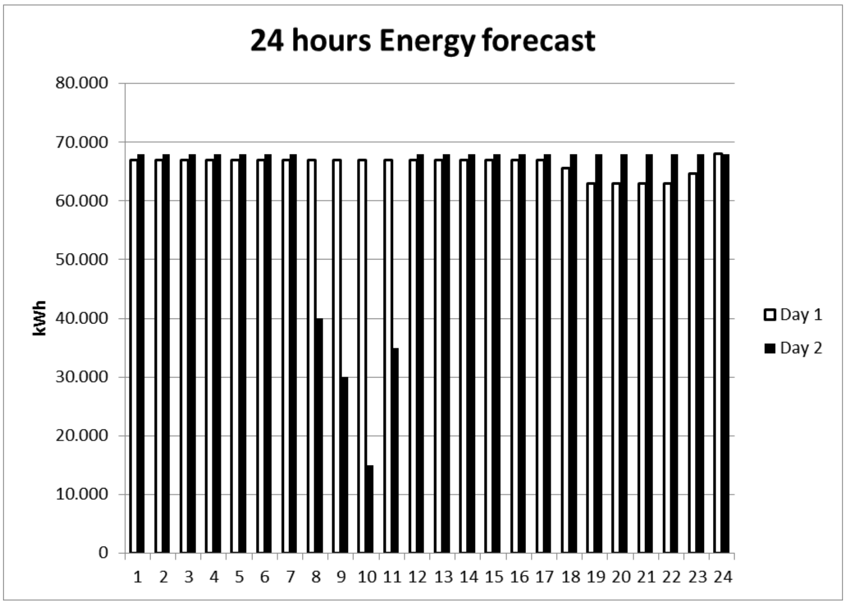


Figure 126 two days examples of energy forecast at ORI

Still the 15% goal was not reached and, therefore, the developed system needs further tune up for the evaluation of the specific energy needs. A simulation of this tune up based on two months production led to the following improvement of the imbalance

Working day (Mon-Fri) from 17,2% to 14,72%

Week end (Sat-Sun) from 15,31% to 14,14%

At AST the adoption of the new way to define the booking energy profile and the participation in ID market led to the following improvement of the imbalance

Hourly imbalance from 15,48% in 2016 to 11,71% in 2017

Monthly imbalance from 12,91% in 2016 to 10,40% in 2017

LSW oxygen-plant as a flexible load

Test period with the use of the oxygen-plant no. 2 as a flexible load

Based on a contract with ENERNOC as a demand response aggregator LSW started in January 2017 to offer the flexibility of the oxygen plant no. 2. Within their contract LSW and ENERNOC defined the principles to sell flexibility of both oxygen plants no. 1 and 2 with the following characteristics:

- The available load is a positive load, that means that the flexibility is created by a potential to "switch off" the plant. A negative load by a "switch on"-characteristic could not be offered in an automatic mode of operation.

- The offered flexible power load of the oxygen plants is limited to the following level
  - PVSA1: max. 1,7 MW
  - PVSA2: max. 2,0 MW

- In general LSW may offer two different types of flexibility:
  - SCR+ positive secondary control reserve
  - MR+ positive minute reserve (tertiary control reserve)

  LSW decided to operate plant no. 2 and offer SCR+ to the power market.

- LSW had to announce the disposability of the oxygen plant as a disconnectable load to Entelios in a defined schedule. The availability or the non-availability of the plant has to be declared for well-defined time slices of 4 hours duration. This declaration takes place at different times
  - for SCR+: at the day before for the next day, latest at 2 o`clock pm
  - for MR+: at Thursday 5 o`clock pm for the following week (Monday-Sunday).

- The time length of a "switch off"-interrupt must not exceed a maximum length of 45 minutes. It was defined additionally that a second successive action is only allowed to be realized after a time delay of 10 minutes at least.

- The aggregator sells the flexibility within the market for control reserve and may stop the plant automatically within that available time slices that have been declared by LSW before.

- The realized operation is rated afterwards. This calculation is always performed one day after the relevant time slot. At that time the real measured energy demand of the plant is considered in relation to the announced power consumption of the plant within intervals of 15 minutes. Differences between the real to the planned data are charged. A withdraw of the announcement of disposability is possible but it is penalized.

- LSW and the aggregator agreed upon two different fees for valuing the flexibility, once a Demand Charge DC (€ per kW) for placing the flexibility and an additional energy price EP that is paid for a real use of the flexibility.

- The demand charge DC_{LSW} (€) is paid to LSW for placing the flexibility. It is calculated according to the following formula

$$DC_{LSW} = Pow_i * PP_{iz} * SDC * CU_i$$

  In this formula the following factors are used:

  DC_{LSW} = Demand charge paid to LSW for placing the flexibility (€)
  Pow_i = Power used within the flexible measure of the machine i (kW)
  PP_{iz} = price paid by market to machine i in time slice z (€/kW)
  SDC = share of the demand charge earned by LSW (%)
  CU_i = capacity utilization of the machine i (%)
  The market price PP_{iz} differs a lot between the HT (Hochtarif) and NT (Niedertarif).

- The additional energy price EP (€/kWh) is paid to LSW for the time slices when the flexibility is used. EP is calculated according to the following formula

$$EC_{LSW} = E_{iz} * PE_{iz} * SEC$$

  In this formula the following factors are used:

  EC_{LSW} = Energy charge paid to LSW for creating the flexibility (€) E_{iz} = Flexible Energy created by the machine i within the time slice z (kWh) PE_{iz} = price paid by market to machine i in time slice z (€/kW)

SEC = share of the energy charge earned by LSW (%)

- The factors SDC and SEC include that both partners may split the total earnings so that every partner participates with his share in the results. The factor SDC is getting smaller if LSW declares the plant to be less available. Within a separate calculation for the factor SDC different targets can be included.
- LSW was allowed to define a minimum energy charge that had to be paid for an interrupt of the process.

Results of the test period January – July 2017

In 2017 LSW decided to use the oxygen plant no. 2 for a flexible production and to offer SCR+ to the control market. PVSA plant no. 1 could not be used for a flexible operation because it was not operating at full capacity at this time. The test period with PVSA2 took place in January to July 2017. The results of the single months of the test are shown below in Table 25.

Table 25: Results of a test period to use the flexibility of the oxygen plant PVSA2 at Lech-Stahlwerke

Period in 2017	Availability of PVSA2 for flexibility	Power load of PVSA2 (MW)	Relative Revenues (%)	No. of events of shut down	Total time of shut down
January	< 70 %	1,796	0,3		
February	< 70 %	1,777	0,4		
March	92,5 – 96,5 %	1,790	26,4		
April	> 99,5 %	1,788	36,4		
May	92,5 – 96,5 %	1,787	36,5	2	15 min
June		1,800		3	24 min
Total			100,0	5	39 min

LSW has got the following results and experiences from the test period:

- During January and February 2017 LSW offered the oxygen plant as disconnectable load only during the day time shifts, so that an engineer is available during a possible shutdown of the oxygen plant. As a result the availability as disconnectable load was less than 70 % of the total production. In this case no real economic result was obtained.
- Starting with March 2017 the disposability was announced on a 7 day 24 hour basis. The declared availability within the months March to June was > 92,5 % and high enough to obtain a relatively good demand charge DC_{LSW}.
- In May and June in total five interrupts occurred at the PVSA2. The interrupts had a length of about 6 -8 minutes and their sequence is shown in Figure 127.

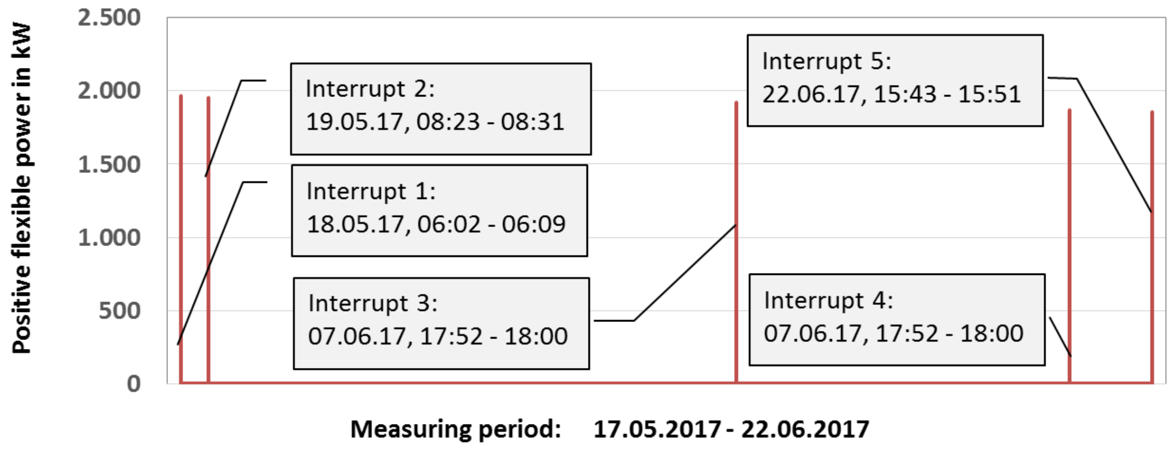


Figure 127: SCR+ interrupts within the test operation of PVSA2 in May and June 2017

- LSW found within this period of May and June 2017 that the automatic process of interrupt management did not work well. Two main problems occurred:
    - The first problem was the missing information about the end of an interrupt. The process managers did not get a signal that they could start the plant again. Therefore the stop of the plant was in some cases much longer than necessary.
    - The second problem was that the level of automation of the PVSA2 plant did not allow an automatic ramp up after an interrupt. Therefore additional personnel were needed in order to start the plant again. This caused sometimes an additional delay of the production as well.

  Because of the delays in plant operation LSW had to buy liquid oxygen in some cases, which caused high costs. It was not profitable to go on in this way. Therefore LSW decided to stop the test period. The PVSA plants will now be optimized so that they will be able to start and stop automatically in future.

2.2.6.6 Task 6.6: Adaptation of the system

The applications developed was running at the industrial partners site for several month. During this time the systems have been monitored both in term of functionalities and problems encountered. The results and the failures have been analyzed during the adaptation phase and the systems has been corrected ensuring the expected results and the stabile operation.

2.3 Conclusions

The analysis of the electricity markets highlights several opportunities to save money for the steel companies. In Day-Ahead & Intra-Day markets the opportunities are based on the possibility to take advantage from the oscillation of the energy price during the day and between working days and weekends / holidays. In Control Reserve markets the opportunities are related to the possibility to dynamically react to grid events providing ancillary (typically balancing) services. The interruptible loads (AbLa-IL) offer another opportunity.

SCR-TCR markets are going to be opened in Italy (pilot projects in 2017) and therefore the experience gained in this project, together with the participation of RSE, can help the Italian authority to better understand steel factories needs.

All the plants having at least an EAF highlight the importance of controlling this process and, more in general, the steel making area, due to the fact that it represents the main consumer of electricity inside a plant. A focus of the project has been also on the rolling mill area, not only for HHO, that doesn't have EAF. Managing these processes can help in minimizing the 15 minutes peak and differences between booked and used electricity. Opportunities to spare money are offered also from ancillaries participating in the balancing markets e.g. oxygen production, hall lighting, air conditioning including fan, cooling towers that can be more easily managed without interfering too much with the production.

The DYNERGYSTeel approach has been implemented and tested in the four industrial partner plan showing that the way taken already gives positive results (e.g.: control and limitation of 15 minutes peaks, imbalance limitation), however still other implementation or adaptations are necessary for further lowering 15 minutes peak and imbalance and participating more actively in balancing markets. Moreover, the energy markets are in continuous evolution and therefore should be monitored in order to be able to catch new opportunities when they arise.

2.4 Exploitation and impact of the research results

2.4.1 Actual applications

The system is actually installed in the four industrial partners plants with the aim of limiting the 15 minutes peaks load, minimising the imbalance between booked and actual electricity demand, test the participation of steel plant in the balancing market both upward-positive and downward-negative.

2.4.2 Technical and economic potential for the use of the results

Limitation of 15Min. peaks is of relevance for plant energy managers. This in particular important from the financial point of view. An exceedance of 1MW leads to cost of 70-90k€ per year (assuming a kW price of 70-90€ per year) in Germany. A limitation of 1MW lead to save 3,800.00 €/MW/month in Italy (40-50k€ per year). The possible earnings is strictly dependent from the energy optimization level of each plant wishing to go in this direction. Considering a plant aiming at reducing the peak by 1 MW and producing 1.000 ktonn/year a spare of 3-4 cent/ton could be achieved in Italy, while an increment of 1 MW for the same plant size in Germany will led to a cost of 7-9 cent/tonn.

In case of HHO a reduction of the max. peak by 1-1.5MW is possible due to the prediction capabilities of the developed system. The prediction can now be used in order to introduce delays in the production in cases when the limit threatens to be exceeded. This was not possible before, because it is not possible to stop the rolling process during the execution. It is only possible to introduce an additional pause between the rolling of two slabs. Accordingly, the time frame for the decision is between 5-3 minutes before the end of the 15-minute interval. The developed prediction module allows now to assume the final 15Min value and to react accordingly.

AST succeeded in lowering by 42 MW the peak load during the project. A further objective of 6 MW is in place.

In case of LSW, the installed SMART-LKA system will allow to distribute the peak load during a 15 min interval in a smoother way, thus avoiding in the future a complete shutdown of the four furnaces (2 EAFs and 2 LFs), by reducing just the power load of the EAF which is expected to exceed the peak limit. This will in the first place lead to a higher overall productivity of the electric steelmaking plant. On a long term perspective, the system will allow LSW to take part in a new contract system for energy supply called "Untypical use of electrical energy" (In Germany: Atypische Netznutzung). Here the peak load limit in the 15 min interval is reduced by 15 MW in the critical months of the year (December – February) during the critical times of the day (7:00-9:00 and 17:00-19:00), whereas for the remaining months of the year no restrictions of the peak load are applied. These restrictions could be easily taken into account by the SMART-LKA system by running the two EAFs in alternate mode. The cost savings for electrical energy supply which can be achieved with this new contact system are significant. Due to the required long-term analysis, it was not possible to prove these assumptions within the framework of the project. The system have to run for at least one calendar year avoiding all the peaks in order to provide the evidence. However, the obtained results confirm the possibility to generate this effect.

Lowering imbalance offers potential to spare more money, however it is difficult to precisely quantify the potential due to the multifactoriality of the cost determination. As an example in 2017 in ORI imbalance accounts for 1% of the total electricity costs.

Regarding flexible disconnectable loads, the results of the tests at LSW showed that it is possible to run the oxygen plant in a flexible operation mode. Technical deficits were identified that still have to be optimized because the plant must be able to be stopped and to be started again in a fully automatic mode. This optimization shall be done within a short time. LSW expects that the economic potential of flexible operations will increase due to the development of the power market in future. This can be expected not only in the market segment of primary or secondary control reserve but also in the market segment of untypical use of electrical energy due to § 19 StromNEV. Due to expected changes of the regulatory framework new ideas are discussed actually in Germany [42]. The result of the experimentation in HHO shows that it is possible to participate in the market, however the possible economic advantage depends strongly from the energy markets.

2.4.3 Publications / conference presentations resulting from the project

F. Marchiori, M. Lupinelli, B. Kleimt, H. Rosemann, J. Denker, A. Ebel, V. Colla, M. Benini, M. Pennesi, M. Freddo, U. De Miranda, R. Bontempi, R. Sternitzke, P. Stahlhofen, H.P. Markus Integrated dynamic energy management for steel production, Workshop on EU Funded Steel Projects 2 February 2016 Brussels

F. Marchiori, A. Belloni, M. Benini, S. Cateni, V. Colla, A. Ebel, M. Lupinelli, G. Nastasi, M. Neuer, C. Pietrosanti, A. Vignali, Integrated Dynamic Energy Management for Steel Production, 8th International Conference on Applied Energy, ICAE2016, 8-11 October 2016, Beijing, China

F. Marchiori, A. Belloni, M. Benini, S. Cateni, V. Colla, A. Ebel, M. Lupinelli, G. Nastasi, M. Neuer, C. Pietrosanti, A. Vignali, Integrated Dynamic Energy Management for Steel Production, Energy Procedia, Volume 105, May 2017, Pages 2772-2777

F. Marchiori, M. Benini, S. Cateni, V. Colla, A. Ebel, M. J. Neuer, L. Piedimonte, A. Vignali, An agent based approach for steel industries for exploitation of opportunities and challenges provided by energy markets, 3rd European Steel Technology and Application Days ESTAD 2017, 26-29 June, Wien

F. Marchiori, M. Benini, S. Cateni, V. Colla, A. Ebel, M. J. Neuer, L. Piedimonte, A. Vignali Agent-based approach for energy demand-side management, Stahl und Eisen 138(2018) Nr.2:25-29 · Februar 2018

2.4.4 Any other aspects concerning the dissemination of results.

The project was mentioned in:

STEEL PRODUCTION & SMART ELECTRICITY GRIDS, Jean-Pierre Birat - ESTEP, Bruxelles, Hervé Lavelaine - ArcelorMittal, Maizières, May 2014.

Smart Steel Research Fund for Coal and Steel : Supporting steelmaking and use in the 21st Century, February 2016

A description of the project has been published on some of the partners internet site and on personal pages of participants such as Linkedin.com and Researchgate.net.

3 List of figures

4 List of tables

5 List of acronyms and abbreviations

A list of acronyms and abbreviations used in the report and in the annexes

Acronym	Definition
AblaV	Abschaltbare Lasten Verordnung (Interruptible loads Regulation)
AC	Alternating Current
AEEGSI	Autorità per l'Energia Elettrica il Gas e il Sistema Idrico (Regulatory Authority for Electricity, Gas and Water)
AMS	Agent Management System
AOD	Argon Oxygen Decarburization
AST	Acciai Speciali Terni
AT	Austria
AUC	Area Under Curve
BCR	Balanced Classification Rate
BF/BOF	Blast Furnace/Basic Oxygen Furnace
BFI	VDEh-BetriebsForschungsInstitut
BSP	BSP Regional Energy Exchange
BST	BauStahl (Structural Steel)
CCGT	Combined Cycle Gas Turbine
CCM	Continuous Casting Machine
CET	Central Europe Time
CDE	Consegna Derivati Energia (Italian platform of financial contracts concluded on the derivatives market)
CH	Switzerland
CIRCABC	Communication and Information Resource Centre for Administrations, Businesses and Citizens
CNORTH	CENTER-NORTH
CSM	Rina Consulting - Centro Sviluppo Materiali
CSV	Comma Separated Value
DE	Germany
DIN-EN-ISO	Deutsches Institut Fur Normung(German Institute for standardization)-Europa- Norm-International Standards Organization (German Institute for standardization)
DISTR	Tariff for distribution services
DOE	Department of Energy
DSO	Distribution System Operator
EAF	Electric Arc Furnace
EC	European Community
ECC	European Commodity Clearing
EEG	Erneuerbaren Energie Gesetz (Renewable Energy Law)

Acronym	Definition
EEGI	European Electricity Grids Initiative
EEX	European Energy Exchange
EFSM	Electricity Flow Sheet Model
ENTSO	European Network of Transmission System Operators for Electricity
EP	Energy Price
EPEX	European Power Exchange
ESTAD	European Steel Technologies and Application Days
ESTEP	European Steel Technology Platform
ETS	EPEX trading system
EU	Europa
FN	False Negative
FP	False Positive
FR	France
GME	Gestore Mercati Energetici
GUI	Graphical User Interface
HHO	Hoesch Hohenlimburg
HLC	High Load Calculator
HMI	Human Machine Interface
HRM	Hot Rolling Mill
HSM	Hot Strip Mill
HT	HochTarif (HighTariff)
HV	High Voltage
ICT	Information and Communication Technology
ID	Intra Day
IDEX	Italian Derivatives Energy Exchange
IEA	International Energy Agency
IGCC	International Grid Control Cooperation
IL	Interruptible Load
IP	Internet Protocol
IPEX	Italian Power Exchange
ISE	Institute for Solar Energy
ISSN	International Standard Serial Number
IT	Italy
KO	Knock Out
KPI	Key Performance Indicator
KWKG	Kraft-Wärme-Kopplungsgesetz (Cogeneration Act)
LAN	Local Area Network
LCA	Life Cycle Assessment
LF	Ladle Furnace

Acronym	Definition
LKA	Last-Kontroll-Anlage (Load-control system)
LSW	Lech-StahlWerke
MAS	Multi Agent System
MB	Mercato del Bilanciamento (Balancing Market)
MGP	Mercato del Giorno Prima (Day Ahead Market)
MI	Mercato Infragiornaliero (Intra day market)
MILP	Mixed Integer Linear Programming
MIND	Method for analysis of INDustrial energy system
ML	Maximum Load
MOO	Multi-Objective Optimization
MR-MRL	Minutenreserveleistung (Minutes Reserve)
MSD	Mercato del Servizio di Dispacciamento (Ancillary Services Market)
MTE	Mercato elettrico a termine (Forward Market)
NAR	nonlinear autoregressive
NARX	Nonlinear autoregressive with external input
NAV	Niederspannungsanschlussverordnung (Low Voltage Connection Ordinance)
NEV	NetzEntgeltVerordnung (network tariffs regulation)
NRV	Netzregelverbund (System control network)
NRW	North Rhine-Westphalia (federal state of Germany)
NSRMSE	Normalized Square Root Mean Square Error
NT	NiederTarif (LowTariff)
NTP	Network Time Protocol
OCGT	Open-Cycle Gas Turbine
OH	Operation Handbook
ORI	ORI Martin
OTC	Over The Counter
PC	Personal Computer
PCE	Piattaforma Conti Energia (platform for electric energy traded Over-The-Counter)
PCR	Price Coupling of Regions
Phelix	Physical Electricity Index
PLC	Programmable Logic Controller
PRL	Primärreserveleistung (Primary reserve power)
PUN	Prezzo Unico Nazionale (Uniform National Purchase Price)
PV	PhotoVoltaic
PVSA	Pressure Vacuum Swing Absorption
QST	Quality Steel
RES	Renewable Energy Sources
RFCS	Research Fund for Coal & Steel
RSE	Ricerca sul Sistema Energetico

Acronym	Definition
RWE	Rheinisch-Westfälisches Elektrizitätswerk
SACOI	SArdinia–COrsica–Italy cable
SAPEI	SArdinia- Italian PEninsula cable
SCR	Secondary Control Reserve
SMOTE	Synthetic Minority Over-sampling TEchnique
SRL	Sekundärreserveleistung (Secondary Reserve Load)
SSSA	Scuola Superiore di Studi universitari e di perfezionamento sant'Anna
SVM	Support Vector Machines
SW	SoftWare
TCP	Transmission Control Protocol
TCR	Tertiary Control Reserve
TG	Technical Group
TGS	Technical Groups for Steel
TN	True Negative
TP	True Positive
TRAS	Tariff for transmission services
TSO	Trasmission System Operator
UCTE	Union for the Co-ordination of Transmission of Electricity
UHP	Ultra High Power
ÜNB	Übertragungsnetzbetreiber (Transmission system operators)
USA	Unites States of America
VAT	Value Added Tax
VD	Vacuum Degassing
VDEW	Verband der Elektrizitätswirtschaft (Electricity Association)
VDN	Verband der Netzbetreiber (Association of network operator)
VOD	Vacuum Oxygen Decarburisation
VPSA	Vacuum Pressure Swing Adsorption
WP	Work Package

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Annex 1

D 1.1 Description of the general and local electricity markets and tariffs in Italy and in Germany (Responsible RSE) (Dec 2014)

Summary

1 Executive Summary

A comprehensive analysis and evaluation of the opportunities to take profit from demand flexibility in electricity purchases by energy intensive industries, both in Italy and in Germany, has been carried out.

In particular, after a general description of the electricity market structure in the two countries, the study focused on the two main ways to purchase electricity by large industrial consumers, i.e.:

- through the Power Exchange;
- through contracts with a supplier.

Short-term[11] electric energy purchases through the Power Exchange can be carried out in the day-ahead spot market, that is typically the most important one, in terms of volumes of energy traded and of significance of the clearing prices, or in the intra-day spot market, where adjustments to the day-ahead market schedule can be done, in order to tackle with changes in the situation that occurred after the closure of the day-ahead market session and to avoid imbalances. For these reasons, the intra-day market typically deals with volumes much lower than the day-ahead one.

Within this context, a detailed analysis of hourly price profiles in the period between December 2013 and November 2014 has been carried out for the day-ahead spot markets of the Italian Power Exchange (IPEX) and of the German one (EPEX Spot). Several charts have been included in the report, such as price hourly values, monthly average, hourly average (annual and for each month), for all the days of the year and for working-days and non-working days only.

The charts reported in Figure Annex1-1 and in Figure Annex1-2, showing the Italian and German day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays, are the most significant ones. They clearly show how cheaper or more expensive can be to consume energy in each hour of each different type of day.

Price differences w.r.t. the average can be significant, ranging from about -18 ÷ +23 €/MWh in Italy and from about -15 ÷ +12 €/MWh in Germany, showing that there is a great opportunity to take profit from demand flexibility in purchasing energy from the day-ahead spot market.

As for the intra-day spot market, the Italian one is characterized by price profiles similar to the day-ahead profiles, while in the German one, that is a continuous auction, price profiles can be different from the day-ahead ones.

[11] We focus on short-term (day-ahead / hours-ahead) since it is the typical time horizon over which demand flexibility can more effectively be exploited. For this reason, we did not consider longer-term forward and future contracts in the analysis.

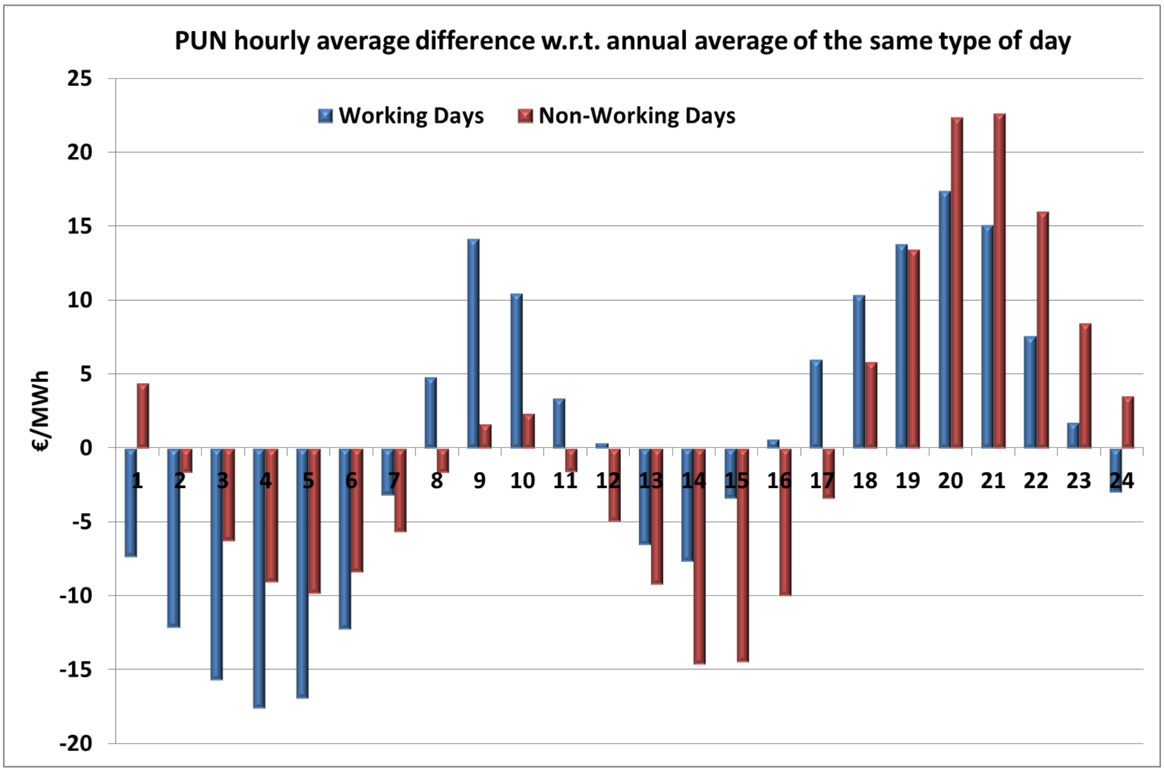

Figure Annex1-1: Italian day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on GME data).

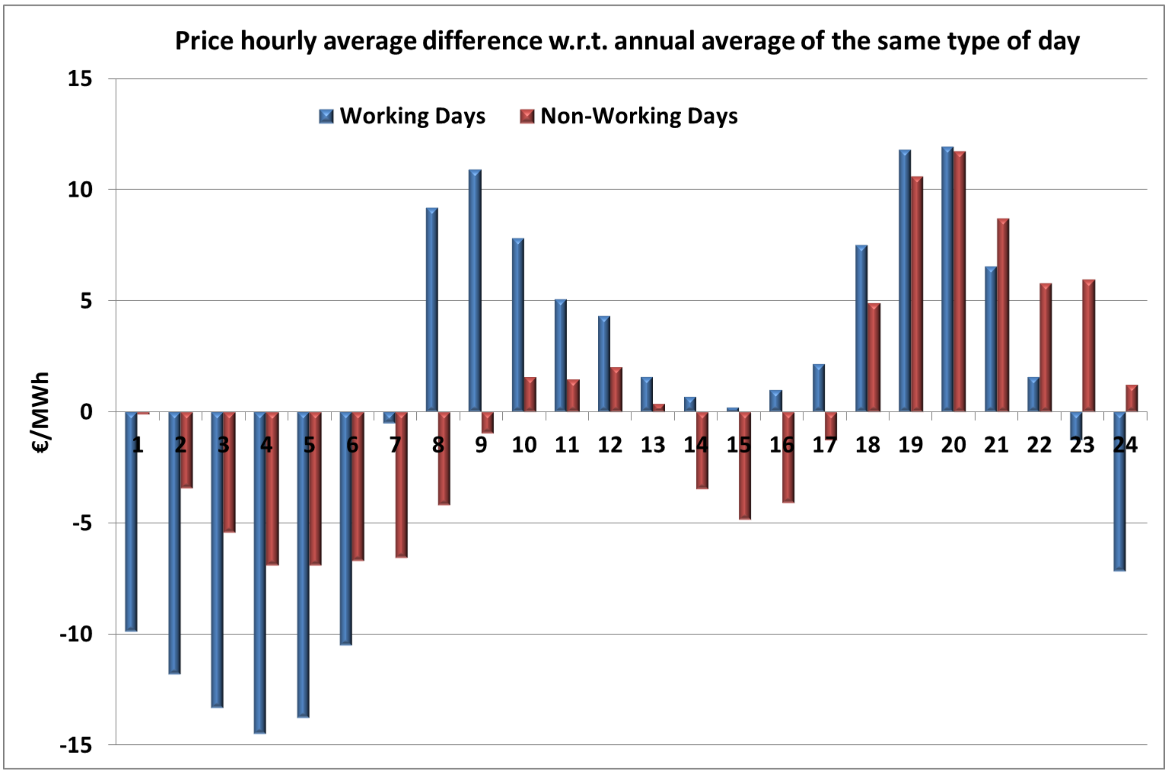

Figure Annex1-2: German day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

Instead of directly on the Power Exchange, energy can also be bought through a supplier, at an agreed price defined according to specific consumption profiles, or paying the energy at the day-ahead spot market price. In such a case, the foreseen consumption profile may have to be communicated to the supplier two days before the day of delivery, to allow the supplier itself to buy the energy on the day-ahead spot market, one day before the delivery.

In any case, contracts with a supplier are in general less flexible than purchases on the Power Exchange.

In case of deviations of consumption from the program agreed with the supplier or deriving from Power Exchange purchases, imbalance energy must be settled at specific imbalance prices. In the Italian regulation, prices are penalizing or profitable according to the concordance or discordance of the imbalance sign with the sign of the overall imbalance of the zone where the consumer is located, while in Germany imbalance energy is settled, for each quarter of an hour, at the price obtained by dividing the control energy costs sustained by the TSO in the balancing market in that specific quarter of an hour, by the balance of the deployed amount of control energy in that same time interval.

Apart from reducing the cost of energy purchases and of possible imbalances, demand flexibility can contribute to reduce peak power consumption and the related fees. In Italy, the fee applied to the monthly peak power consumption measured in any quarter of an hour of each month is currently equal to 1.528 €/kW-month, while in Germany the monthly fee ranges from 6 to 9.38 €/kW-month, or an annual fee can be paid, ranging from 35.99 to 60.79 €/kW-year.

2 Introduction

This report is the deliverable 1.1 of Work Package 1 of the DYNERGYSteel project.

Aim of the report is to analyze the opportunities to exploit demand flexibility to optimize electric energy purchases for large industrial loads in the Italian and in the German electricity market.

In particular, after a general description of the electricity market structure in the two countries, the study will focus on the two main ways to purchase electricity by large industrial consumers, i.e.:

- through the Power Exchange;
- through contracts with a supplier.

As for the Power Exchange, the different energy markets will be described and a detailed analysis of price profiles will be carried out.

As for the contracts with a supplier, the typical arrangements of the industrial partners of the DYNERGYSteel project will be analyzed, focusing on the flexibility margins that could be exploited by an active demand.

2.1 General electricity market structure

2.1.1 Italy

The electricity market was liberalized in Italy as a result of the approval of Legislative Decree 79/99, as part of the process of transposition of Directive 96/92/EC concerning common rules for the internal market in electricity. This decree, which marked the beginning of the structural reform of the Italian electricity sector, responded to the following needs:

- promoting competition in electricity generation, wholesale trading and retail supply;
- maximising transparency and efficiency in the natural monopolies, i.e. transmission & dispatching and distribution.

According to an open-market context, the above mentioned activities are carried out by separate entities (unbundling).

The entity entitled to guarantee the promotion of competition and efficiency in the sector, with regulating and monitoring tasks, is the Regulatory Authority for Electricity, Gas and Water (AEEGSI). The Authority mission includes defining and maintaining a reliable and transparent tariff system, reconciling the economic goals of operators with general social objectives, and promoting environmental protection and the efficient use of energy. It provides an advisory and reporting service to the government and parliament, and formulates observations and recommendations concerning issues in the regulated sectors of electricity, gas and water.

The structure of the Italian electricity market is shown in Figure Annex1-3. The entity responsible for managing the Power Exchange is “Gestore del Mercato Elettrico” (GME). Unlike other European energy markets, GME’s market is not a merely financial market, where only prices and volumes are determined, but a real physical market, where physical injection and withdrawal schedules are defined.

The Power Exchange is composed of different markets:

- the Day-Ahead Market (MGP),
- the Intra-Day Market (MI),
- the Forward Market (MTE),
- the Ancillary Services Market / Balancing Market (MSD / MB),

in addition to the Over The Counter (OTC) contracts Registration Platform (PCE) and to the Platform for physical delivery of financial contracts concluded on the derivatives market IDEX (CDE).

The Italian Transmission System Operator (TSO) TERNA guarantees the security of the system through the availability of an adequate amount of generation reserve by selecting bids/offers of variation of the schedules submitted by participants in the framework of the Ancillary Services Market (MSD). On this market, also organized by GME, bids/offers are selected by TERNA and remunerated according to the pay-as-bid criterion. During the real time TERNA possibly uses such reserves for balancing purposes on the Balancing Market (MB) and for guaranteeing a secure and reliable operation of the overall power system.

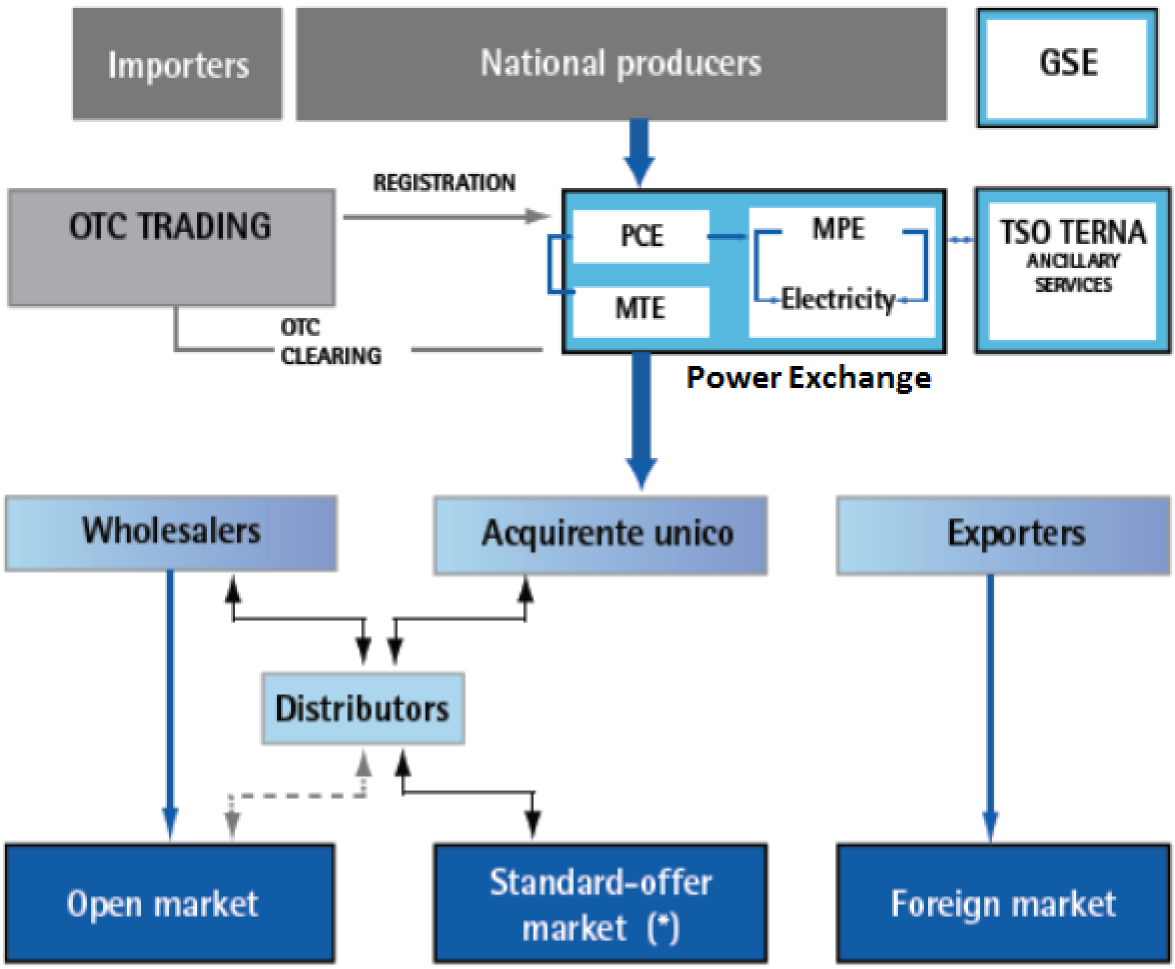

Figure Annex1-3: Italian electricity market framework [source: GME]

The power generation in Italy has changed rapidly due to an increasing development of renewable energy sources, especially wind power and solar photovoltaic. Figure Annex1-4 shows the trend of the total installed power for wind and PV in the last years, while Figure Annex1-5 shows the total installed power including all technologies.

As a consequence, the energy produced by each generation technology for supplying the demand has notably changed. Figure Annex1-6 shows a comparison of the total generation shares in 2008 and 2013: the increase of RES generation has forced the marginal technology (Combined Cycle Gas Turbine - CCGT) to reduce its power generation, while coal keeps unchanged its market share, as it is a base load service, characterized by lower generation costs.

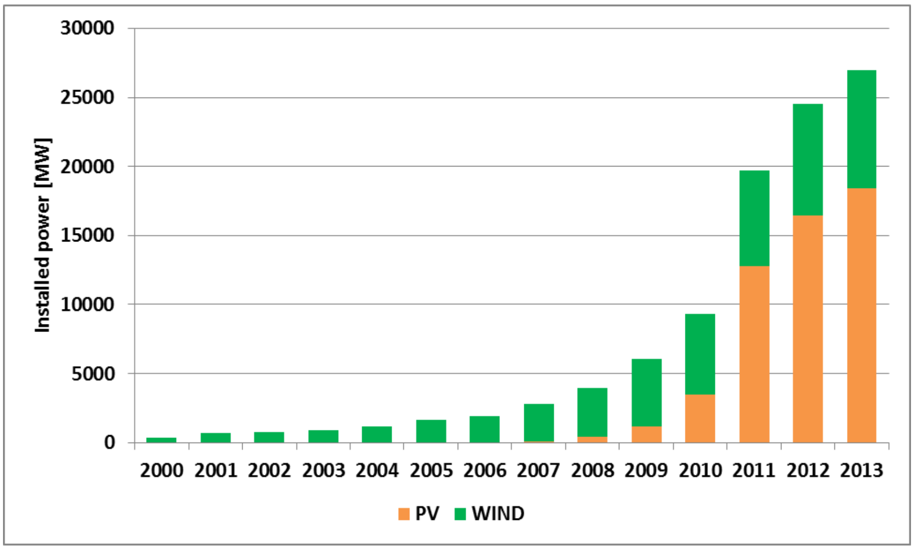

Figure Annex1-4: Net installed power in Italy for wind plants and solar PV.

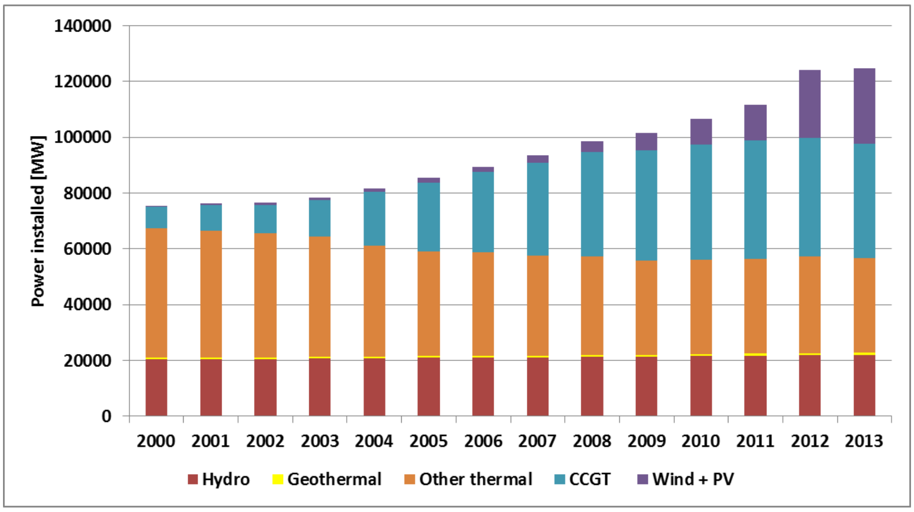

Figure Annex1-5: Net installed power in Italy.

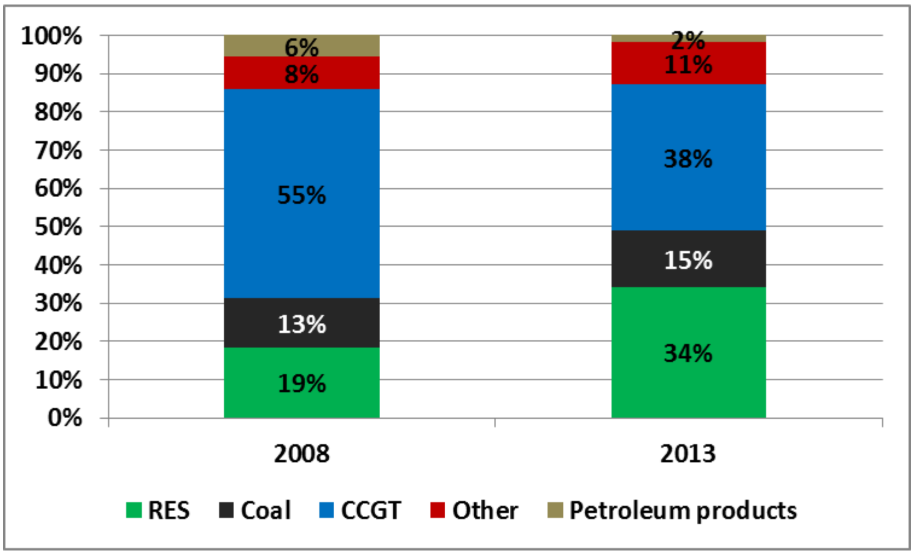

Figure Annex1-6: Generation shares per technologies in 2008 and 2013.

In Italy the operation of the transmission system is performed by TERNA, as the owner of the transmission network. TERNA provides grid access to the electricity market players according to non-discriminatory and transparent rules and acts as counterpart in the ancillary services market in order to ensure the security of supply and the safe operation of the system. The Italian transmission system is constituted by about 11000 km of 380 kV lines, 9500 km of 220 kV lines and more than 37000 km of HV lines at a voltage level lower than 150 kV.

On the other hand, the distribution network is owned and operated by 138 Distribution System Operators (DSOs), that supply about 37 millions of withdrawal points.

The use of the network, both at the distribution and transmission level, is charged to the consumers separately from the costs of the supplied energy. The tariffs for the use of the network are regulated by the authority (AEEGSI) and constantly updated. The tariffs include the use of the grid infrastructure including power transforming and switching. Tariffs don't include losses and the balancing services, that are charged separately. Figure Annex1-7 shows how the revenues from tariffs for the use of the network are transferred from the users to the grid operators.

The domestic users pay to the DSO a single tariff (D2 or D3) that includes the services of transmission, distribution and measurement. On the other hand, the non-domestic users are charged with two different tariffs: one for the transmission service (TRAS) and one for the distribution service (DISTR). Finally DSOs, on behalf of consumers, pay to the TSO a tariff for the transmission service.

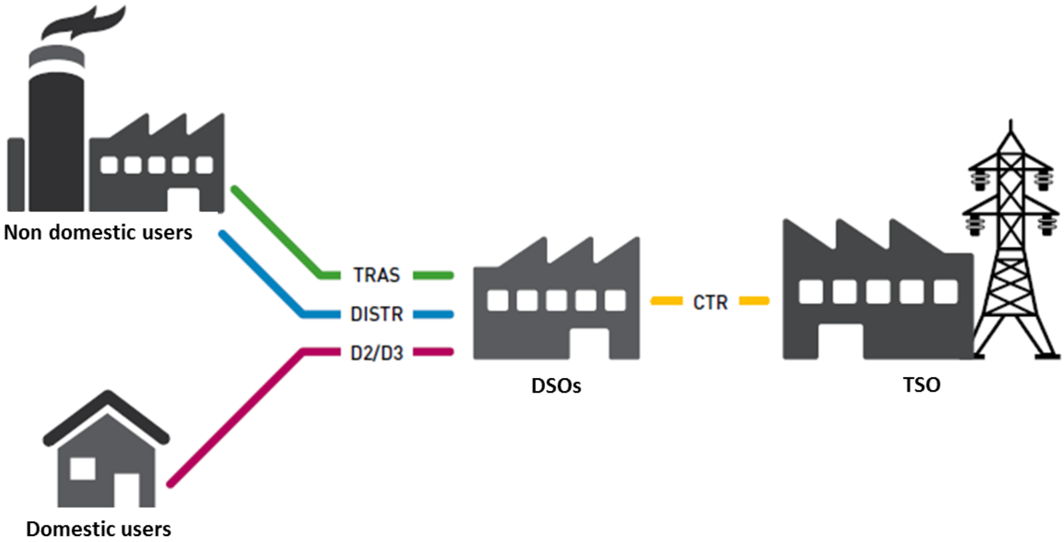

Figure Annex1-7: Charge scheme of tariffs for the use of the network.

Table Annex1-1 shows the tariff for transmission service, in force in 2015 in Italy for a non-domestic user. It can be noted that for consumers connected at the high voltage level the tariff is charged both on the peak power consumptions and on the energy supplied. In particular the TRASp component is charged monthly (152.8 c€/kW-month) and is applied to the monthly peak power consumption measured in any quarter of an hour in each month.

In Table Annex1-2 tariffs for the distribution service for non-domestic users are reported.

Table Annex1-1: Tariffs for the transmission service for non-domestic users.

	TRASp [c€/kW-year]	TRASe [c€/kWh]
Low voltage user	-	0.69
Medium voltage user	-	0.644
High voltage user (<220 kV)	1833.60	0.105
Ultra high voltage user (≥220 kV)	1833.60	0.104

Table Annex1-2: Tariffs for the distribution service for non-domestic users.

	Fixed	Power	Energy
	c€/year	c€/kW	c€/kWh
Low voltage user - maximum power up to 16,5 kW			
≤ 1.5 kW	503.07	3'242.26	0.067
1.5 kW - 3 kW	503.07	3'070.72	0.067
3 kW - 6 kW	503.07	3'413.82	0.067
6 kW - 10 kW	553.38	3'413.82	0.067
≥ 10 kW	553.38	3'413.82	0.067
Low voltage user - maximum power ≥ 16,5 kW	503.07	3'242.26	0.064
Medium voltage user - maximum power up to 100 kW	47'719.60	3'666.49	0.063
Medium voltage user - maximum power 100 kW - 500 kW	42'947.63	3'292.36	0.057
Medium voltage user - maximum power ≥ 500 kW	41'495.30	2'888.30	0.049
High voltage user	2'098'682.36	-	0.021
Ultra high voltage user	2'098'682.36	-	-

Beside the network tariffs, each energy consumer pays a set of “*system charges*” to finance activities of public interest in the energy sector such as renewable support schemes, energy efficiency, public research. About these *system charges,* a recent decree of the Ministry of Economy (5th April 2013) introduced new exemptions for the large industrial consumers connected to the medium and high voltage network. For these consumers the *system charges* for the energy exceeding a certain threshold are zero; moreover below that threshold, energy intensive industries can benefit from discounts, whose amount depends on the ratio between energy costs and turnover of the industry.

Finally the general structure of the energy price for the end users is reported. The cost components are:

- Sales services – including the cost of energy, the cost of dispatching services and the cost of the retail sale activity;
- Network services – including the tariffs for the transmission, distribution and measurement services;
- System charges – including the costs of activities of public interest such as renewable support schemes, energy efficiency incentive, public research, etc.;
- Taxes – including the excise tax and VAT.

Figure Annex1-8 shows the evolution the electricity price for a domestic user between 2012 and 2014, with the detail of single cost components.

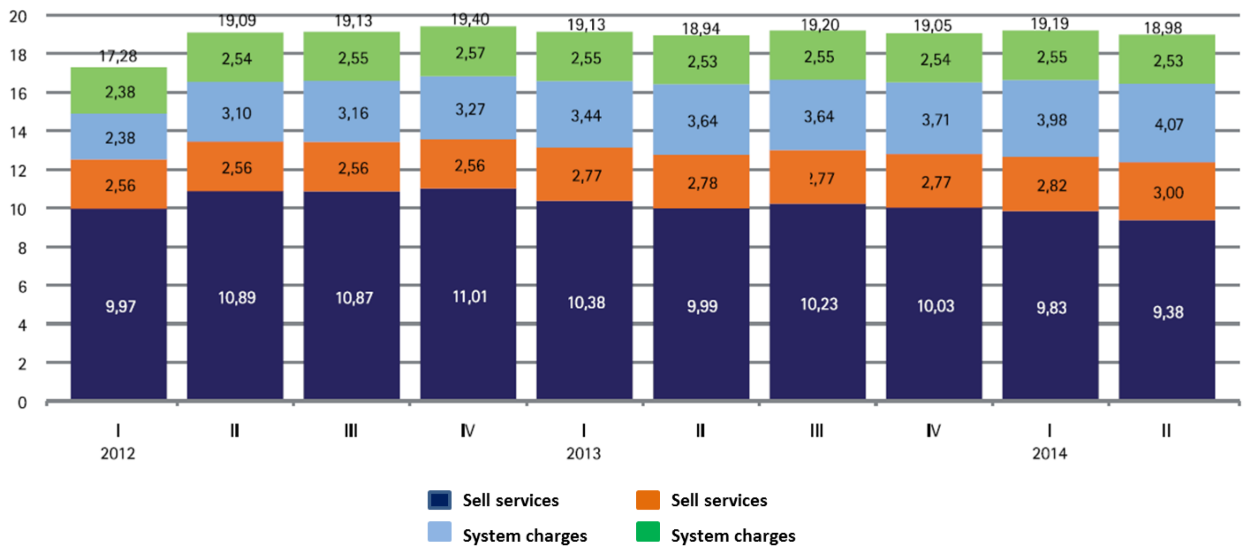

Figure Annex1-8: Evolution of electricity price components for household customers in Italy [c€/kWh].

2.1.2 Germany

The structure of the electricity market in Germany is shown in Figure Annex1-9 [12]. Generation, transmission and distribution of power is today managed by separate companies in order to foster the competition for the production and distribution of power.

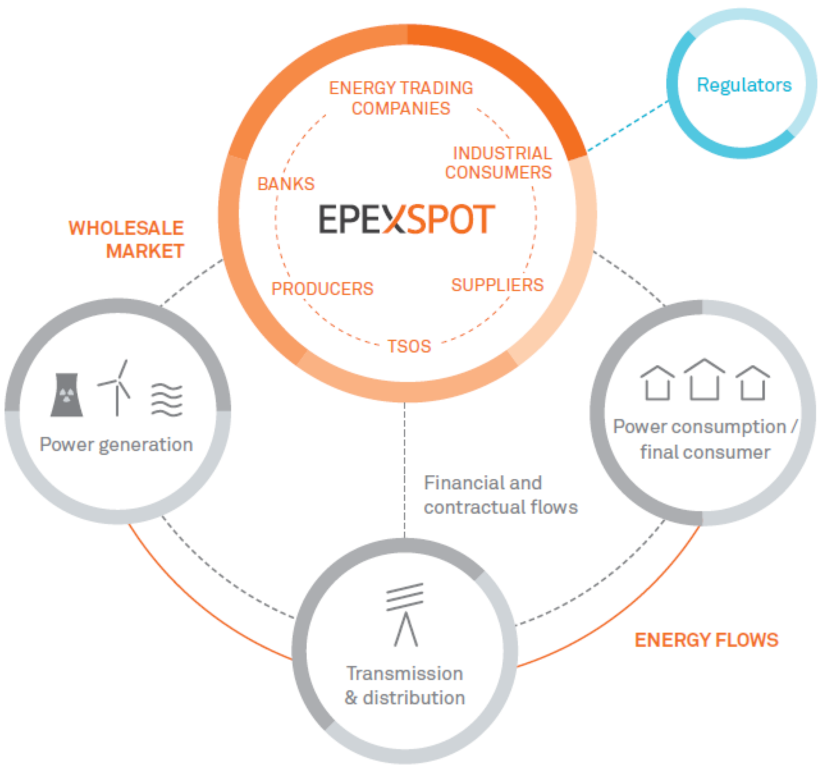

Figure Annex1-9: Structure of the Power Market in Germany.

The Energy Act assigned the task of regulating Germany's electricity and gas markets to the Federal Network Agency (Bundesnetzagentur, http://www.bundesnetzagentur.de/). The purpose of regulation is to establish fair and effective competition in the supply of electricity and gas. The responsibilities of the Federal Network Agency therefore include ensuring non-discriminatory third-party access to networks and policing the use-of-system charges levied by market players. A non-discriminatory, reasonably priced supply of electricity and gas for all who want it will encourage greater competition in these important (wholesale) markets. The Federal Network Agency will use the regulatory experience it has gained in the telecommunications and postal markets to implement a lean and efficient system of regulation.

Within Germany the federal electricity grid infrastructure is subdivided among 4 TSOs, namely Tennet, Amprion, Transnet BW and 50 Hertz, that operate the transmission grids independently from other electricity market players. They are responsible for the bulk transmission of electric power on the main high voltage electric networks. TSOs provide grid access to the electricity market players according to non-discriminatory and transparent rules. In order to ensure the security of supply, they also guarantee the safe operation and maintenance of the system. They

[12] EEXSpot: Annual Report 2013.

are members of the European Network of Transmission System Operators for Electricity, ENTSO-E. The market areas of these companies are depicted in Figure Annex1-10.

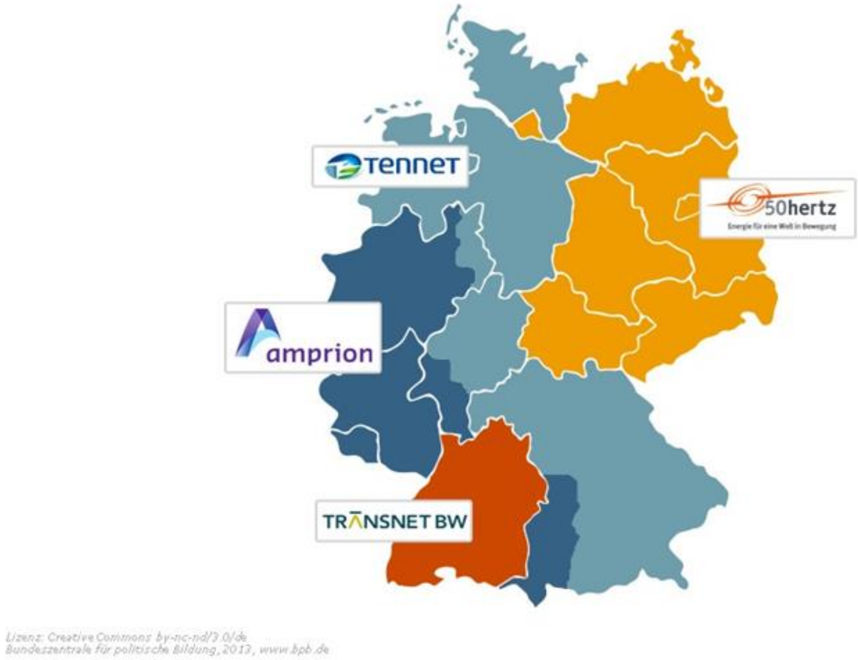

Figure Annex1-10: TSOs in Germany.

Table Annex1-3 gives an overview and the links to the homepages of the relevant TSO companies.

Table Annex1-3: Transmission System Operators (TSO's) in Europe and Germany.

TSO Company	Link
European Transmission System Operators	https://www.entsoe.eu
TransnetBW GmbH	http://www.transnetbw.de/de
TenneT TSO GmbH	http://www.tennet.eu/de/home.html
Amprion GmbH	http://www.amprion.net
50Hertz Transmission GmbH	http://www.50hertz.com/de
Übertragungsnetzbetreiber (ÜNB)	www.netztransparenz.de
Management of regulation energy	www.regelleistung.net
Development of German grids	www.netzentwicklungsplan.de

In Germany the grids are divided in different voltage areas:

- Maximum voltage (Höchstspannungsnetz) 220 k V and 380 kV
- High voltage (Hochspannungsnetz) 110 kV (partly also 60 kV)
- Medium voltage (Mittelspannung) 10 / 20 kV and 15 / 30 kV

The operation of grids and the transformation of voltage is charged separately to the costs of the supplied energy. The tariffs of the four German TSO´s are published on their homepages. The tariffs are charged for the use of following services:

- use of the infrastructure of the grid including power transforming and switching,
- use of the services for frequency and voltage stabilization,
- energy losses from transforming,
- reactive power.

Table Annex1-4 shows a comparison of these tariffs of the German TSOs. The peak load that is measured as a mean value of intervals of ¼ of an hour can be measured and charged either for single months or for the whole year. Therefore the tariffs are different.

Table Annex1-4: Costs for the use of the grids in 2015 incl. power transforming into high voltage for companies with use of the grid for more than 2.500 h/a.

Measurement of the peak load		**Transnet-BW**	**Tennet**	**Amprion**	**50Hertz**
per year	€/kW a	53.82	56.30	35.99	60.79
	€ct/kWh	0.03	0.13	0.176	0.14
per month	€/kW m	--	9.38	6.00	--
	€ct/kWh	--	0.13	0.176	--

Additional fees are charged if the reactive power exceeds the limits that have been declared in the contract.

Furthermore different fees and levies are charged to the end-consumer of energy due to different national laws:

- levies due to the “Kraft-Wärme-Kopplungsgesetz“ (KWKG),
- levies due to the “Erneuerbaren Energie Gesetz” (EEG),
- extra expenses due to the requirements of § 19 Abs. 2 StromNEV,
- licences of the grid operator to communities,
- value added taxes and energy taxes.

Table Annex1-5: Fees due to different laws in Germany for energy-intensive industries in 2015 [13]

Levy or Fee	**Law**	**Costs**
EEG-Umlage	EEG	Usually: 6.24 €ct/kWh. but for energy-intensive industry: 0.05

[13] www.netztransparenz.de

		€ct/kWh
KWK-Aufschlag (für 2015)	KWKG	0.025 €ct/kWh
Umlage StromNEV	§ 19 Strom NEV	0.025 €ct/kWh
Offshore-Haftungs-Umlage	§ 17f EnWG	0.025 €ct/kWh
Umlage abschaltbare Lasten	§ 18 AbLaV	0.006 €ct/kWh
Konzessionsabgabe	NAV	0.11 – 0.13 €ct / kWh
Tax on power generation	StromStG	up to 2.05 €ct/kWh, but reduced for producing / energy-intensive industry

The power generation in Germany has changed rapidly due to an increasing use of renewables for power generation. Additional capacities for Wind and Solar power have been installed. Figure Annex1-11 shows the installed capacities for power generation with the use of different primary energies in 2014[14].

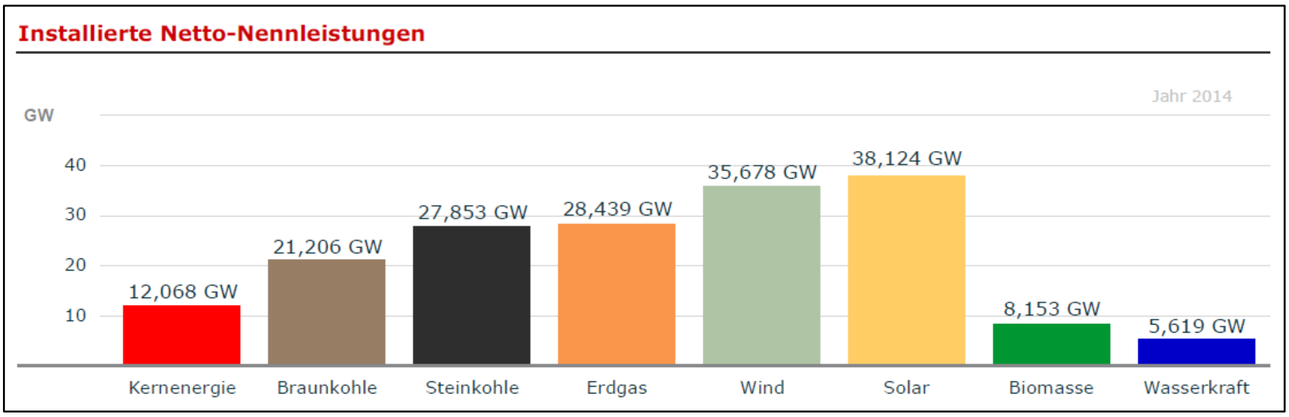

Figure Annex1-11: Installed capacities for power generation with use of different primary energies in 2014[15].

Figure Annex1-12 shows the generation of power in 2014 in Germany and the use of different primary energies.

[14] Burger, B.: Stromerzeugung aus Solar und Windenergie im Jahr 2014, Fraunhofer ISE.
[15] Burger, B.: Stromerzeugung aus Solar und Windenergie im Jahr 2014, Fraunhofer ISE.

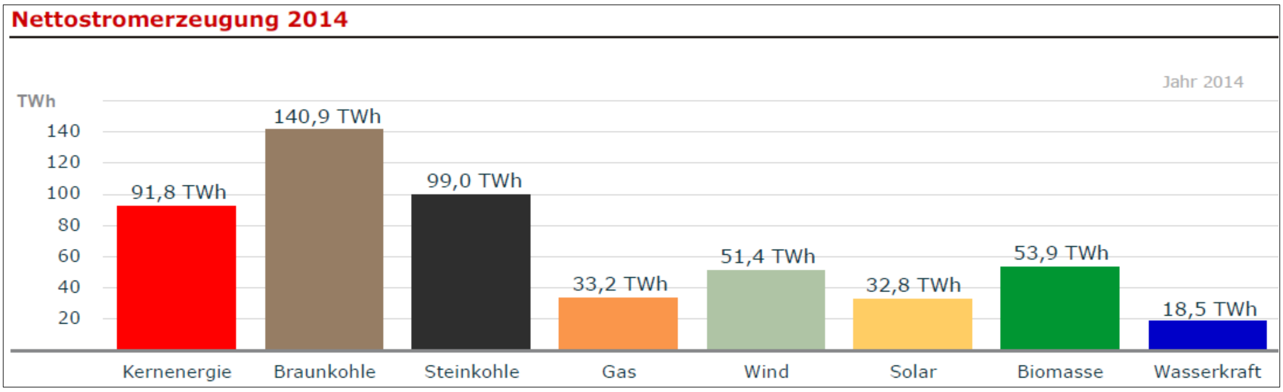

Figure Annex1-12: Power production by the use of different primary energy sources in Germany 2014 16.

In 2014 in total 521,5 TWh of net power has been produced including 156,6 TWh produced of renewable sources. The share of renewable energy was 30%.

Figure Annex1-13 shows the relevant submarkets for electricity in Germany. The power exchange includes the trading of energy and the delivery services as well and needs an additional balancing of the grids.

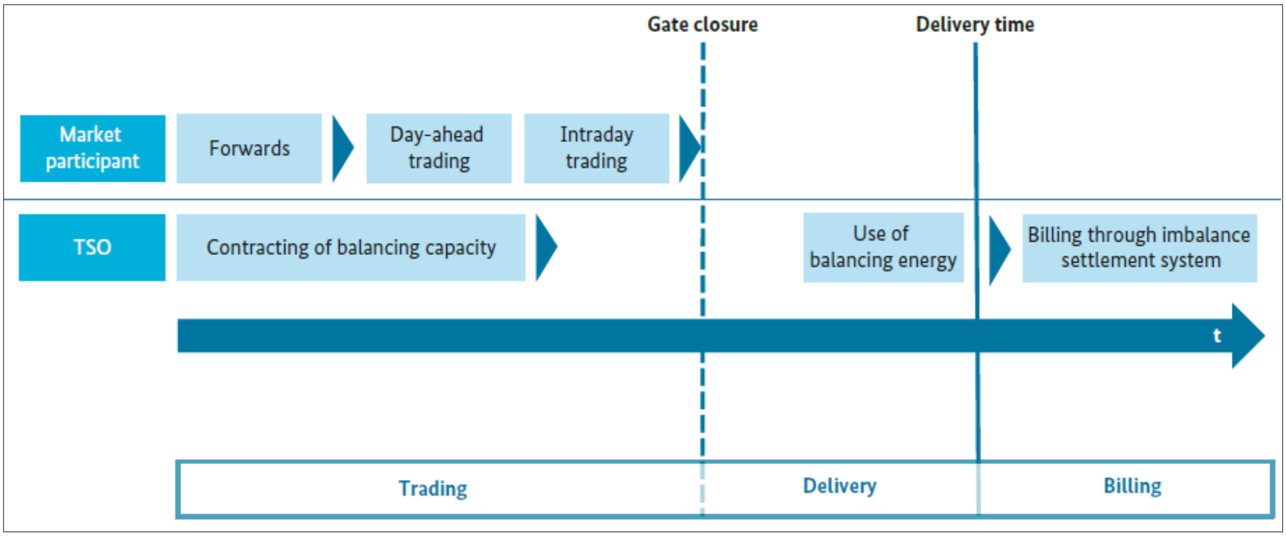

Figure Annex1-13: Submarkets of the electricity market in Germany, chronological representation[17].

The energy exchange markets for power typically include:

- the forward market,
- the day-ahead spot market,
- the intra-day spot market.

16 Fraunhofer ISE, Freiburg 2014.

17 An Electricity Market for Germany's Energy Transition. Discussion Paper of the Federal Ministry for Economic Affairs and Energy, Oct. 2014.

All such kinds of markets foresee the physical delivery of energy or future financial derivatives. In this report we will focus on the day-ahead and on the intra-day markets, i.e. the ones that can provide short-term flexibility to electricity consumption.

In Germany the Phelix index has been defined (Physical Electricity Index) for a comparison of the prices of the products traded at the EEX. Within the forward market future derivatives and options are offered for the time slots of the “base load”, “peak load” or “off-peak” of the day, valid for daily, weekly, monthly, quarterly and yearly delivery periods. These products were designed to supply the bulk of the energy consumption but they do not provide flexibility.

The day-ahead and intra-day spot markets provide more flexibility for short-term contracts. New markets and opportunities to reduce the energy costs are given today by the balancing market and the opportunities for a demand side management as well.

The different price components of power that have to be paid in Germany are shown in Figure Annex1-14 for household customers. These cost elements are mainly relevant for:

- costs for the procurement of energy,
- tariffs for the use of the network, grid and transformation of power,
- levies as a kind of cross-subsidization, mainly for renewable energy,
- taxes e.g. for the use of fuels and the power production itself.

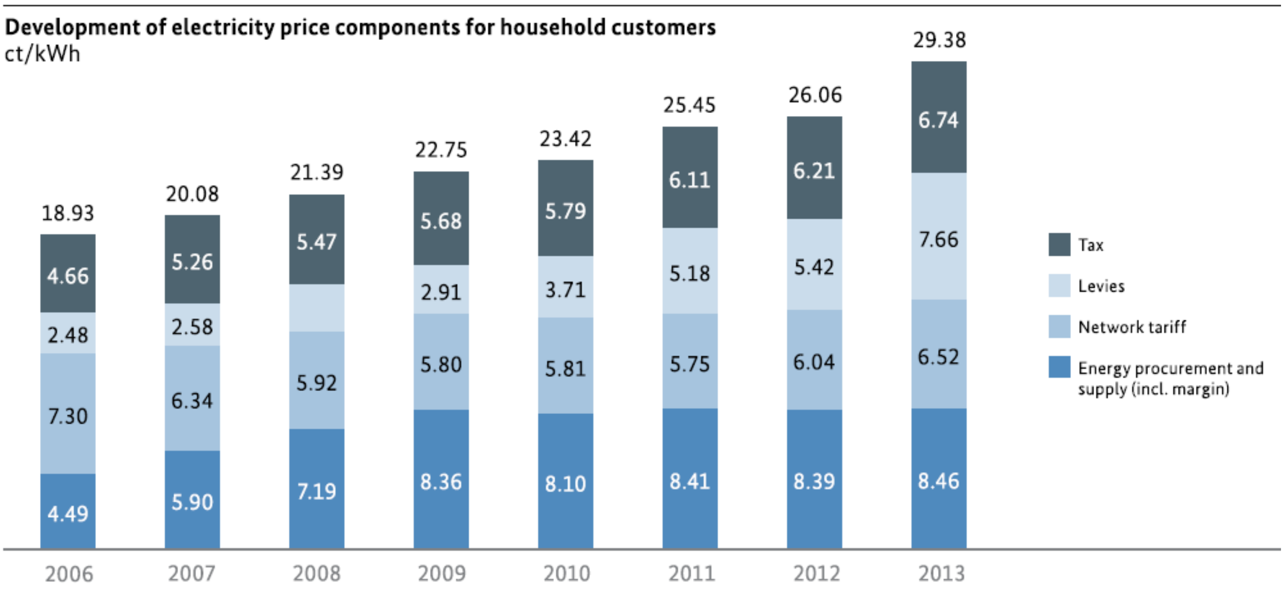

Figure Annex1-14: Evolution of electricity price components for household customers[18].

The power costs for industrial processes are significantly lower than that for household customers because taxes and levies are reduced for energy intensive industries.

[18] Bundesnetzagentur, Annual Report 2013.

3 Power Exchange

3.1 Day-ahead spot market

The day-ahead spot market is typically the most important one, in terms of volumes of energy traded and of significance of the clearing prices.

In the following an analysis of the day-ahead spot markets in Italy and in Germany is provided.

3.1.1 Italy

The Italian day-ahead spot market is called Mercato del Giorno Prima – MGP. The Italian Power Exchange, including the day-ahead spot market, is managed by GME - Gestore dei Mercati Energetici (www.mercatoelettrico.org).

3.1.1.1 Market description

The Italian day-ahead spot market is not a mandatory market, i.e. it is also possible to trade electric energy outside the market (Over The Counter – OTC) through bilateral contracts.

In the day-ahead spot market, producers, wholesalers and consumers may sell / buy electric energy for each hour of the next day, by submitting supply offers / demand bids in the relevant market session.

The session relevant for the day D starts at 08:00 of D-9 and closes at 09:15 of the day D-1 (i.e. the day-ahead).

Offers / bids consist of pairs of values, i.e. volume and unit price of electric energy (MWh, €/MWh). They express the willingness to sell / buy a volume of energy not higher than the one specified in the offer / bid at a price not lower / not higher than the one specified in the same offer / bid.

Prices and volumes must not be negative and demand bids may also not specify any purchasing price; in this case, they express the market participant's willingness to purchase electric energy at any price. The highest price considered by the market clearing algorithm is 3000 €/MWh, i.e. the Value of Energy Not Supplied defined by the Authority for Electric Energy, Gas and Hydric System (AEEGSI), the Italian regulatory authority [[19]]. Demand bids that do not specify any purchasing price are therefore equivalent to bids at 3000 €/MWh.

Offers / bids may be:

- simple, consisting of a pair of values indicating the volume of electric energy to be sold or bought in the market by a market participant and the related price for a given hour;

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[19] AEEGSI Order no. 111/06: *"Condizioni per l'erogazione del pubblico servizio di dispacciamento dell'energia elettrica sul territorio nazionale e per l'approvvigionamento delle relative risorse su base di merito economico, ai sensi degli articoli 3 e 5 del decreto legislativo 16 marzo 1999, n. 79"*.

- multiple, consisting of a set of at most 4 simple offers / bids that allow to split with different prices an overall volume to be sold or bought in the market by the same market participant for the same hour, the same generating unit or the same withdrawal point;
- pre-defined, consisting of simple or multiple offers / bids which are daily repeatedly automatically submitted to the market.

Offers / bids refer to “offer points” and to individual hours: this means that, for each day and each “offer point”, a maximum of 24 independent offers / bids may be submitted. Supply offers and demand bids, to be considered valid, must be consistent with the injection or withdrawal capabilities of the “offer points” to which they refer and, above all, they must correspond to the real willingness to inject or withdraw the related volumes of electric energy.

According to [[20]] an “offer point” is a “dispatching point” as defined in the dispatching regulation [[19]] issued by AEEGSI and in the Grid Code [[21]] issued by the Italian Transmission System Operator TERNA. As far as consumption units are concerned, a “dispatching point” is the set of withdrawal points corresponding to consumption units located in a single “zone” and for which a “dispatching user” signed a contract for transmission and distribution services.

In fact, for each “offer point”, a “dispatching user” is identified. This user is responsible towards the Italian TSO TERNA both for the implementation of injection and withdrawal schedules defined in the market and for the execution of balancing commands. These commands may be sent by TERNA to dispatching users in real time in order to maintain the security of the system. Non-compliance with the final schedules involves the payment of imbalance charges, applied to each offer point.

As far as “zones” are concerned, the power system is divided into portions of the transmission grid (called “zones”) where, according to security requirements, there are physical limits to transmission of electric energy to/from the corresponding neighboring zones. These transmission limits are determined through a computational model that is based on the balance between electricity generation and consumption in different scenarios, taking into account the impact of possible faults of network elements and aiming to satisfy the “N-1” security criterion. According to this criterion the power system must in any circumstance withstand the fault of one network element and remain in safe operation.

The identification of the zones and the definition of transmission capacities between them is made by the Italian TSO TERNA. The zones may correspond to physical geographical areas, to virtual areas (i.e. not directly corresponding to physical areas) and to “limited production poles”, i.e. virtual zones composed of a set of generators whose overall maximum power production is higher than the available transmission capacity connecting them to the neighboring zones.

The “geographical zones” are currently 6: Northern Italy, Central-Northern Italy, Central-Southern Italy, Southern Italy, Sicily and Sardinia (see Figure Annex1-15), for each of which the transmission capacity to / from the neighboring zones / poles is defined by TERNA.

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[20] GME: *“Testo integrato della disciplina del mercato elettrico approvato con D.M. del 19 dicembre 2003 come successivamente modificato e integrato”*.
[21] TERNA: *“Codice di Rete – Capitolo 4 – Regole per il dispacciamento”*.

Figure Annex1-15: Geographical zones of the Italian electricity market (source: GME).

The "virtual zones" are currently 8 and correspond to neighboring countries (France, Switzerland, Austria, Slovenia, BSP[22], Corsica, Corsica AC[23] and Greece). The Italian transmission grid is interconnected with neighboring countries via 22 lines: 4 with France; 12 with Switzerland; 1 with Austria; 2 with Slovenia; 1 direct-current submarine cable with Greece, in addition to the SACOI direct-current cable linking Sardinia to mainland Italy through Corsica, and an additional alternating-current cable between Sardinia and Corsica and the SAPEI direct-current link between Sardinia and mainland Italy. All these lines and cables are aggregated into "equivalent" interconnections between Italy and each neighboring country, for each of which the transmission capacity to / from Italy is defined by TERNA.

The "limited production poles" are currently 4: Foggia, Brindisi, Rossano and Priolo, for each of which the transmission capacity to the neighboring geographical zones is defined by TERNA.

[22] It corresponds to the Slovenian electricity market, coupled with the Italian one with a "price coupling" algorithm.

[23] It corresponds to the Corsica island interconnected through an Alternating Current (AC) cable.

To manage any congestion which may be caused by injection or withdrawal schedules (whether defined in the market or deriving from bilateral contracts) and to clear the market, GME uses the map of geographical and virtual zones shown in Figure Annex1-16.

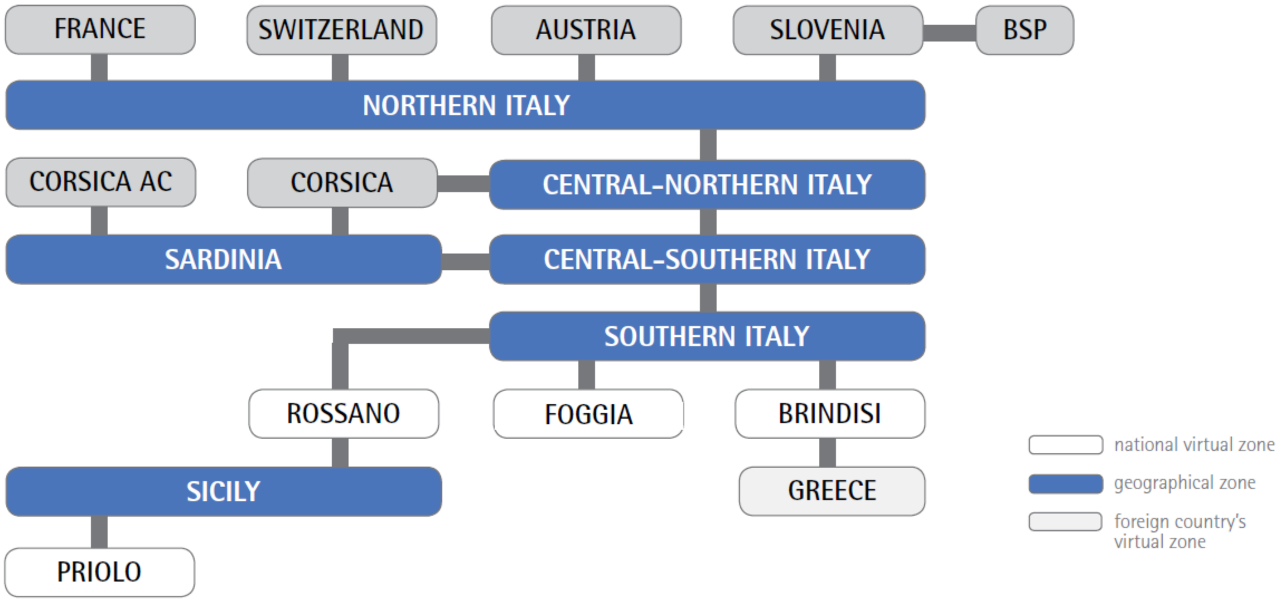

Figure Annex1-16: Map of the geographical and virtual zones used by GME for congestion management and market clearing (source: GME).

Before the 09:15 "gate closure" of the market session, GME receives by the Italian Transmission System Operator TERNA and publishes at 08:45 the following information, that could be of interest for market participants:

- the maximum hourly transmission capacity between geographical zones,
- the maximum hourly transmission capacity with foreign market zones,
- the maximum hourly export capacity from limited production poles,
- an estimation of hourly electric energy demand for each geographical zone.

After the 09:15 "gate closure", GME activates the market clearing process. For each hour of the following day, the market algorithm accepts offers / bids in such a way as to maximize the value of transactions, while complying with the maximum transmission limits between zones.

The clearing process may be summarized as follows:

- All valid supply offers are ranked in increasing price order on an aggregate supply curve and all valid demand bids are ranked in decreasing price order on an aggregate demand curve. The intersection of the two curves gives (see Figure Annex1-17):
  - the overall traded volume,
  - the clearing price,
  - the accepted offers / bids,
  - the injection and withdrawal schedules obtained as the sum of the accepted offers / bids pertaining to the same hour and to the same "offer point".

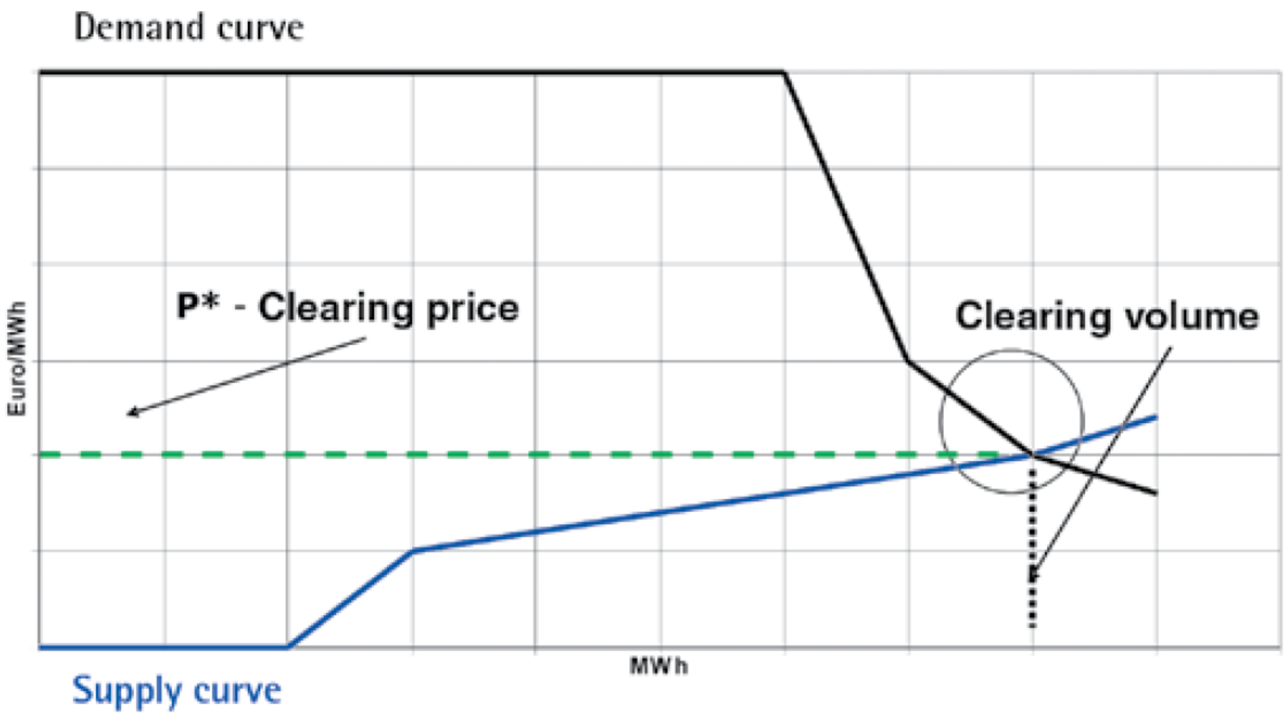

Figure Annex1-17: Schematization of the market clearing process (source: GME).

- If the flows on the grid resulting from the schedules do not violate any transmission capacity limit, the clearing price is the same in all the zones and equal to P*. Accepted offers / bids are those having a selling price not higher than P* and a purchasing price not lower than P*.
- If at least one transmission capacity limit is violated, the algorithm “splits” the market into two aggregates of geographical and/or virtual zones called “market zones”: an exporting market zone, including all the zones upstream the constraint, and an importing market zone, including all the zones downstream the constraint. Then, the algorithm repeats the above-mentioned clearing process and, for each market zone, it builds an aggregate supply curve (including all the supply offers submitted in the same zone, as well as the maximum importable volume) and an aggregate demand curve (including all the demand bids submitted in the same zone, as well as the maximum exportable volume). The result is a zonal clearing price (Pz), which is different in the two market zones. In particular, Pz is higher in the importing market zone and lower in the exporting one. If, as a result of this solution, additional transmission capacity limits within each market zone are violated, the “market splitting” process is repeated again within this zone until a result which is compliant with all transmission capacity limits is obtained. The “market splitting” mechanism is a non-discriminatory implicit auction for the assignment of transmission rights. This process is also called “congestion management” since in this way all inter-zonal network congestions are removed.
- The zonal price Pz is applied to all sales and purchases of energy related to injection offer points (i.e. generators), to mixed offer points (e.g. pumped storage hydro power plants) and to withdrawal offer points belonging to neighboring countries’ virtual zones.
- On the contrary, all withdrawal offer points belonging to national geographical zones pay the same Uniform National Purchase Price, called PUN (*Prezzo Unico Nazionale*). The PUN is equal to the average of zonal selling prices Pz, weighted on zonal electric energy demand.

The overall market clearing algorithm above described can be summarized as reported in Figure Annex1-18.

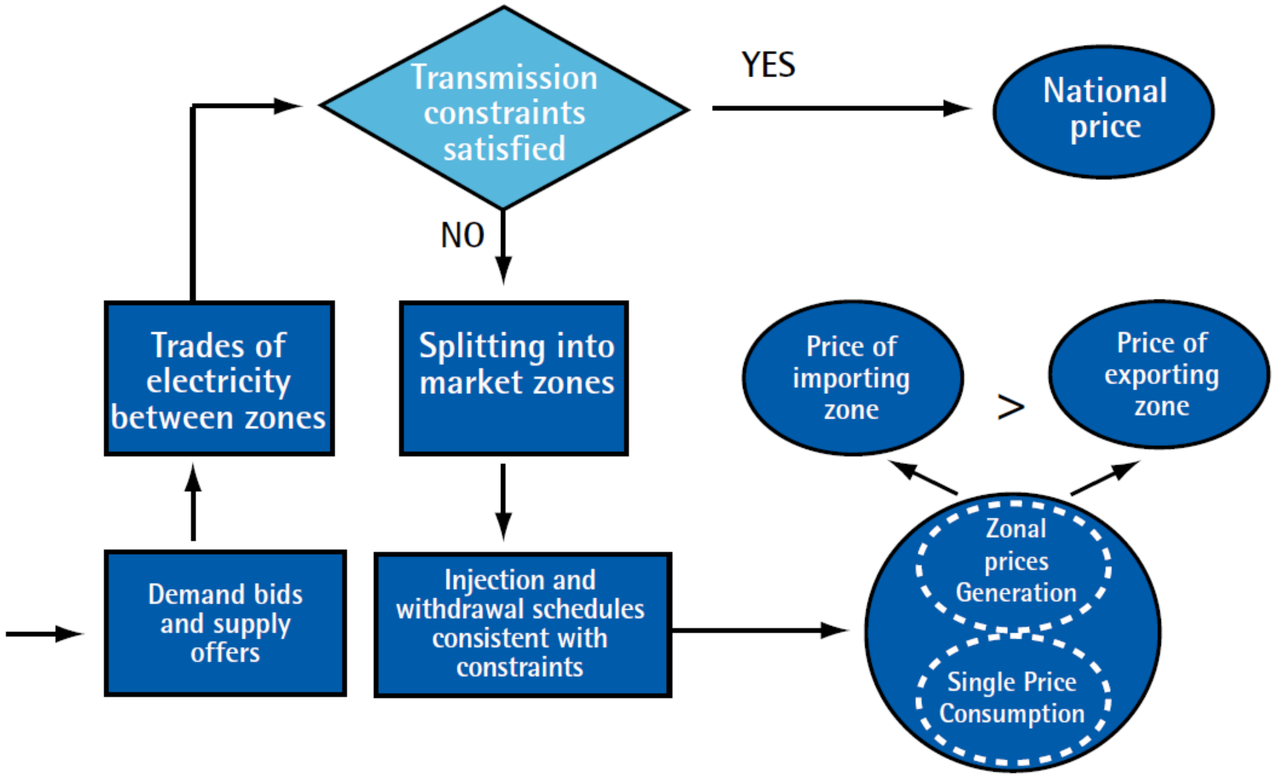

Figure Annex1-18: Schematization of the market clearing algorithm (source: GME).

The electric energy traded Over-The-Counter through bilateral transactions (that must be registered onto a specific platform managed by GME, i.e. the *Piattaforma Conti Energia* – PCE) participates to the above-described process, since it contributes both to use a share of the available inter-zonal transmission capacity and to determine the volumes to be weighted for the Uniform National Purchase Price (PUN).

The schedules registered onto the PCE are therefore submitted to the day-ahead market in the form of pairs of offers / bids and in such a way contribute to determine the results of the market itself. To this aim, for bilateral contracts registered by operators enabled to participate to the day-ahead market, a price must be specified in the registration and such price characterizes the corresponding pair of offers / bids submitted to the market. On the contrary, for bilateral contracts registered by operators not enabled to participate to the day-ahead market, an offer at a price equal to zero and a bid without purchasing price specification is submitted to the market.

The results of the day-ahead market are then communicated to each market participant at 10:45.

3.1.1.2 *Market Coupling*

In the first half of 2015 the Italian day-ahead market will join the Europe-wide Price Coupling of Regions – PCR initiative[24] that puts together all the day-ahead markets of the different European countries and clears them with a single algorithm that preserves the peculiarities of the different national markets (e.g. types of offers, PUN in the Italian market, etc.).

The price coupling algorithm manages congestion between the different countries with a "market splitting" where each zone is a country, or a subset of a country (like in Italy, that is in turn subdivided into zones). In such a way cross-border available transmission capacity is optimally used, differently from the previous situation where transmission capacity was allocated in dedicated auctions, before knowing the electric energy prices that would have been subsequently defined in the day-ahead markets. In such situation it could happen that between two countries with different electric energy prices not all the available transmission capacity is used or, worse, the energy flow goes from the highest price country to the lowest price one (so-called "adverse flow"), leading to a non-optimal use of the transmission capacity itself.

At the beginning the only impact of the price coupling on the Italian day-ahead market procedures will be a change of the "gate closure" time, that will be moved from the current 09:15 to 12:00, like the other European markets. Moreover, the price limits (0 €/MWh ÷ 3000 €/MWh) will remain the current ones, even if negative prices are allowed in the other European markets.

3.1.1.3 *Analysis of recent market results*

The day-ahead market of the Italian Power Exchange in November 2014 accounted for 63.5% of the overall electric energy trades ("Liquidity": see Figure Annex1-19). The remaining 36.5% was traded Over-The-Counter with bilateral contracts. From Figure Annex1-19 it can be seen that liquidity was higher in the first half of 2013, when it reached almost 80%.

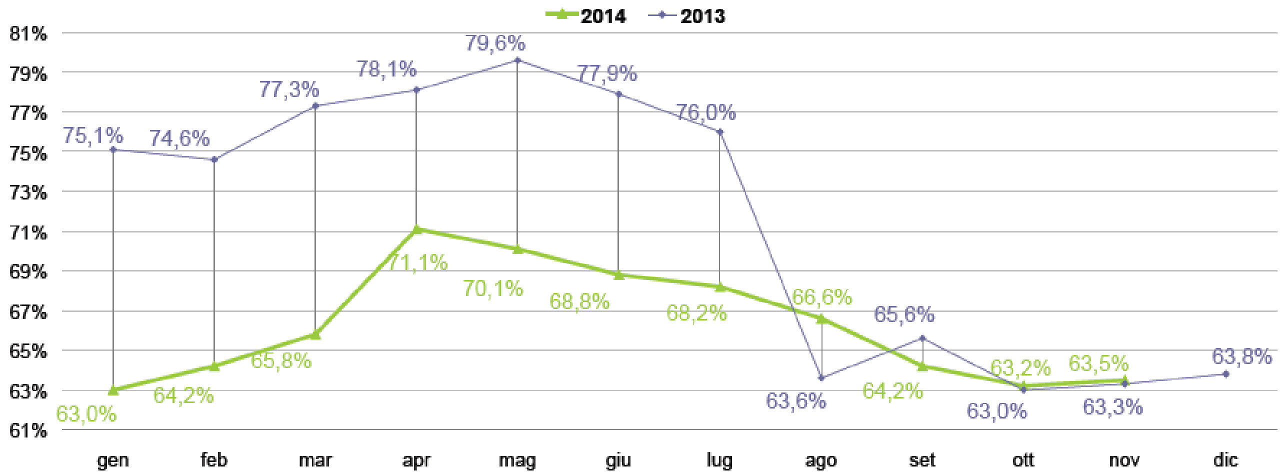

Figure Annex1-19: "Liquidity" of the day-ahead market of the Italian Power Exchange (source: GME).

[24] The Price Coupling of Regions (PCR) is an initiative by 7 European Power Exchanges (APX-ENDEX, Belpex, EPEX SPOT, GME, Nord Pool Spot, OMIE and OTE) operating in Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Since we are specifically interested in purchases of electric energy on the day-ahead market, to look for opportunities to take profit from demand flexibility, in the following the analysis will focus on the Uniform National Purchase Price – PUN in the one-year period between December 2013 and November 2014.

The following Figure Annex1-20 shows hourly PUN values in the considered period. PUN variability is clear: values range from 2.23 €/MWh to 149.43 €/MWh.

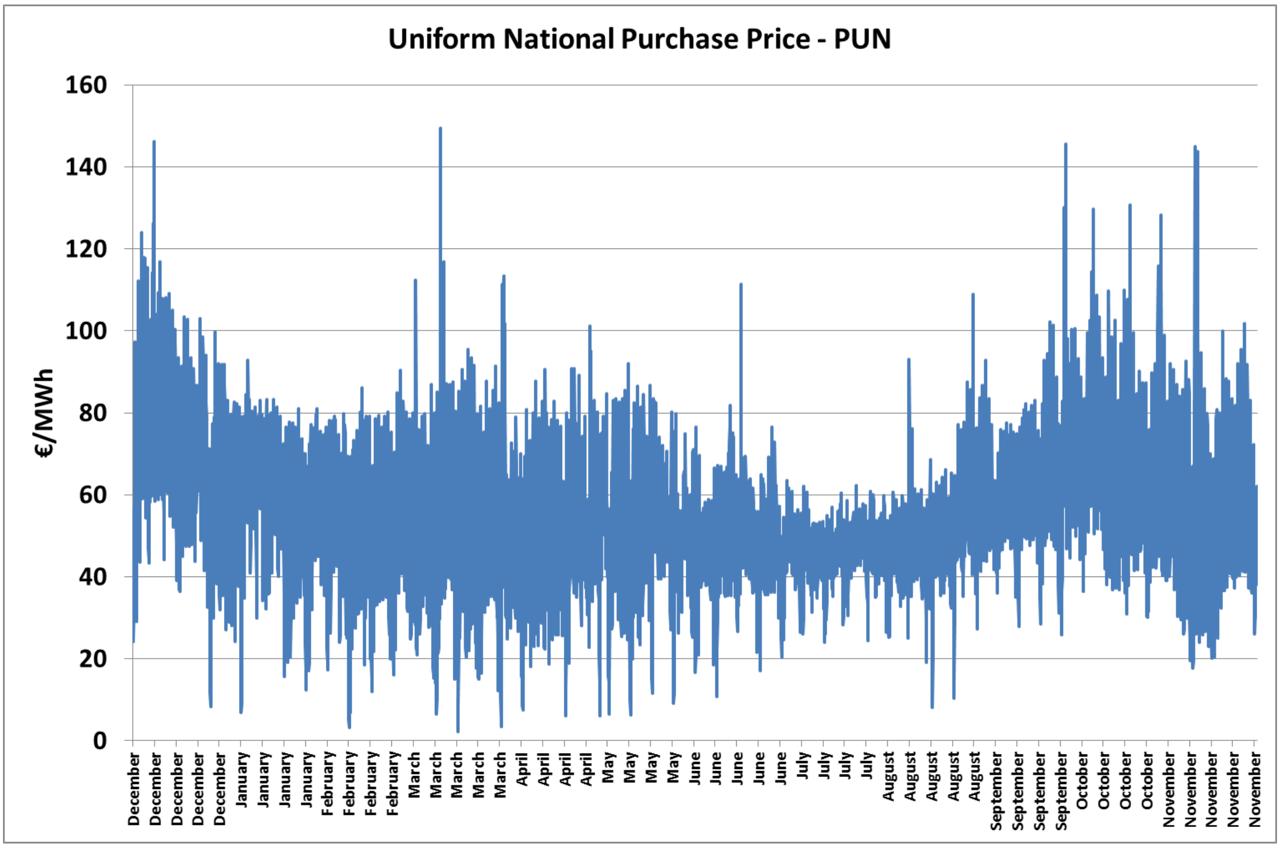

Figure Annex1-20: Hourly PUN values from December 2013 to November 2014 (source: RSE elaboration on GME data).

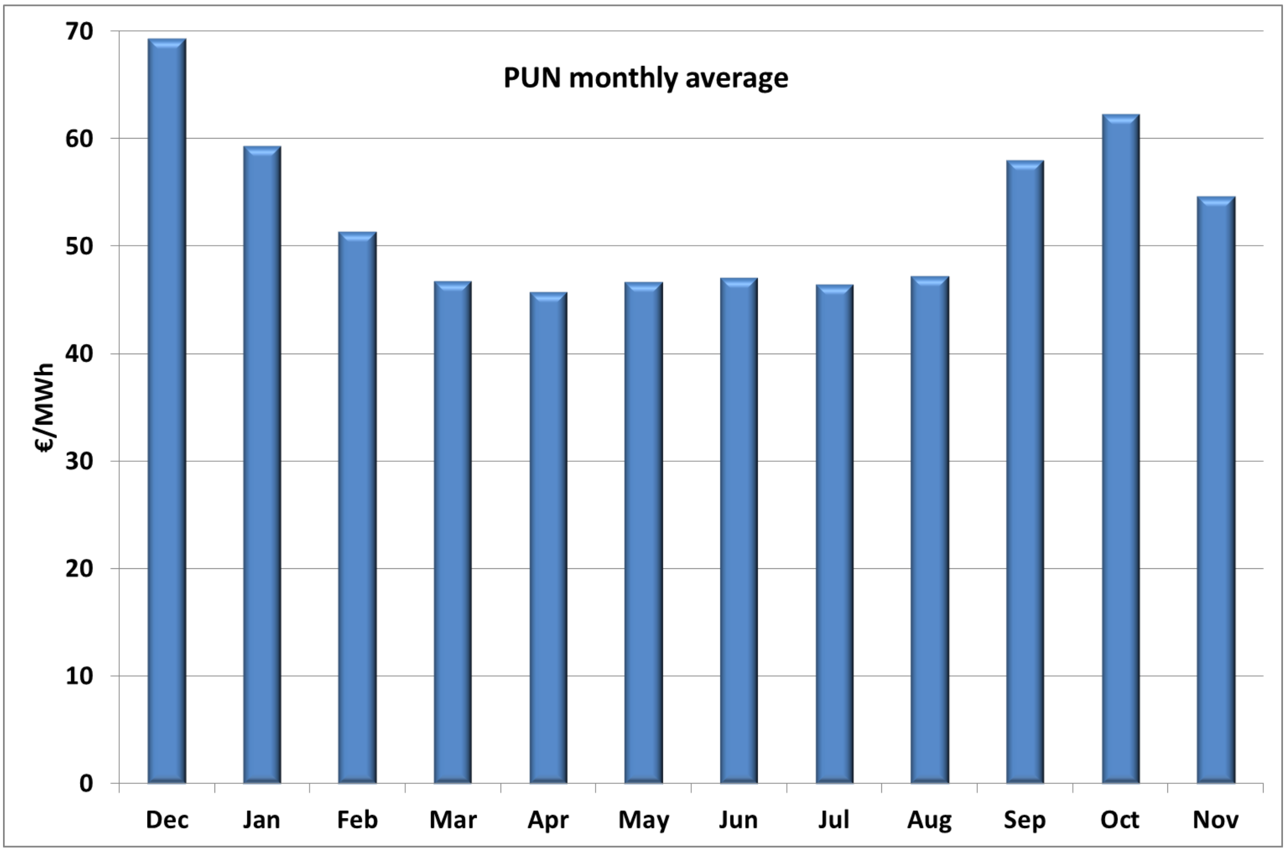

Figure Annex1-21: PUN monthly average (source: RSE elaboration on GME data).

In Figure Annex1-21 the PUN monthly average is shown. The months from March to August show the lowest values, also due to the high renewable generation (especially photovoltaic) that characterizes such months and that is offered in the day-ahead market at a price equal to zero.

In Figure Annex1-22 the PUN monthly average in working days and in weekends and holidays (non-working days) is shown. Since demand in non-working days is lower, also electric energy prices are lower. In the considered period, PUN reduction in non-working days ranged from about 6% (2.7 €/MWh) to about 30% (14.2 €/MWh).

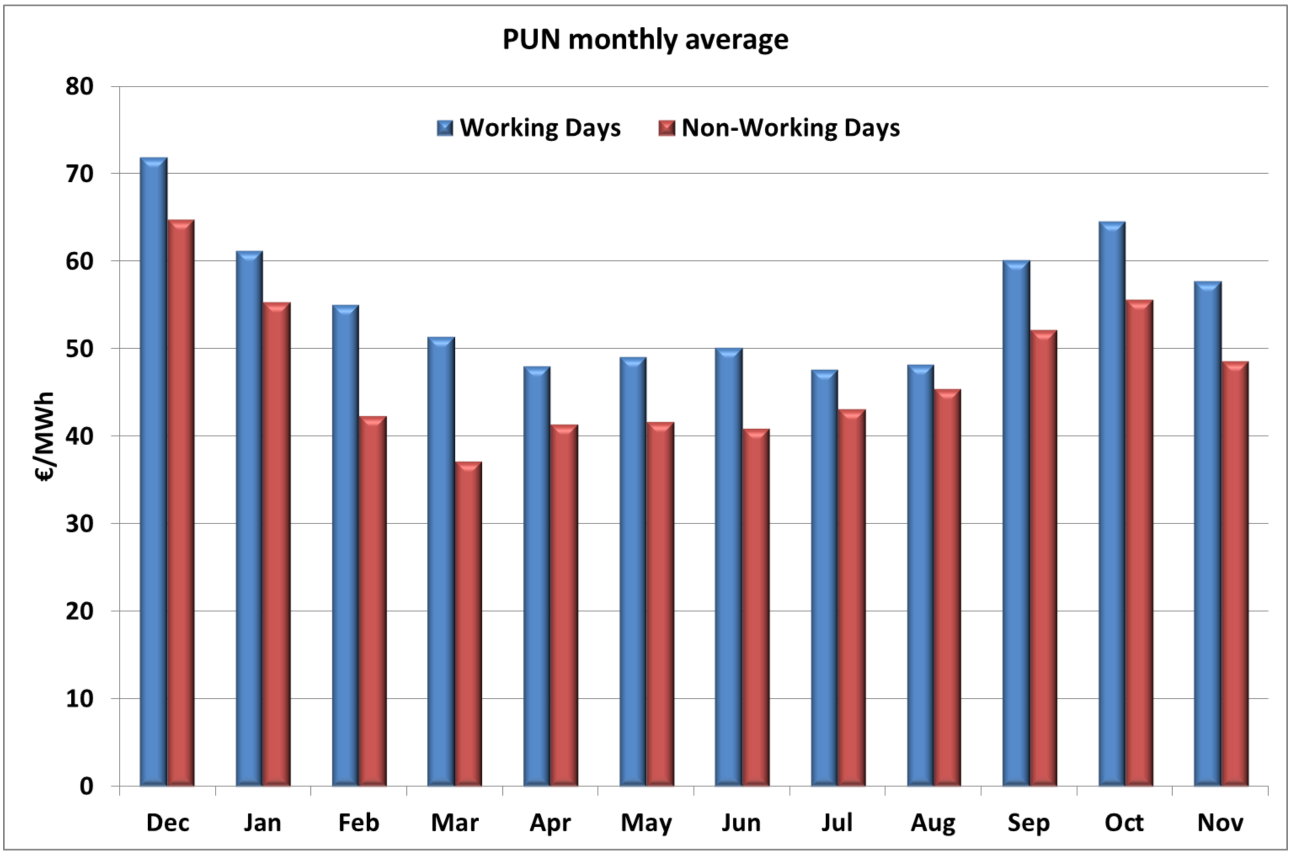

Figure Annex1-22: PUN monthly average in working days and in weekends and holidays (source: RSE elaboration on GME data).

In Figure Annex1-23 the average hourly PUN profile is shown. In the considered period the PUN on average reached the lowest minimum between 3 and 5 a.m. (when demand is low), followed by a first peak from 8 to 9 a.m. (demand rises steeply and photovoltaic generation is still low), followed by a second minimum from 1 to 2 p.m. (photovoltaic generation is high) and then followed by the highest peak from 7 p.m. to 8 p.m. (photovoltaic generation stops and demand is still high).

In Figure Annex1-24 the PUN hourly average difference w.r.t. the overall annual average is shown. In the considered period, consuming electric energy between 11 p.m. and 7 a.m. and between 11 a.m. and 4 p.m. would have allowed to pay a price lower than the annual average (saving from about 1 €/MWh to about 15 €/MWh), while in the remaining hours the price paid would have been higher than the annual average (range from about +2 €/MWh to about +19 €/MWh).

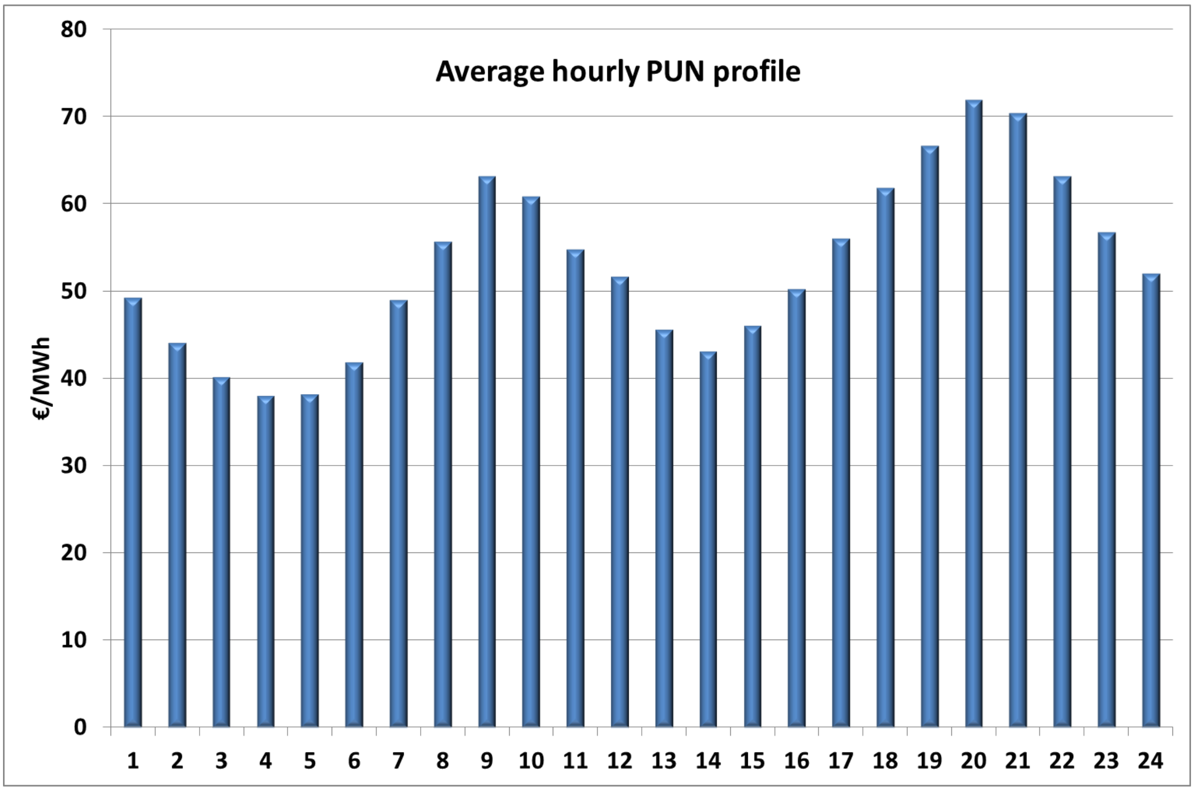

Figure Annex1-23: Average hourly PUN profile (source: RSE elaboration on GME data).

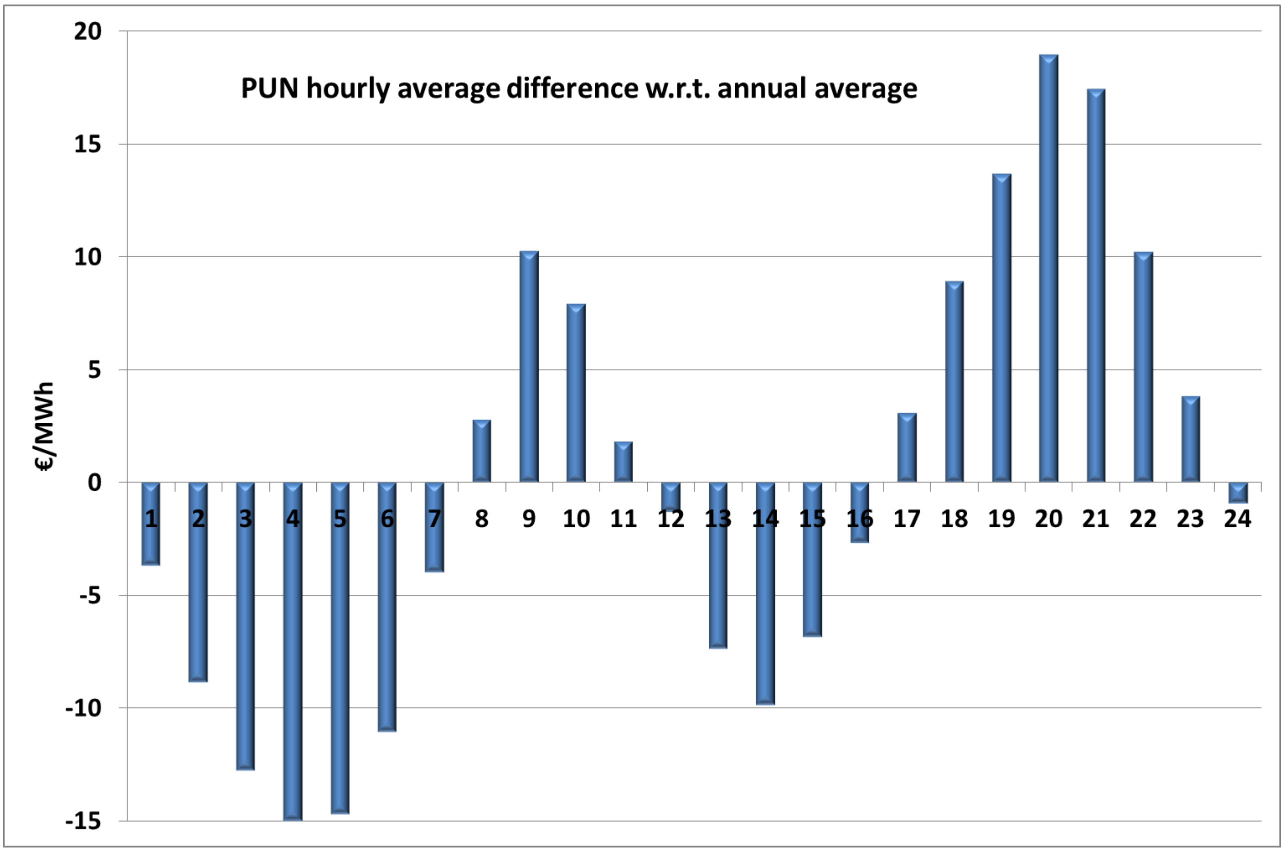

Figure Annex1-24: PUN hourly average difference w.r.t. the overall annual average (source: RSE elaboration on GME data).

In terms of average percentage difference (Figure Annex1-25), in the considered period, consuming electric energy between 11 p.m. and 7 a.m. and between 11 a.m. and 4 p.m. would have allowed to pay a price lower than the annual average (saving from about 2% to about 28%), while in the remaining hours the price paid would have been higher than the annual average (range from about +3% to about +36%).

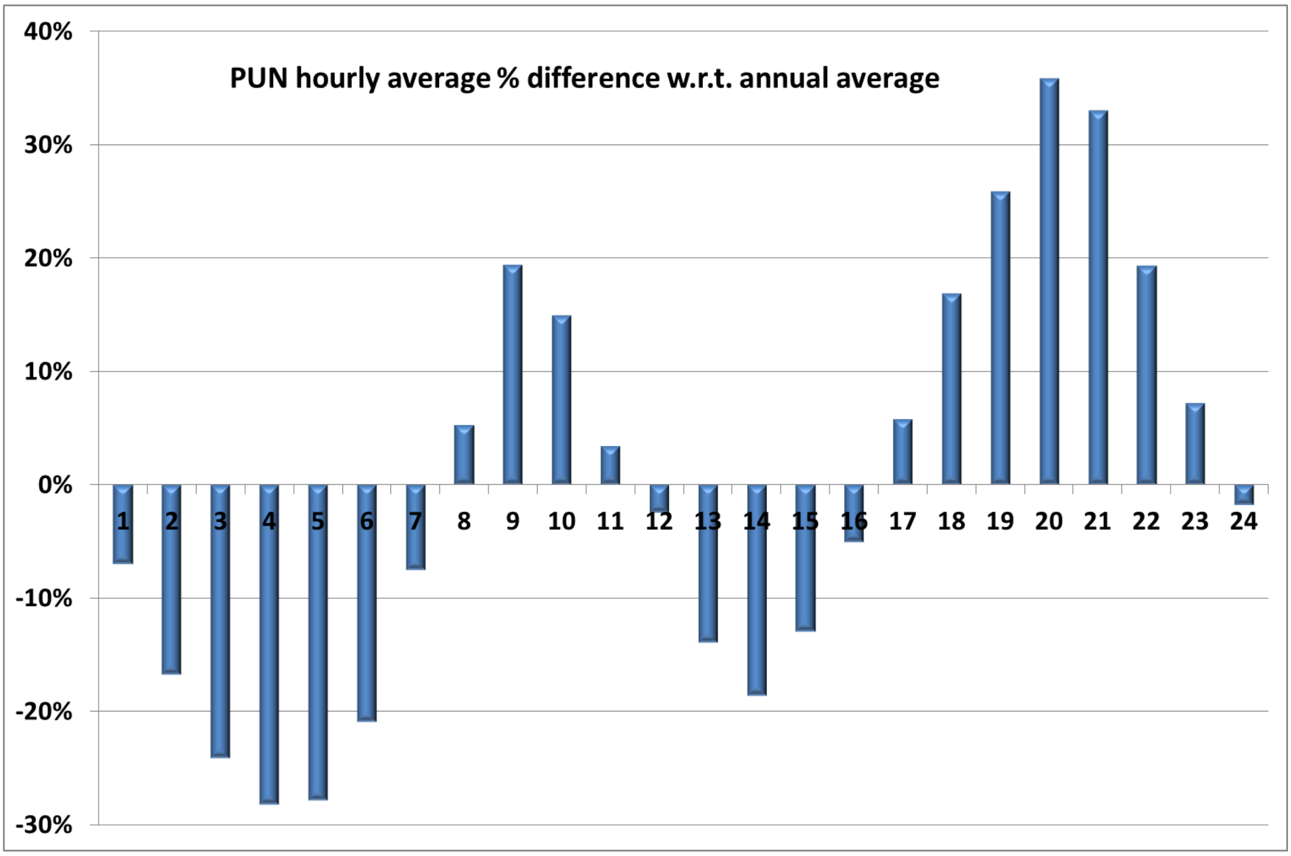

Figure Annex1-25: PUN hourly average percentage difference w.r.t. the overall annual average (source: RSE elaboration on GME data).

It is also interesting to look at the differences of the average hourly PUN profiles in working days and in weekends and holidays (non-working days): see Figure Annex1-26. In the considered period, from 8 p.m. to 5 a.m. PUN was on average similar both in working and in non-working days. In the remaining hours working days PUN was significantly higher.

In Figure 2 the PUN hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (non-working days) is shown. It can be seen that in the considered period the differences were lower in non-working days than in working ones in the first half of the day, while in the second half they were higher.

Figure Annex1-28 shows that in working days the difference ranged about from -30% to +30%, while in non-working days the difference ranged about from -30% to +50%.

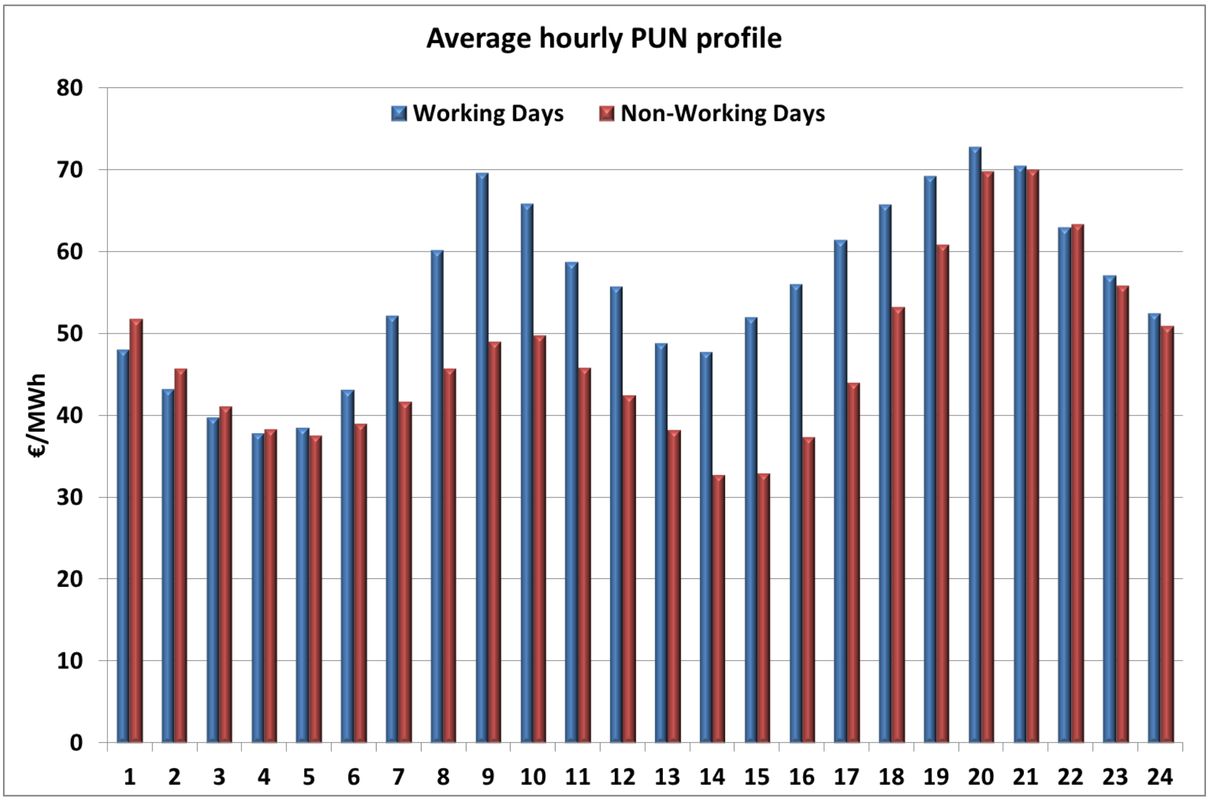

Figure Annex1-26: Average hourly PUN profiles in working days and in weekends and holidays (source: RSE elaboration on GME data).

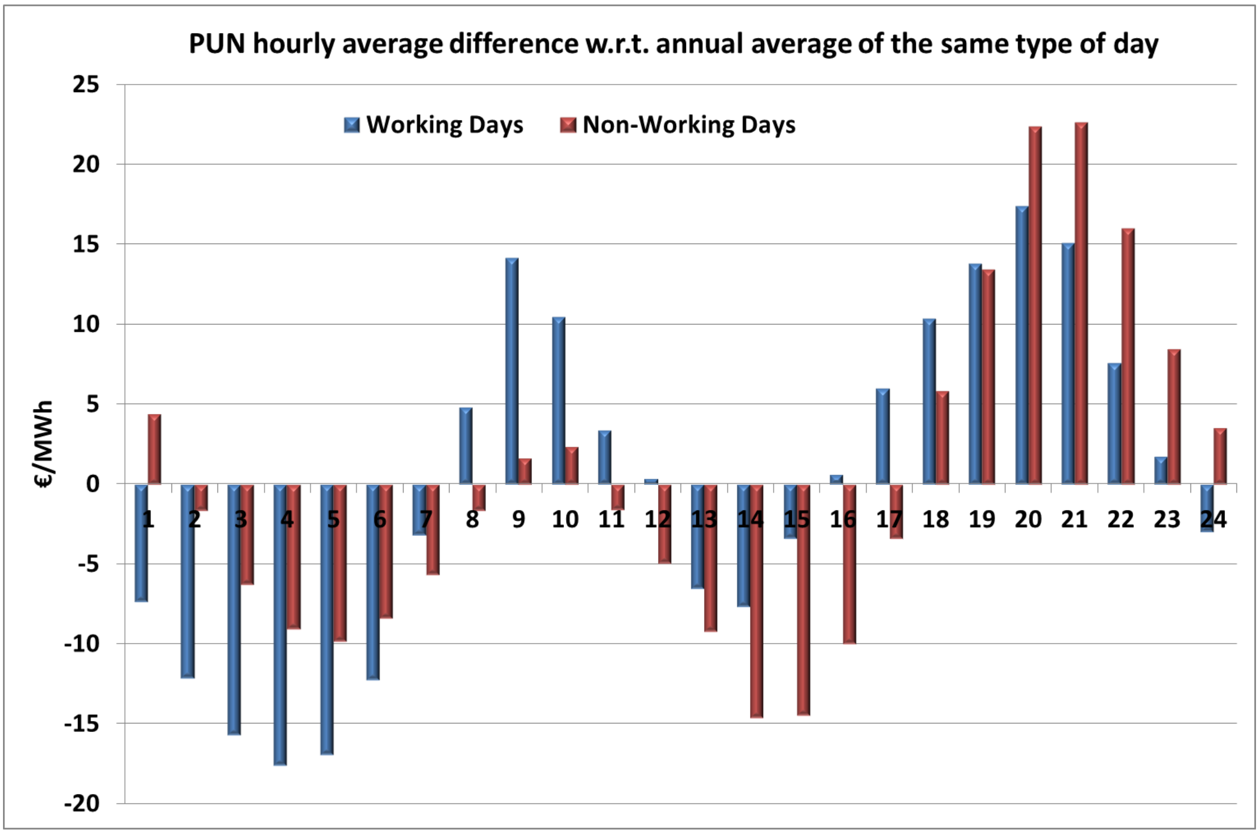

Figure Annex1-27: PUN hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on GME data).

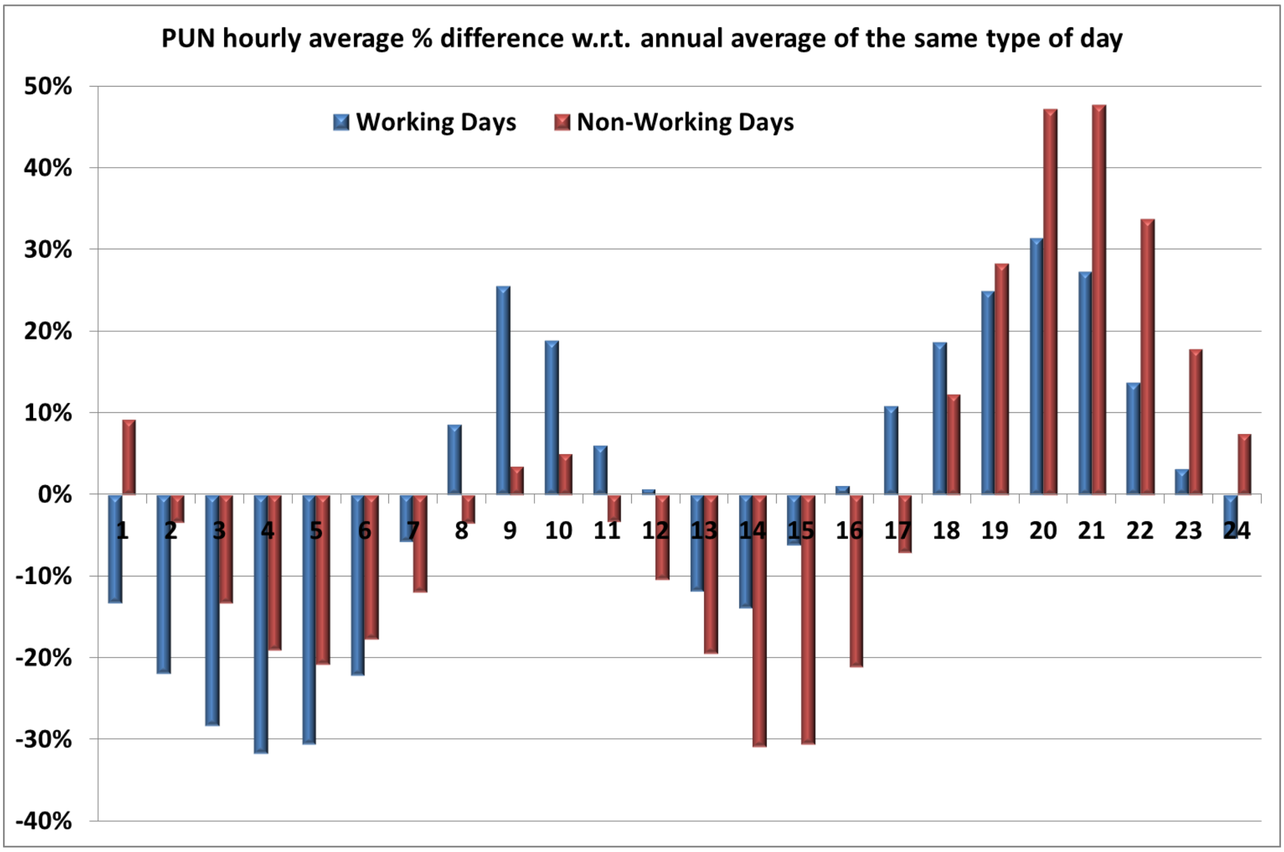

Figure Annex1-28: PUN hourly average percentage difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on GME data).

In Figure Annex1-29, the average hourly PUN profiles in December 2013 and in January and February 2014 are shown. The profiles in the three months are similar (except for the more pronounced evening peak from 5 p.m. to 6 p.m. in December), but with a progressive price reduction.

The profiles of working days, shown in Figure Annex1-30, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-31) show significantly lower prices, especially in February, when PUN, in the last hours of the night and in the first hours of the afternoon, on average is around 25 €/MWh.

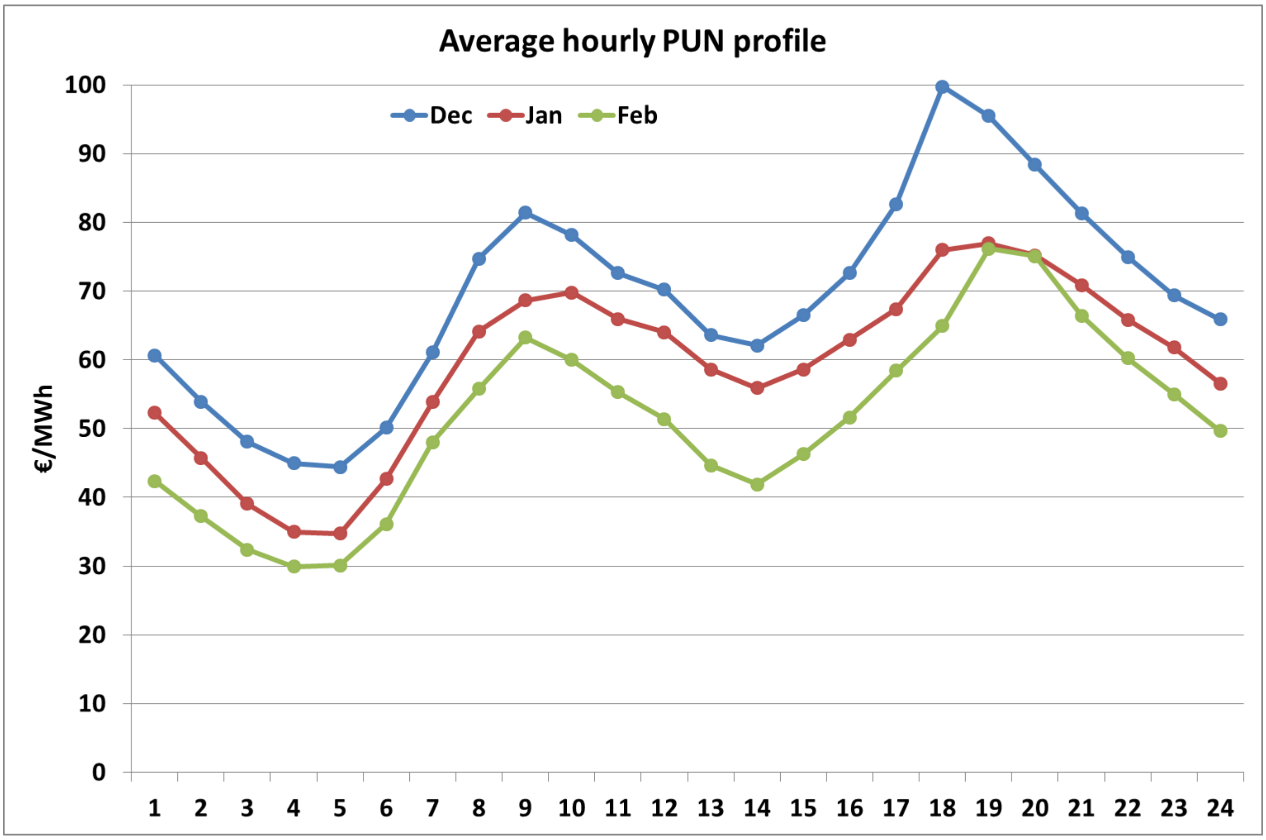

Figure Annex1-29: Average hourly PUN profile in December 2013 and in January and February 2014 (source: RSE elaboration on GME data).

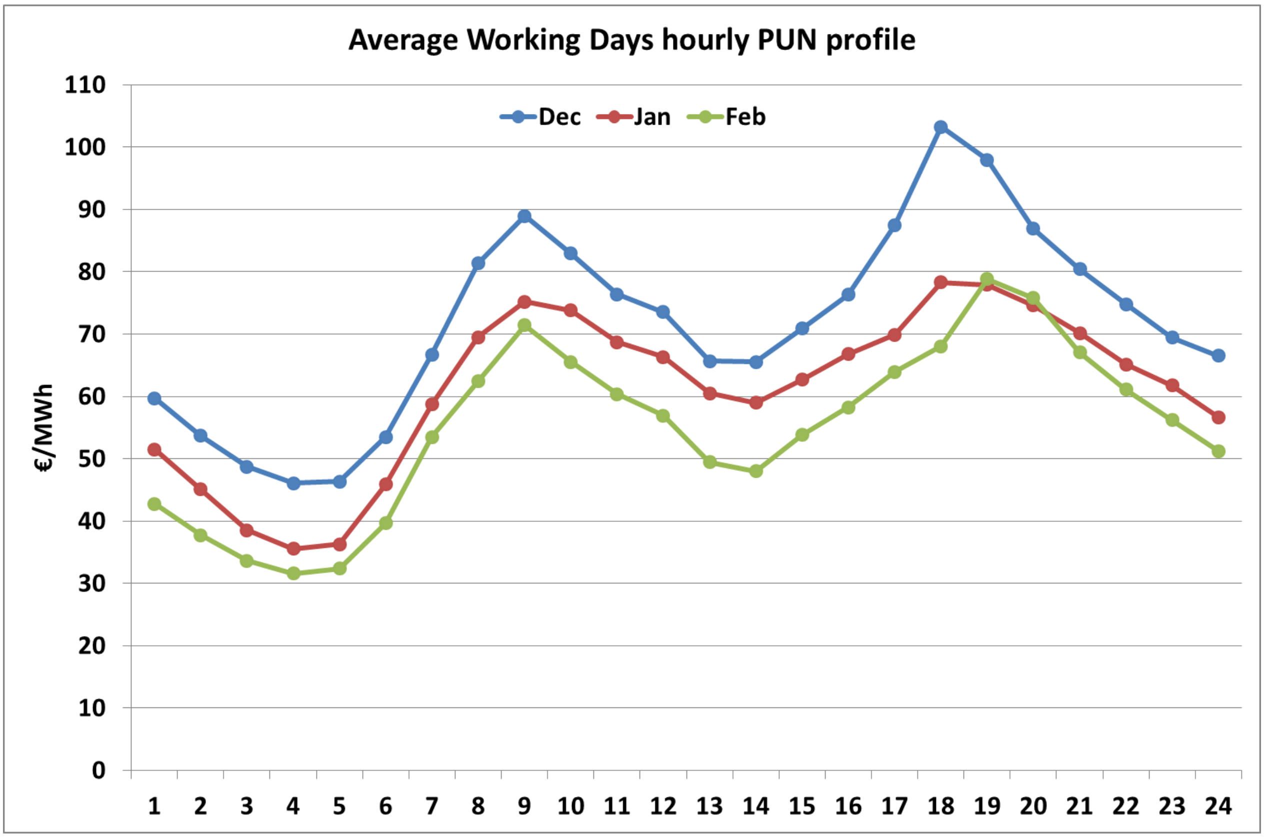

Figure Annex1-30: Average working days hourly PUN profile in December 2013 and in January and February 2014 (source: RSE elaboration on GME data).

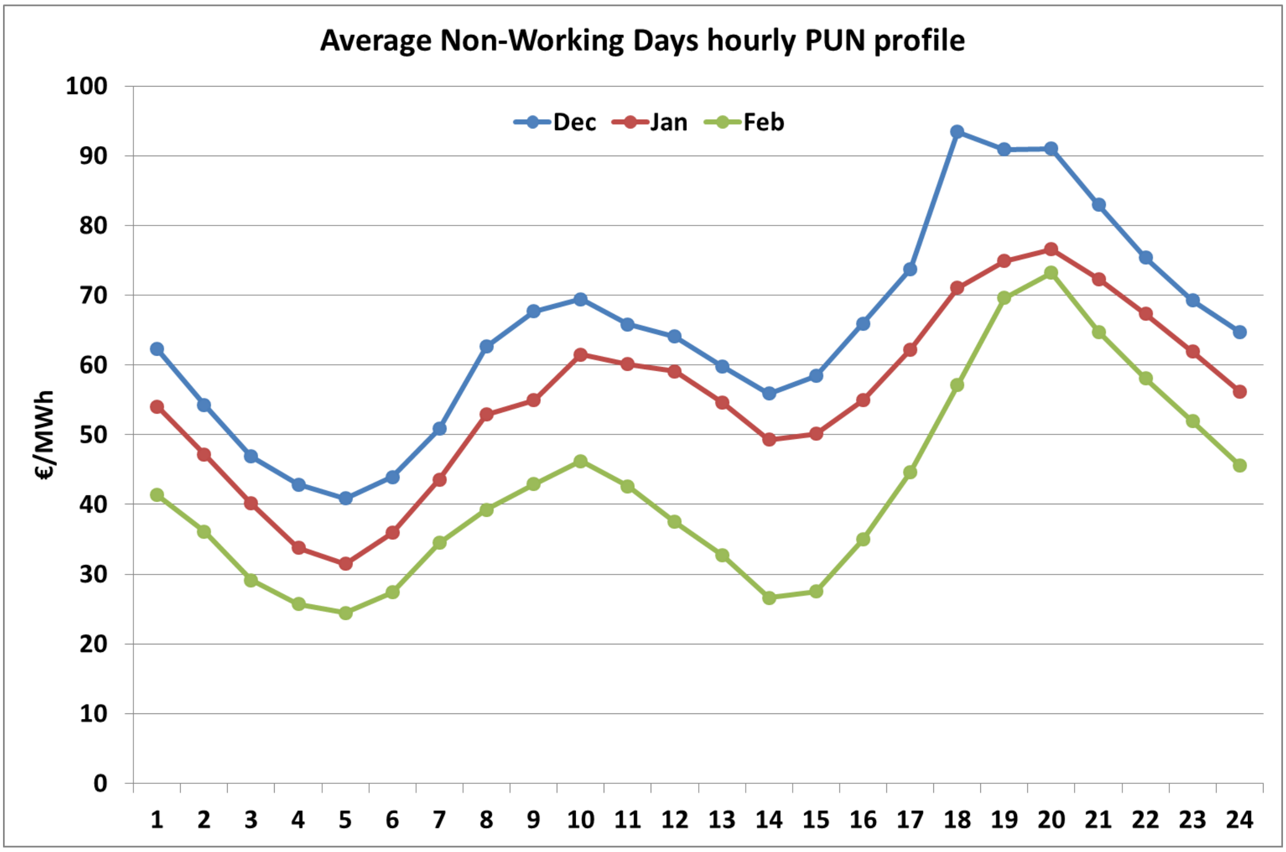

Figure Annex1-31: Average non-working days hourly PUN profile in December 2013 and in January and February 2014 (source: RSE elaboration on GME data).

In Figure Annex1-32, the average hourly PUN profiles in March, April and May 2014 are shown. The profiles in the three months are similar, except for the higher night prices in May and for the more pronounced and anticipated by one hour evening peak in March, when the sunset occurs earlier.

The profiles of working days, shown in Figure Annex1-33, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-34) show a much lower morning peak and significantly lower prices in the first hours of the afternoon, with PUN in March and in May below 20 €/MWh. On the contrary, the evening peak reaches values similar to working days.

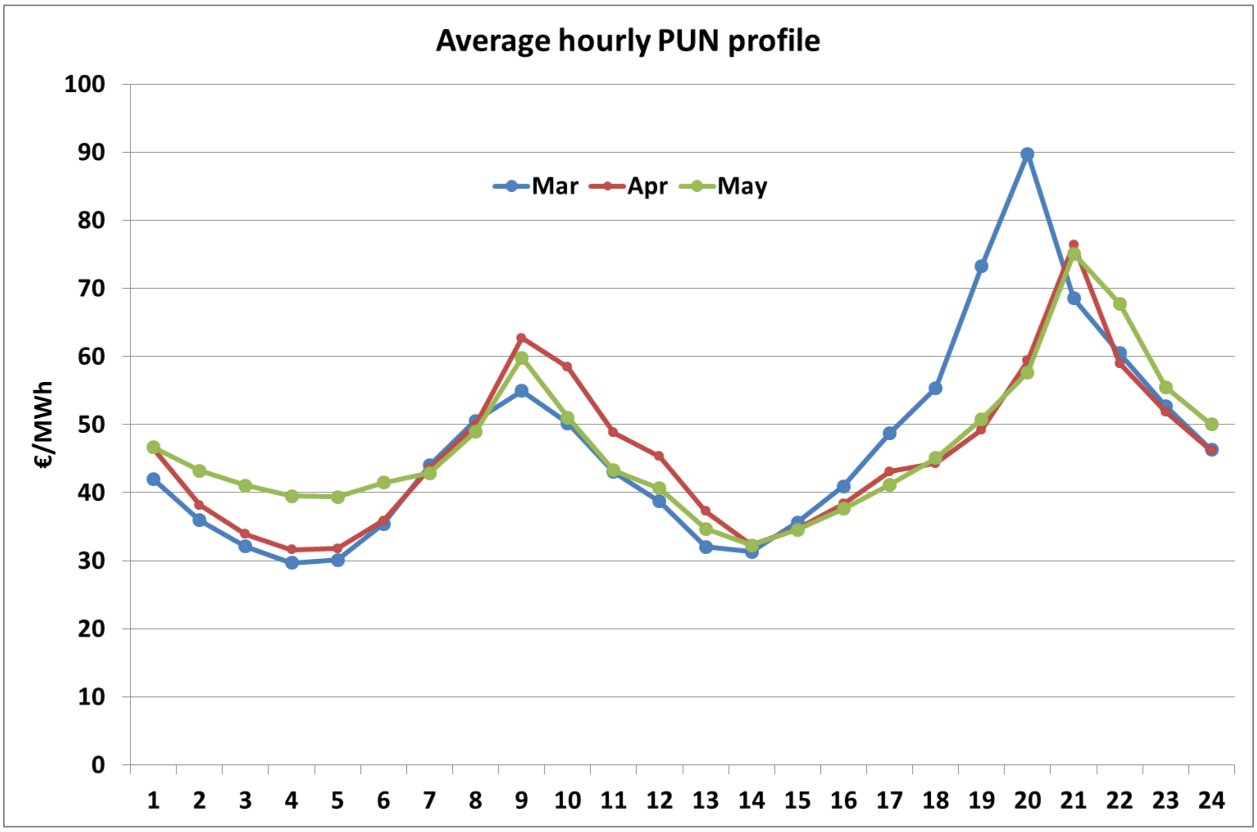

Figure Annex1-32: Average hourly PUN profile in March, April and May 2014 (source: RSE elaboration on GME data).

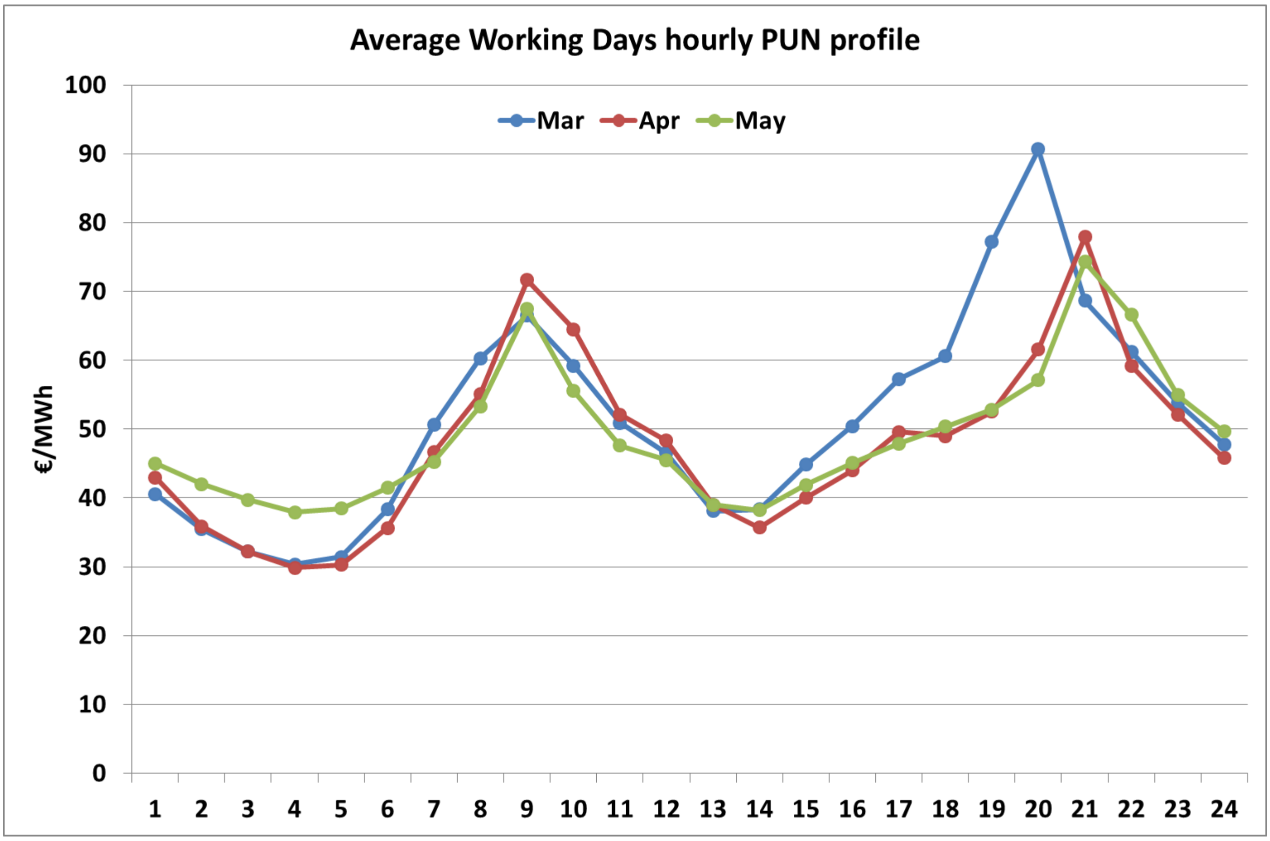

Figure Annex1-33: Average working days hourly PUN profile in March, April and May 2014 (source: RSE elaboration on GME data).

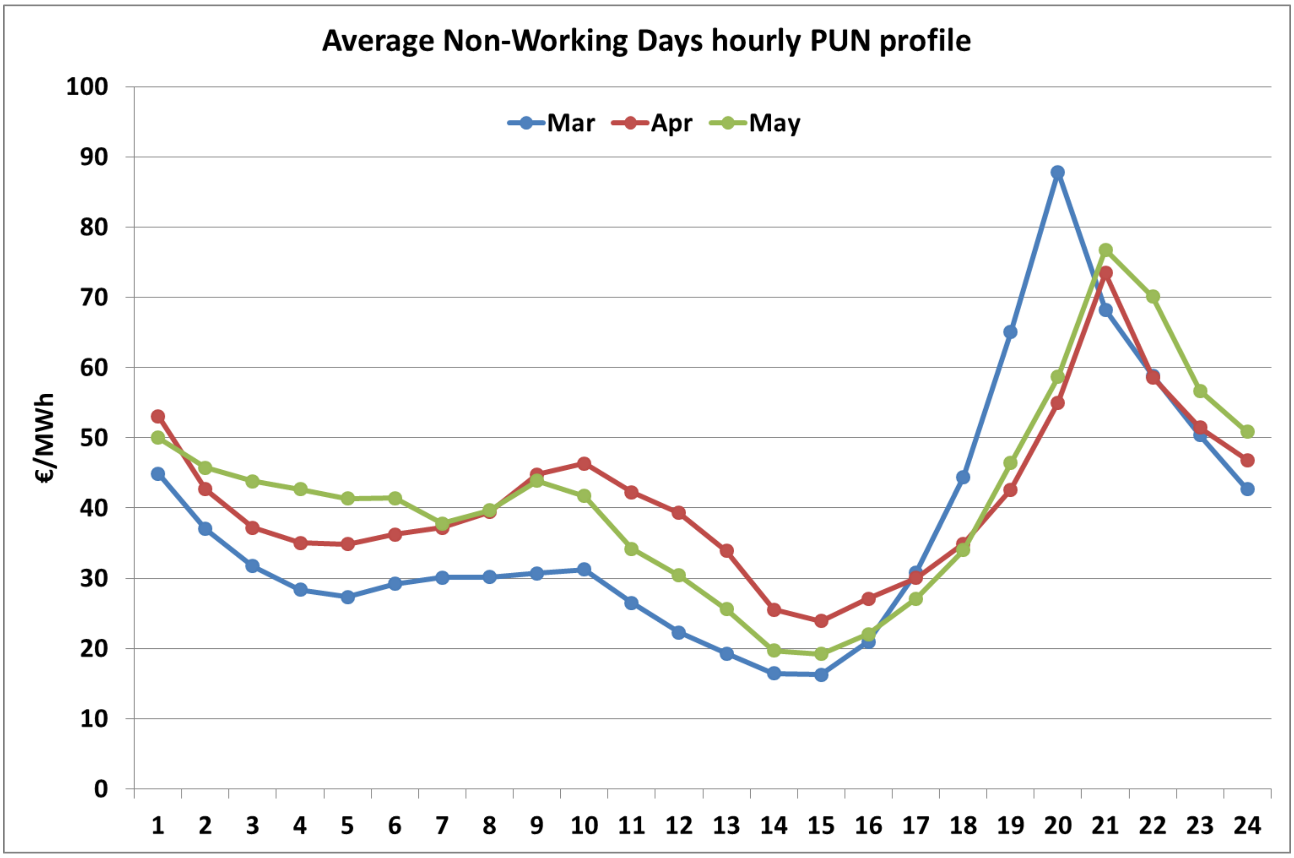

Figure Annex1-34: Average non-working days hourly PUN profile in March, April and May 2014 (source: RSE elaboration on GME data).

In Figure Annex1-35, the average hourly PUN profiles in June, July and August 2014 are shown. The profiles in the three months are similar and quite "flat": prices are almost always between 40 and 60 €/MWh.

The profiles of working days, shown in Figure Annex1-36, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-37) show a quite low morning peak and significantly lower prices in the first hours of the afternoon, with PUN in June approaching 20 €/MWh. On the contrary, the evening peak reaches values similar to working days.

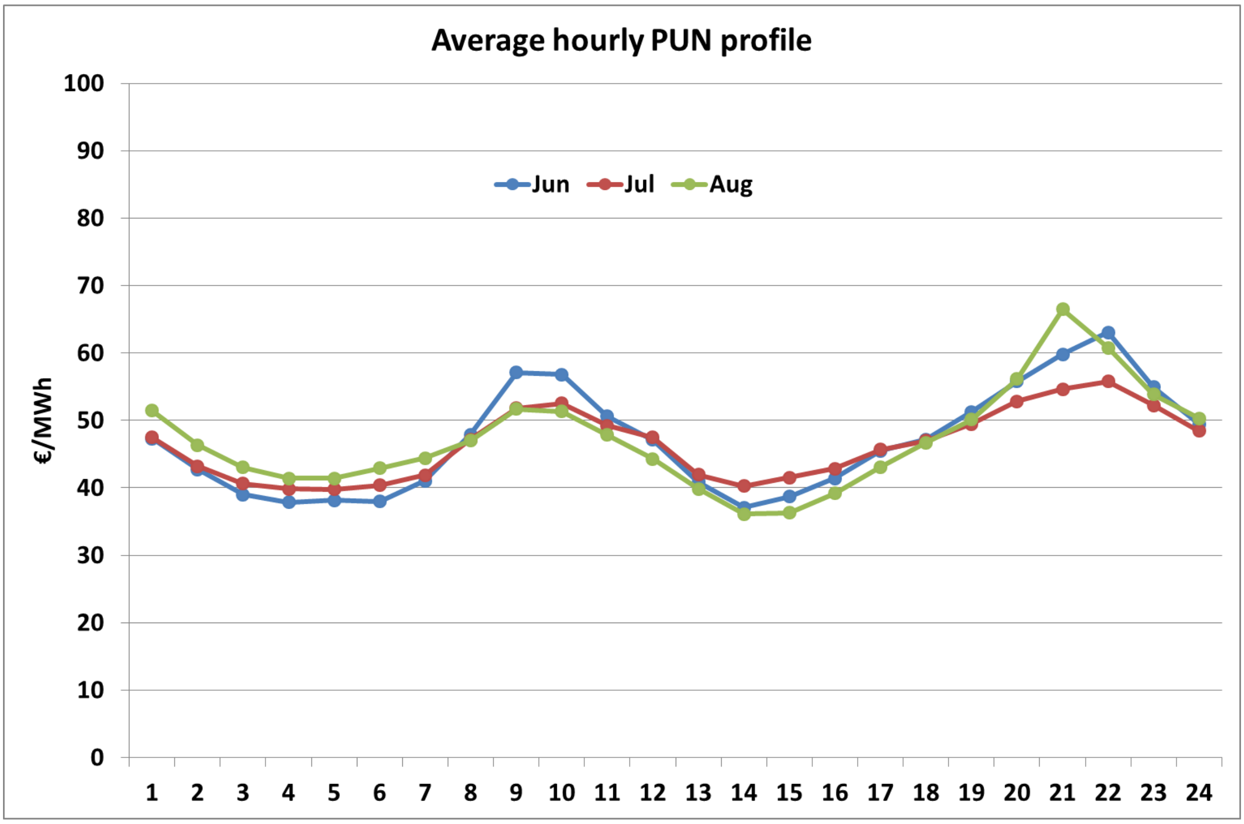

Figure Annex1-35: Average hourly PUN profile in June, July and August 2014 (source: RSE elaboration on GME data).

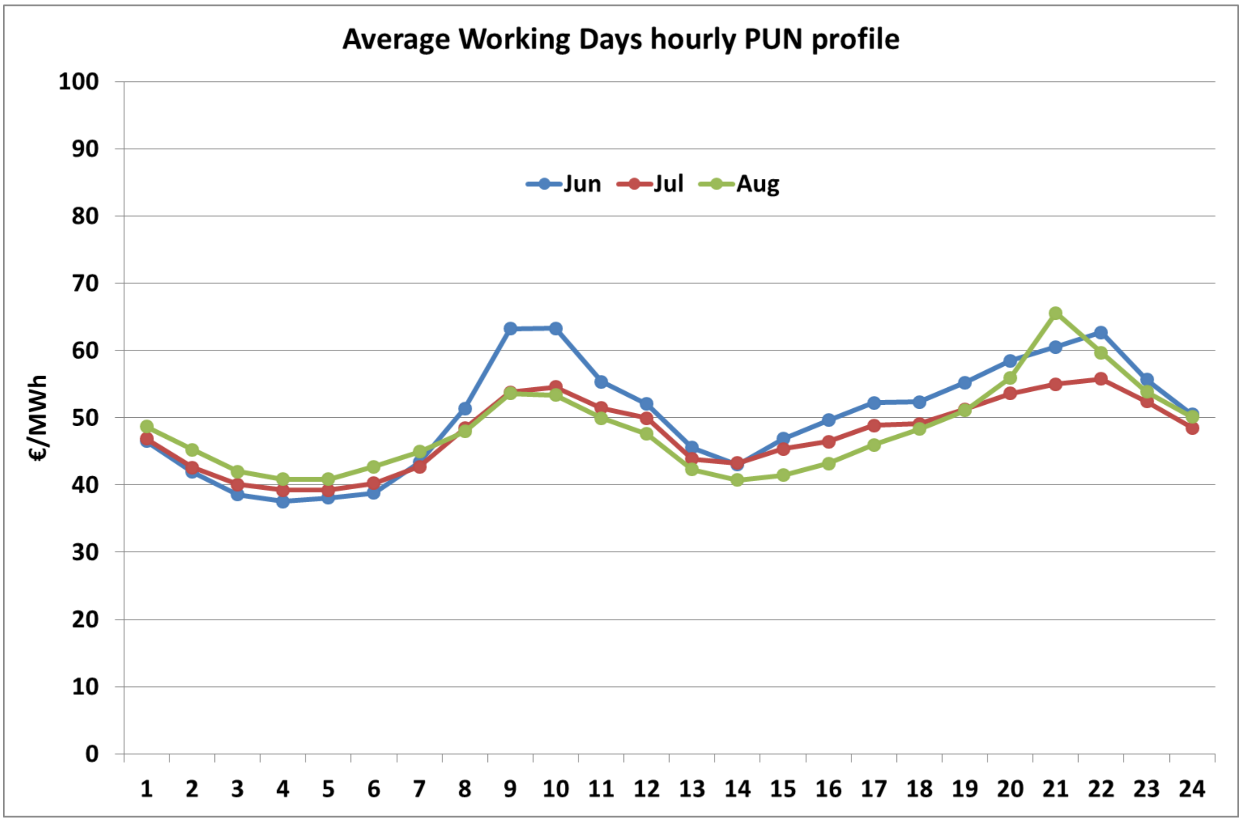

Figure Annex1-36: Average working days hourly PUN profile in June, July and August 2014 (source: RSE elaboration on GME data).

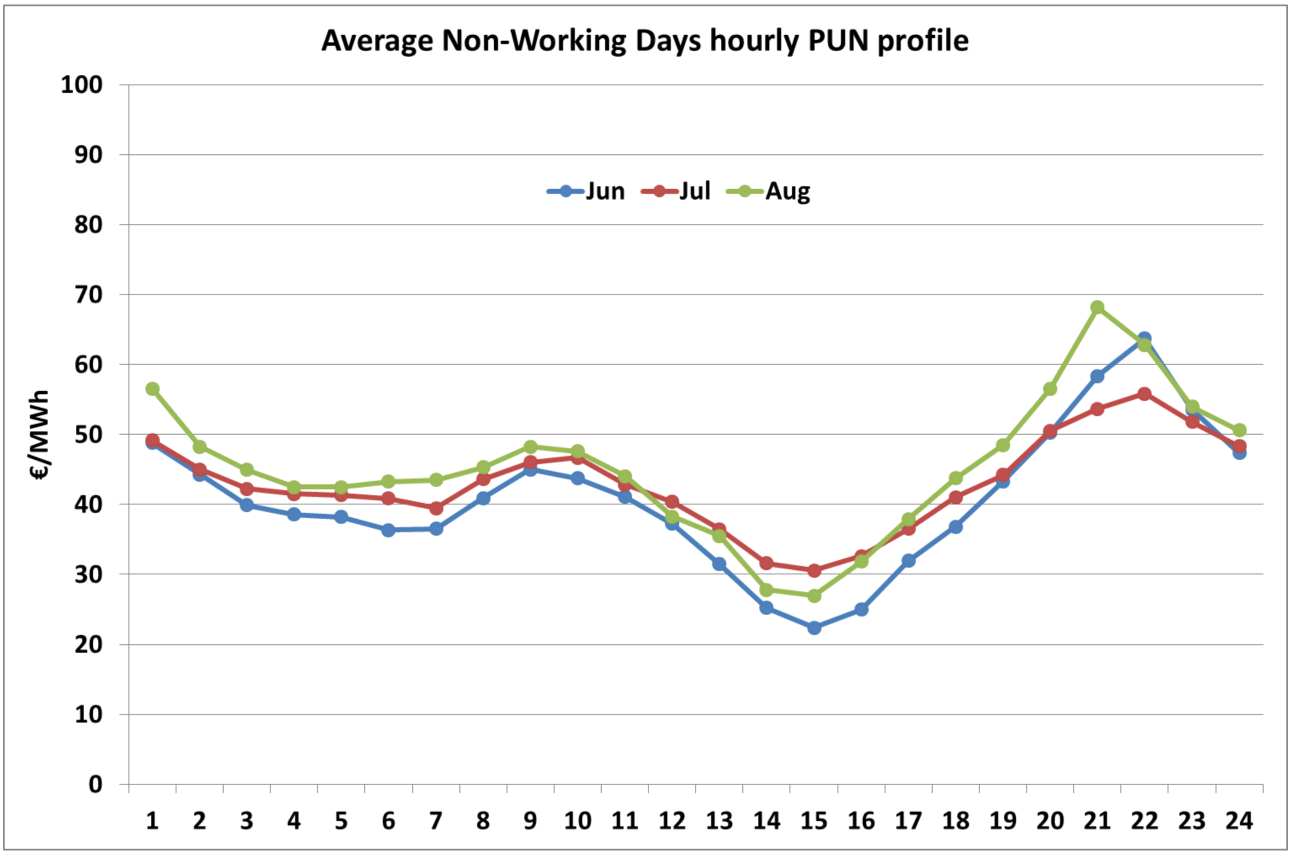

Figure Annex1-37: Average non-working days hourly PUN profile in June, July and August 2014 (source: RSE elaboration on GME data).

In Figure Annex1-38, the average hourly PUN profiles in September, October and November 2014 are shown. In the first half of the day the profiles of September and of October are similar, while the profile of November shows significantly lower prices. In the second half of the day, profiles differentiate for the evening peak, that occurs earlier according to the sunset in the three months and is much higher in October.

The profiles of working days, shown in Figure Annex1-39, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-40) show a quite low morning peak (with much lower prices in November) and lower prices in the first hours of the afternoon. The evening peak reaches values about 10 €/MWh lower than working days.

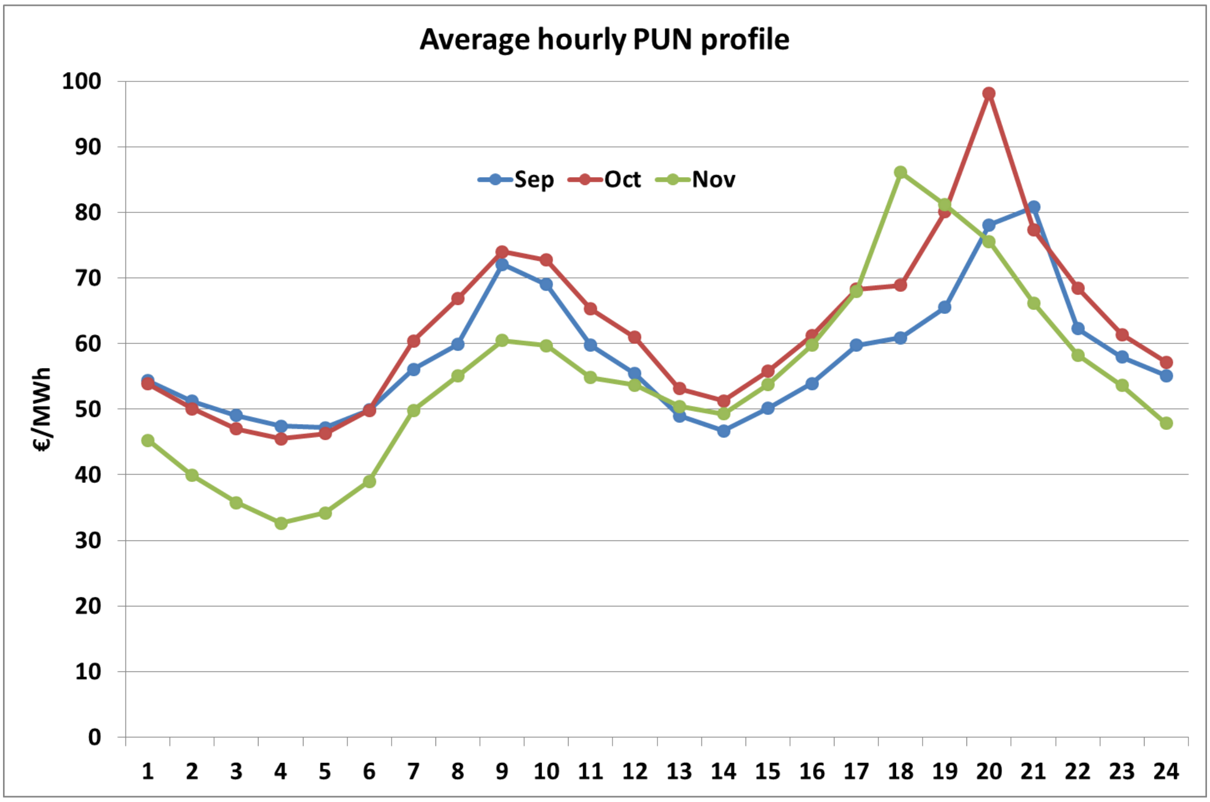

Figure Annex1-38: Average hourly PUN profile in September, October and November 2014 (source: RSE elaboration on GME data).

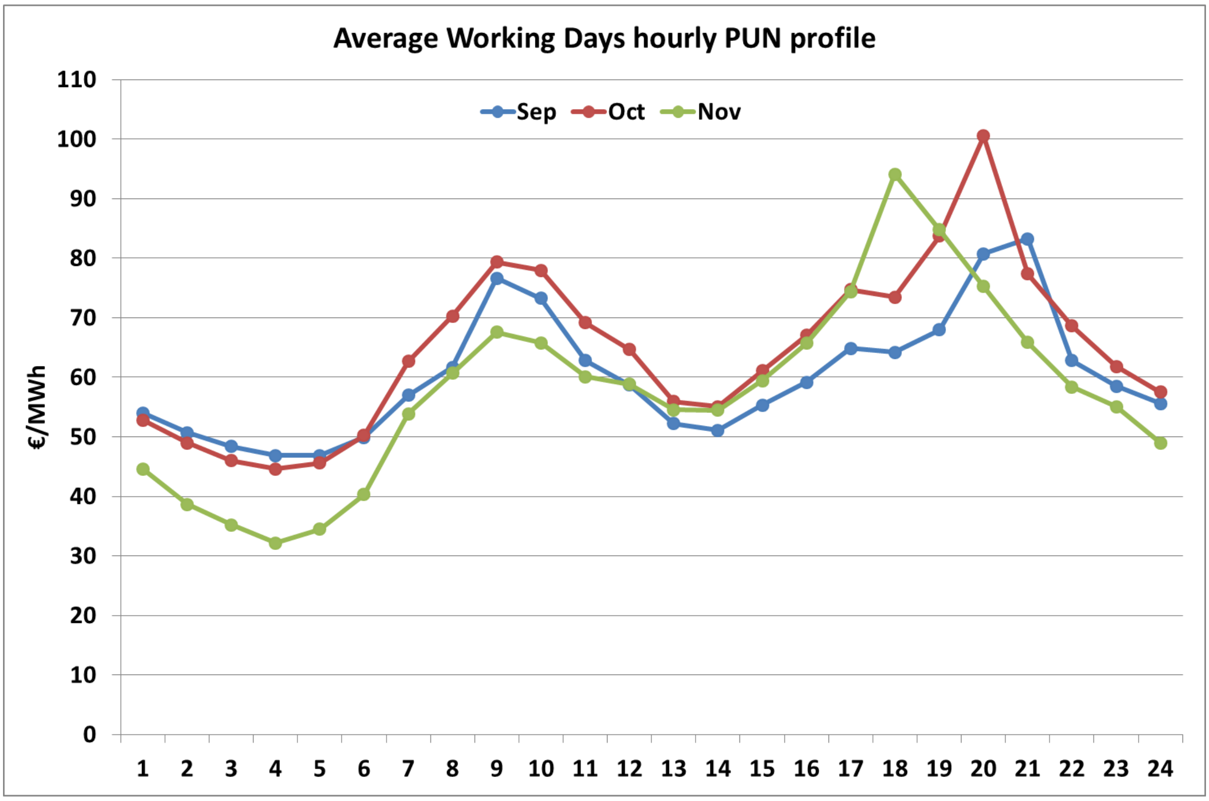

Figure Annex1-39: Average working days hourly PUN profile in September, October and November 2014 (source: RSE elaboration on GME data).

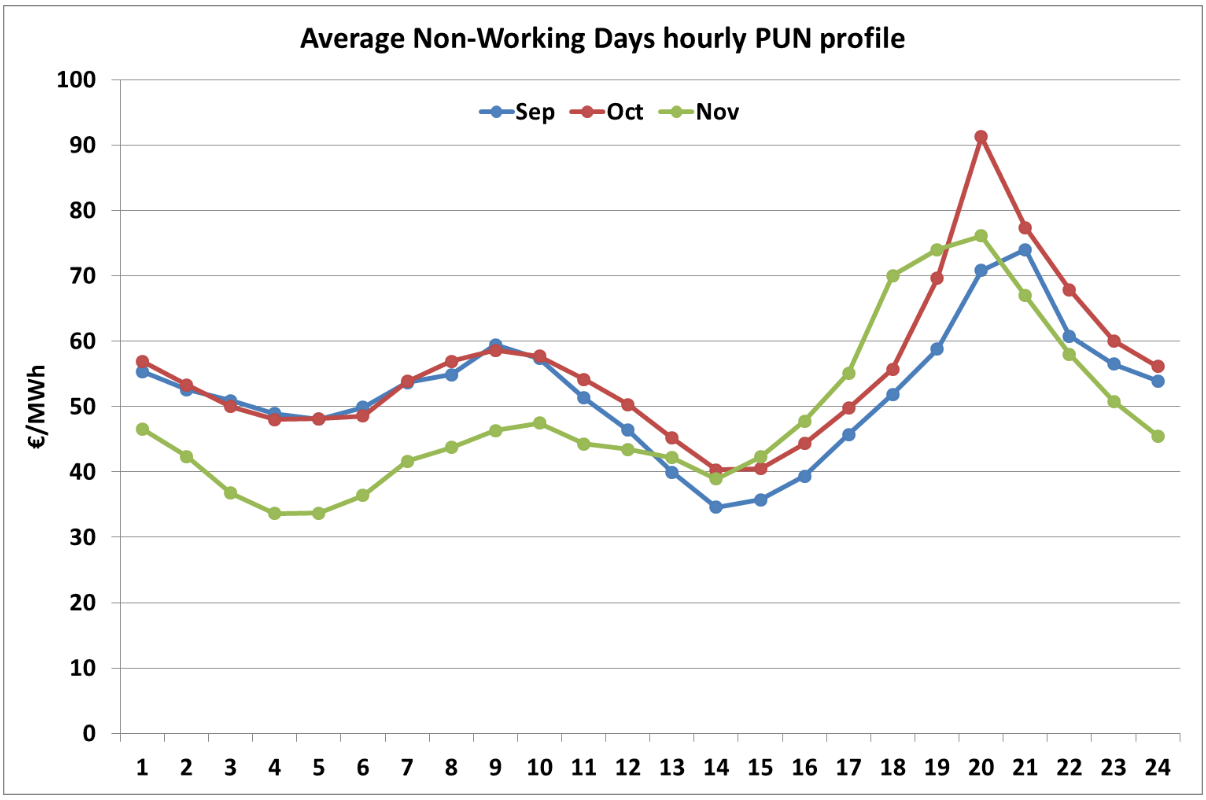

Figure Annex1-40: Average non-working days hourly PUN profile in September, October and November 2014 (source: RSE elaboration on GME data).

3.1.2 Germany

3.1.2.1 Market description

In Germany the trading of energy is managed by the European Energy Exchange (EEX). It is the leading energy exchange in Europe. It develops, operates and connects secure, liquid and transparent markets for energy and related products. On the EEX markets, power, natural gas, CO_2 emission allowances, coal and guarantees of origin are traded. Clearing as well as financial and physical settlement of all trading transactions are provided by European Commodity Clearing (ECC). ECC is a subsidiary of EEX and also provides clearing services for other European exchanges. EEX Group has its headquarters in Leipzig with offices in London, Paris and Brussels.

The EEX Market for the trade of power has three different segments:

1) the Spot Market (trade volume in 2013: 346 TWh) including the day-ahead market and the intra-day market;
2) the Derivatives Market (trade volume in 2013: 1264 TWh);
3) the Trade Registration.

The power **Spot Market** for Germany, France, Austria and Switzerland is operated by EPEX SPOT, a joint venture between EEX and the French power exchange Powernext. Further information on EPEX SPOT is available at www.epexspot.com. On this market, power products with delivery on the same day (Intra-day) or on the following day (Day-ahead) are traded. The spot market permits the short-term optimization of procurement and sale.

Within the **Derivatives Market** trading transactions are only fulfilled financially or physically at a specific time agreed in advance. The derivatives market facilitates medium to long-term portfolio optimisation. Hedging against risks of price changes is possible for up to six years in advance.

The **Trades** have to be registered. Trades concluded bilaterally can be registered on the exchange for clearing. The clearing house provides protection against payment and delivery default.

For the trade of power the following spot markets are supported by the EEXSPOT:

- Day-ahead auction (CH), gate closure at 11 a.m. CET,
- Day-ahead auction (DE/AT, FR), gate closure at 12 a.m. CET,
- Intra-day auction (DE, AT, FR, CH), continuous 24/7.

The Day-ahead auctions are the historical core of the short-term power market. They are organized by EPEX SPOT for the German/Austrian, French and Swiss market areas. Trading takes place one day before the delivery of power. Organized as an auction, market participants send their orders until noon. EPEX SPOT then closes the market and aggregates all bids into supply and demand curves. Price and volume are determined at the intersection of the curves for each hour of the following day. Results are published at 12:55.

The following characteristics have to be mentioned for the day-ahead-market (see **Table Annex1-6)**:

- blind auction procedures, on seven days a week, all year round,
- 24 hours of the respective next day can be traded, hour and block contracts,
- integrated into market coupling (depending on the market area),
- trading via the EPEX trading system (ETS),
- establishment of the Phelix index (Physical Electricity Index) – the reference price on the European wholesale market.

Table Annex1-6: Day ahead auctions by EPEXSpot for Germany / Austria.

Bid types	Place of delivery	Contract size	Tick size	Time of auction
Hours, blocks	Within the TSO zones of 50Hertz Transmission GmbH, Amprion GmbH, TenneT TSO GmbH, TransnetBW GmbH and Austrian Power Grid AG	0.1 MW	€ 0.1 per MWh	12 am CET

3.1.2.2 *Analysis of recent market results*

EPEXSpot has published the results of its operation within the Annual Report 2013 [25]. Figure Annex1-41 shows the results of the trading volumes within the market areas of EEXSPOT in Germany, France and Switzerland.

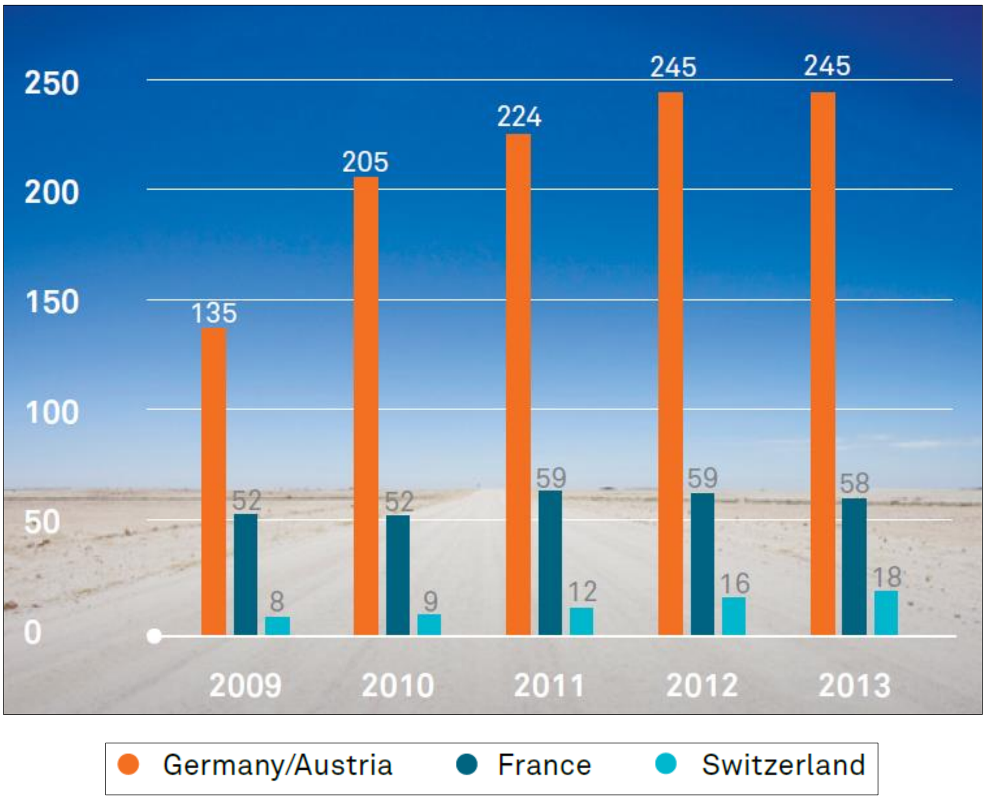

Figure Annex1-41: Trading volumes of EEXSpot on all three day-ahead markets (in TWh).

The figure shows that the trade volume increased to 245 TWh in 2013 and to 263 TWh in 2014.

In Figure Annex1-42 the yearly average base price of the day-ahead markets is shown (in €/MWh). In Germany it fell below 40 €/MWh since 2013.

25 EPEXSpot Annual Report 2013: http://static.epexspot.com/document/29102/EPEX%20SPOT%20Annual%20Report%202013.pdf

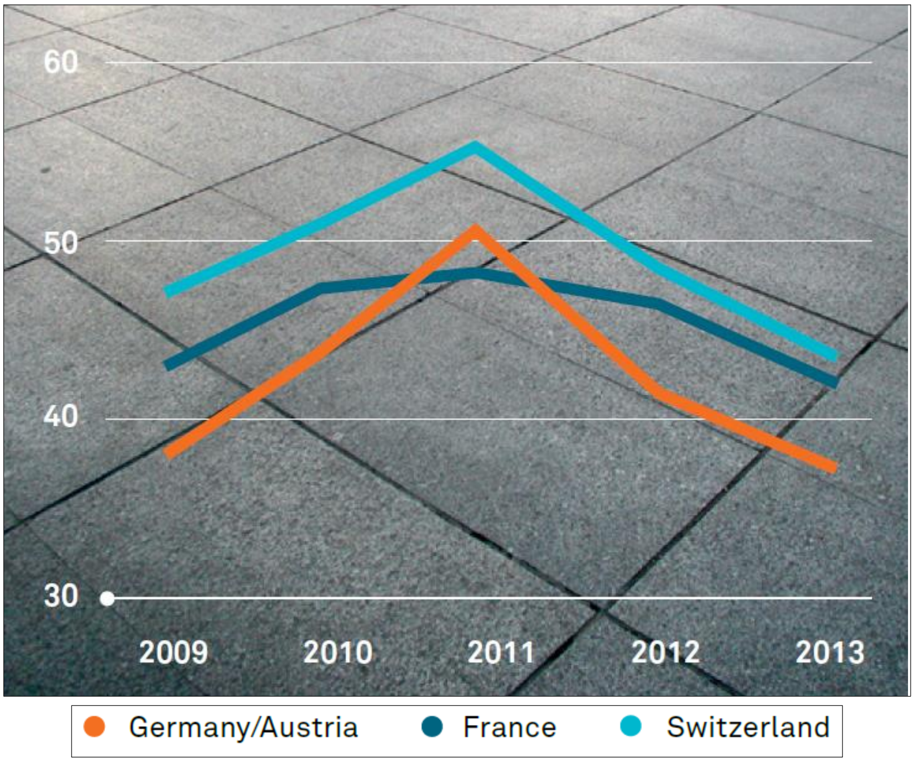

Figure Annex1-42: Yearly average base price of the Day-Ahead market (in €/MWh).

Since we are specifically interested in purchases of electric energy on the day-ahead market, to look for opportunities to take profit from demand flexibility, in the following the analysis will focus on the price in the one-year period between December 2013 and November 2014.

The following Figure Annex1-43 shows hourly price values in the considered period. Price variability is clear: values range from -65.03 €/MWh to 116.53 €/MWh. Negative prices occurred in 60 hours.

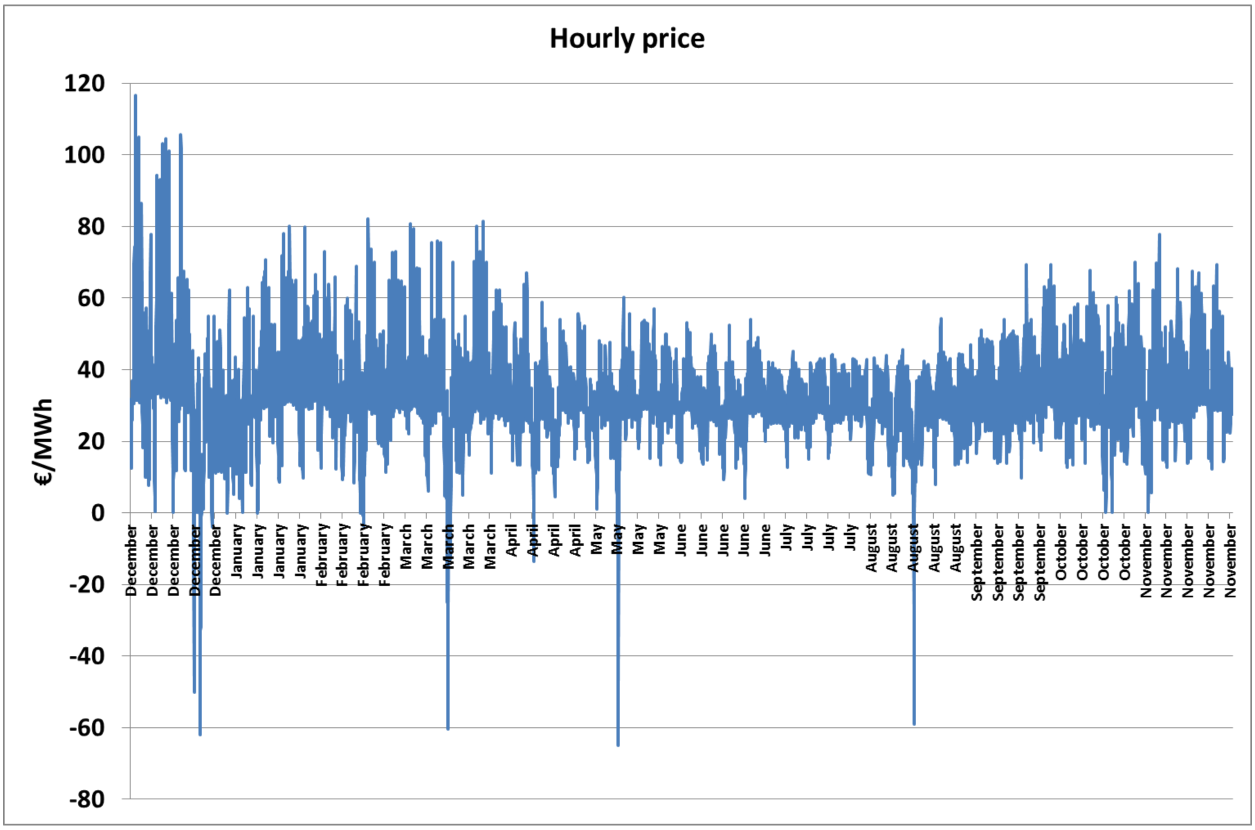

Figure Annex1-43: Hourly price values from December 2013 to November 2014 (source: RSE elaboration on EPEX Spot data).

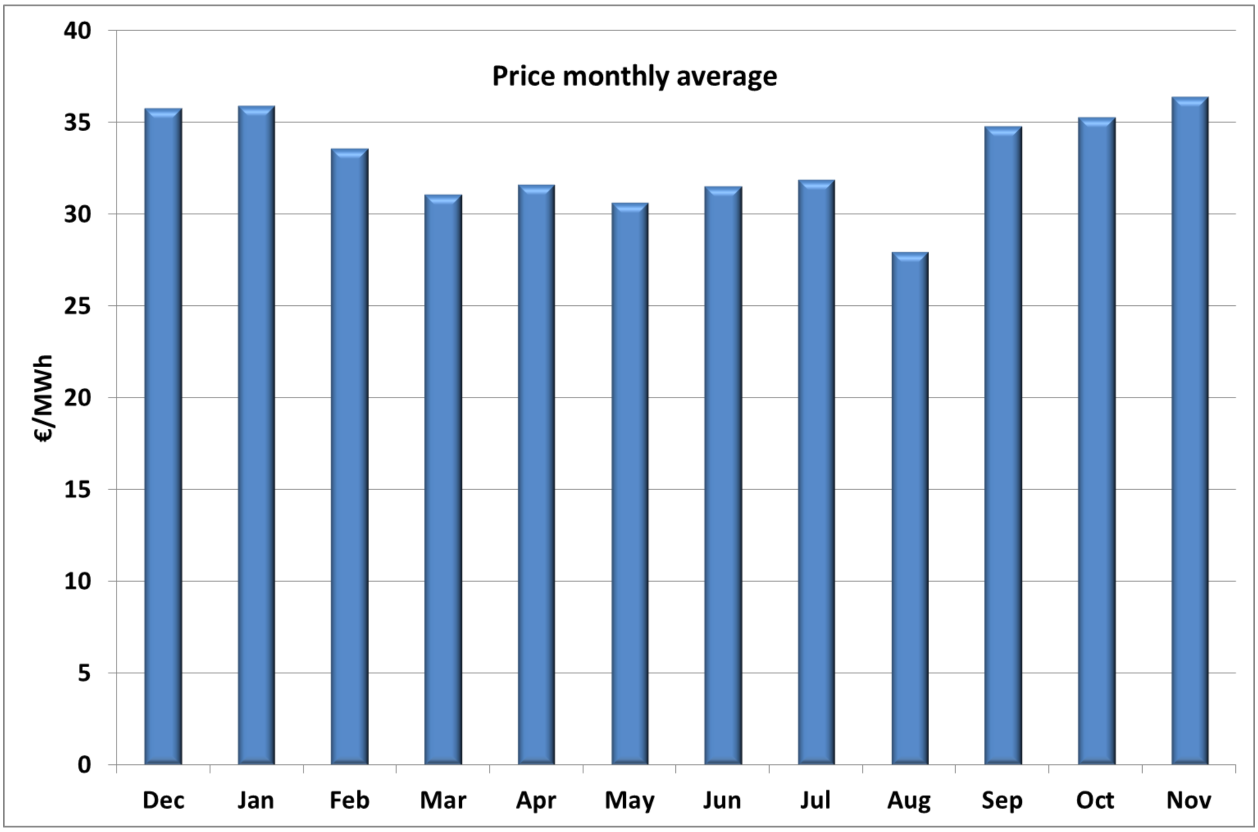

Figure Annex1-44: Price monthly average (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-44 the price monthly average is shown. Just like in Italy, the months from March to August show the lowest values, also due to the high renewable generation (especially photovoltaic) that characterizes such months.

In Figure Annex1-45 the price monthly average in working days and in weekends and holidays (non-working days) is shown. Since demand in non-working days is lower, also electric energy prices are lower. In the considered period, price reduction in non-working days ranged from about 18% (6.6 €/MWh) to about 41% (13.3 €/MWh). The largest reduction is 14.67 €/MWh in December.

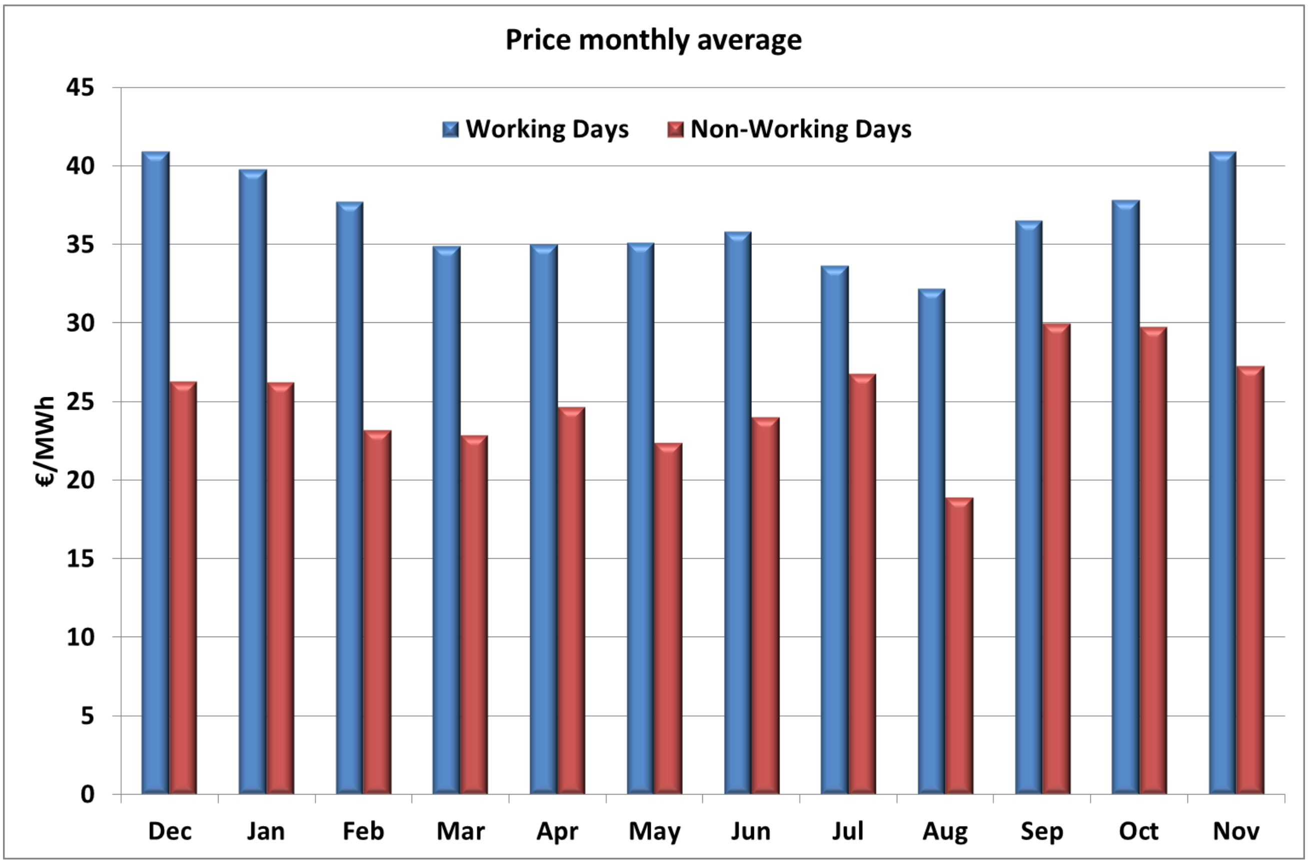

Figure Annex1-45: Price monthly average in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-46 the average hourly price profile is shown. In the considered period the price on average reached the lowest minimum between 3 and 5 a.m. (when demand is low), followed by a first peak from 8 to 9 a.m. (demand rises steeply and photovoltaic generation is still low), followed by a second minimum from 2 to 3 p.m. (photovoltaic generation is high) and then followed by the highest peak from 7 p.m. to 8 p.m. (photovoltaic generation stops and demand is still high).

In Figure Annex1-47 the price hourly average difference w.r.t. the overall annual average is shown. In the considered period, consuming electric energy between 11 p.m. and 7 a.m. and between 1 p.m. and 4 p.m. would have allowed to pay a price lower than the annual average (saving from less than 1 €/MWh to about 12 €/MWh), while in the remaining hours the price paid would have been higher than the annual average (range from about +1 €/MWh to about +12 €/MWh).

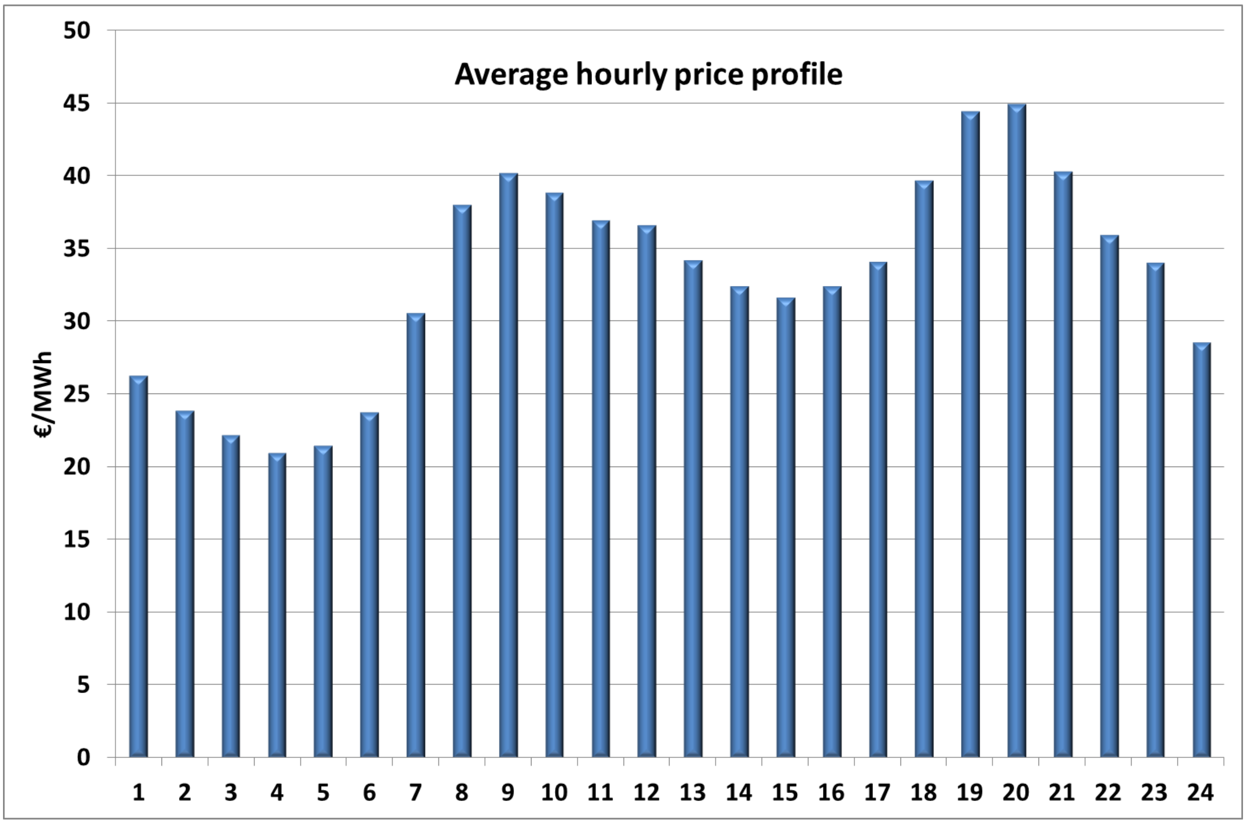

Figure Annex1-46: Average hourly price profile (source: RSE elaboration on EPEX Spot data).

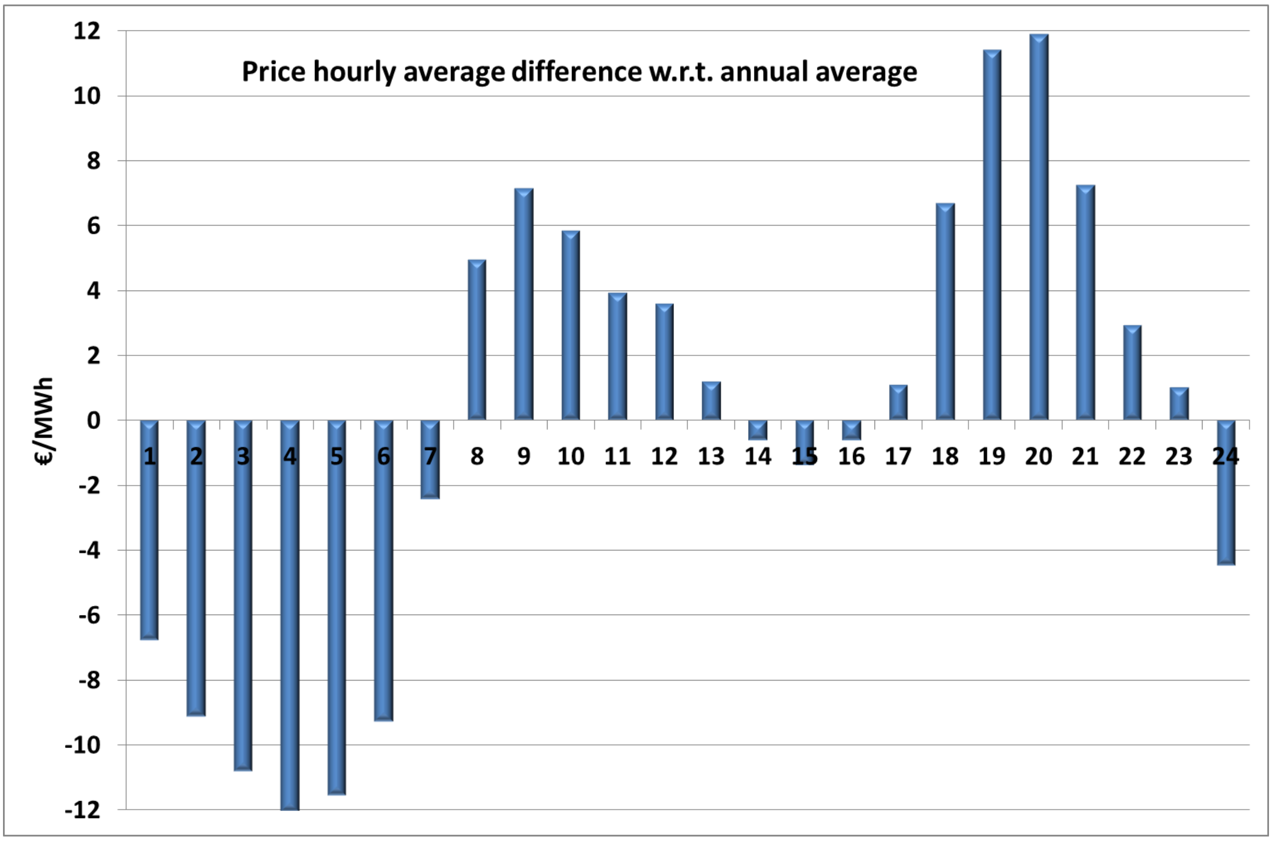

Figure Annex1-47: price hourly average difference w.r.t. the overall annual average (source: RSE elaboration on EPEX Spot data).

In terms of average percentage difference (Figure Annex1-25), in the considered period, consuming electric energy between 11 p.m. and 7 a.m. and between 1 p.m. and 4 p.m. would have allowed to pay a price lower than the annual average (saving from about 2% to about 36%), while in the remaining hours the price paid would have been higher than the annual average (range from about +3% to about +36%).

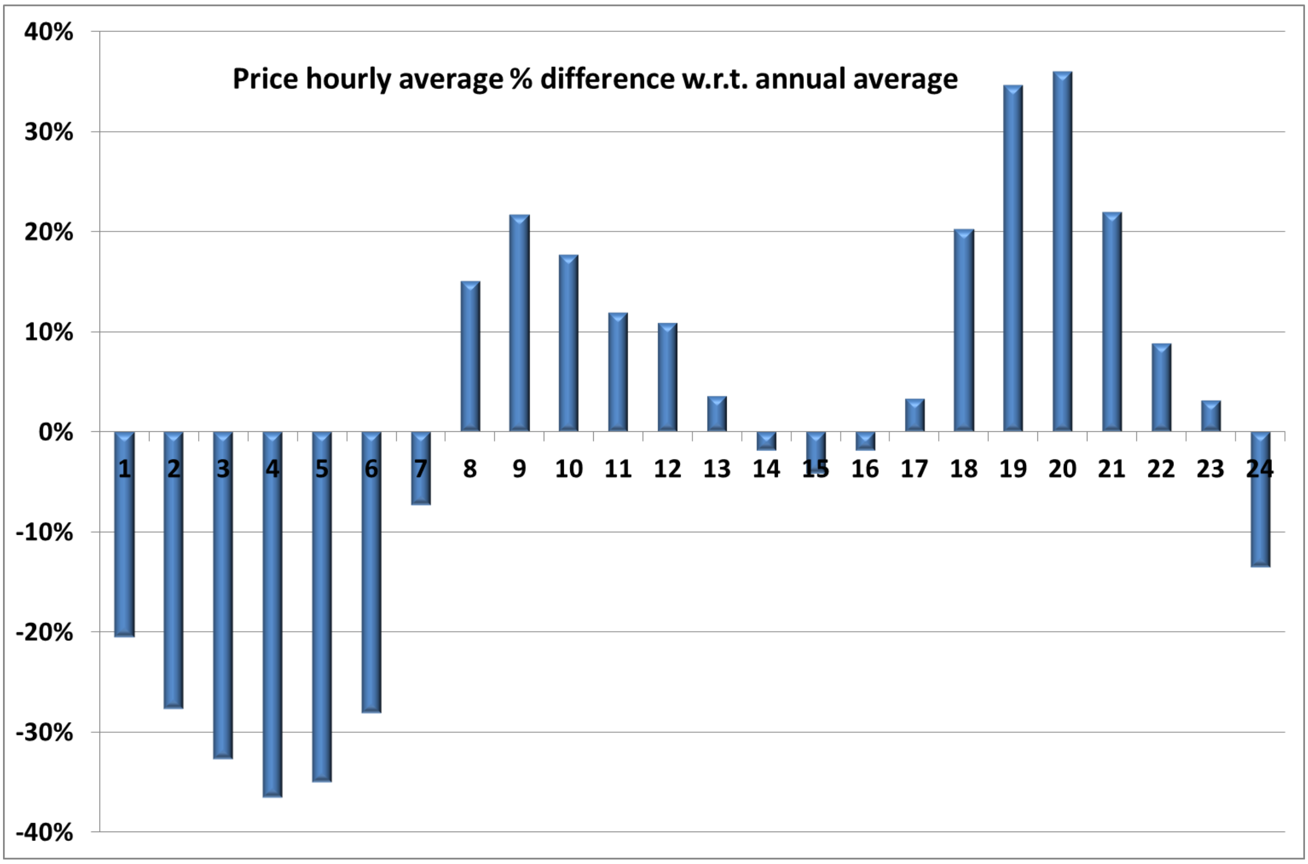

Figure Annex1-48: price hourly average percentage difference w.r.t. the overall annual average (source: RSE elaboration on EPEX Spot data).

It is also interesting to look at the differences of the average hourly price profiles in working days and in weekends and holidays (non-working days): see Figure Annex1-49. In the considered period, working days price was always higher, but with a limited difference during the night.

In Figure Annex1-50 the price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (non-working days) is shown. It can be seen that in the considered period the differences were lower in non-working days than in working ones in the first half of the day, while in the second half they were in most cases higher.

Figure Annex1-51 shows that in working days the difference ranged about from -40% to +33%, while in non-working days the difference ranged about from -27% to +47%.

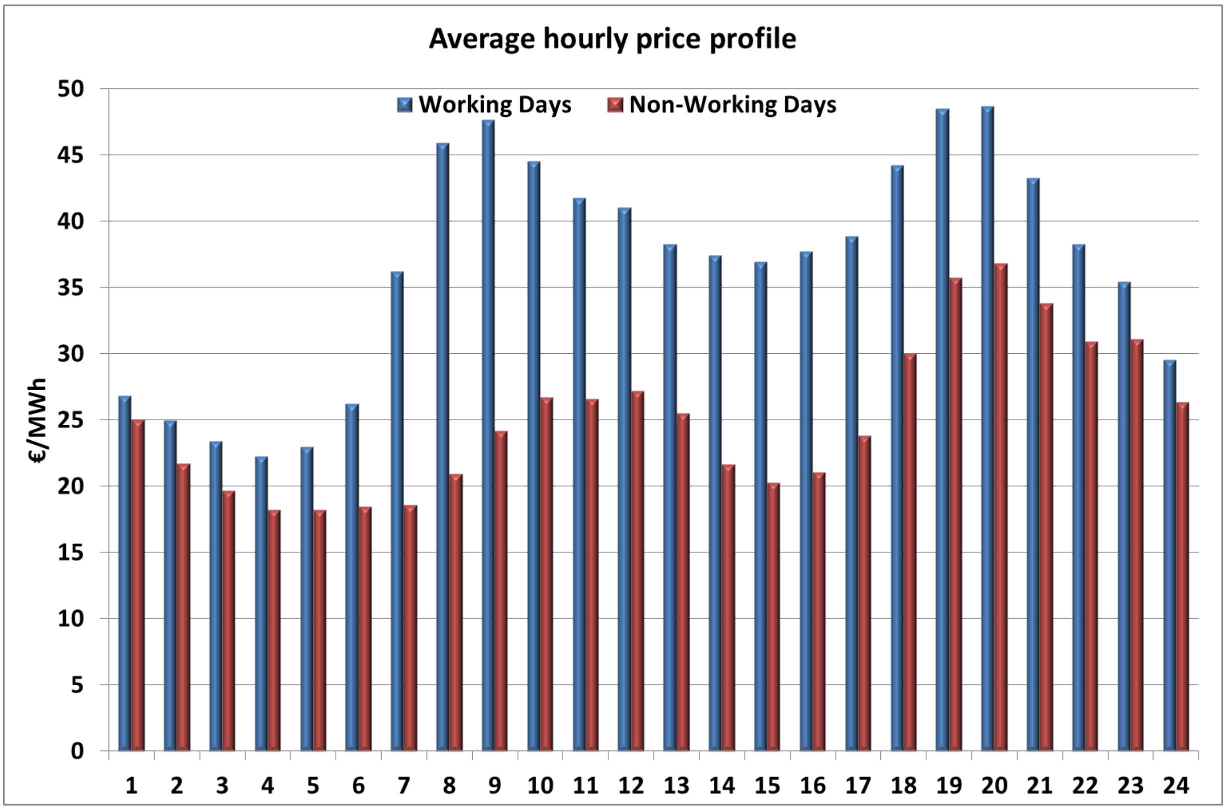

Figure Annex1-49: Average hourly price profiles in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

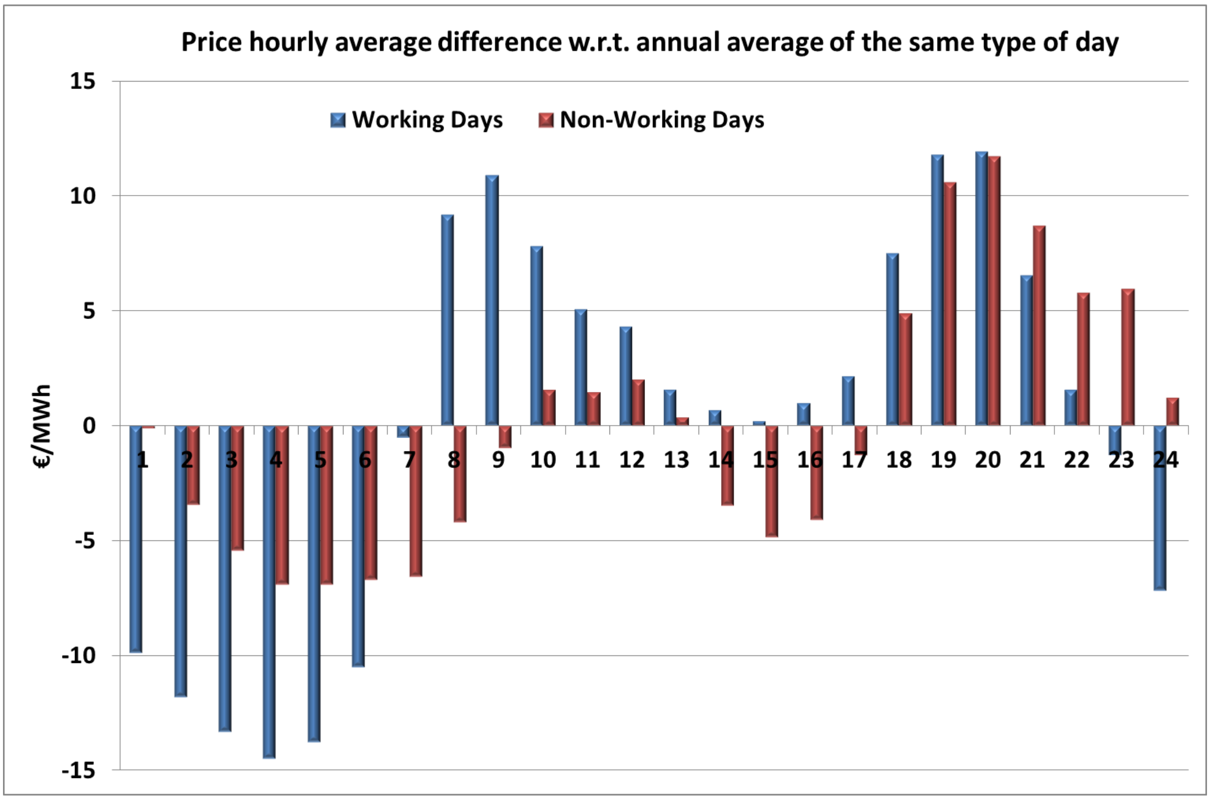

Figure Annex1-50: price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

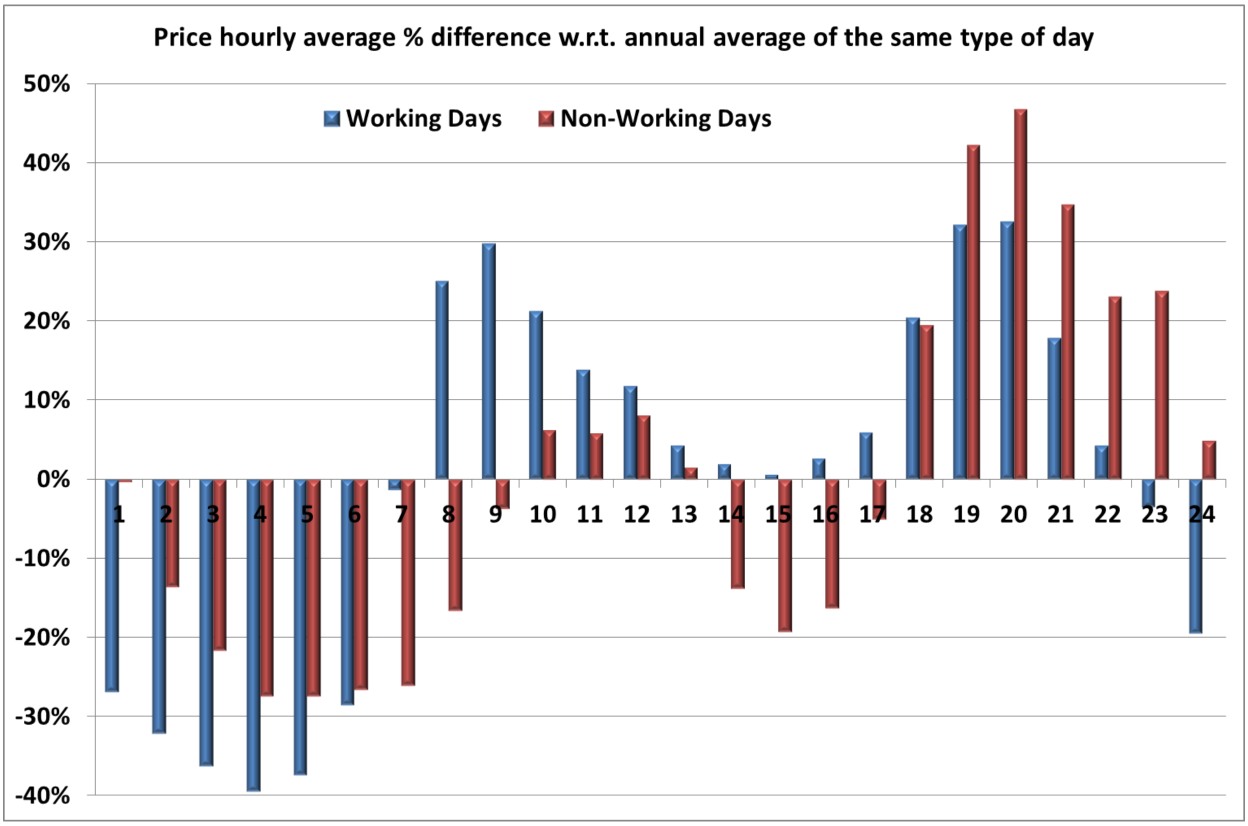

Figure Annex1-51: price hourly average percentage difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-52, the average hourly price profiles in December 2013 and in January and February 2014 are shown. The profiles in the three months are similar (except for the more pronounced evening peak from 5 p.m. to 6 p.m. in December). Prices during daytime in February are lower, probably due to the impact of photovoltaic generation, higher than in December and in January.

The profiles of working days, shown in Figure Annex1-53, are characterized by higher morning and evening peaks, while profiles of non-working days (Figure Annex1-54) show significantly lower prices, especially in February during daytime.

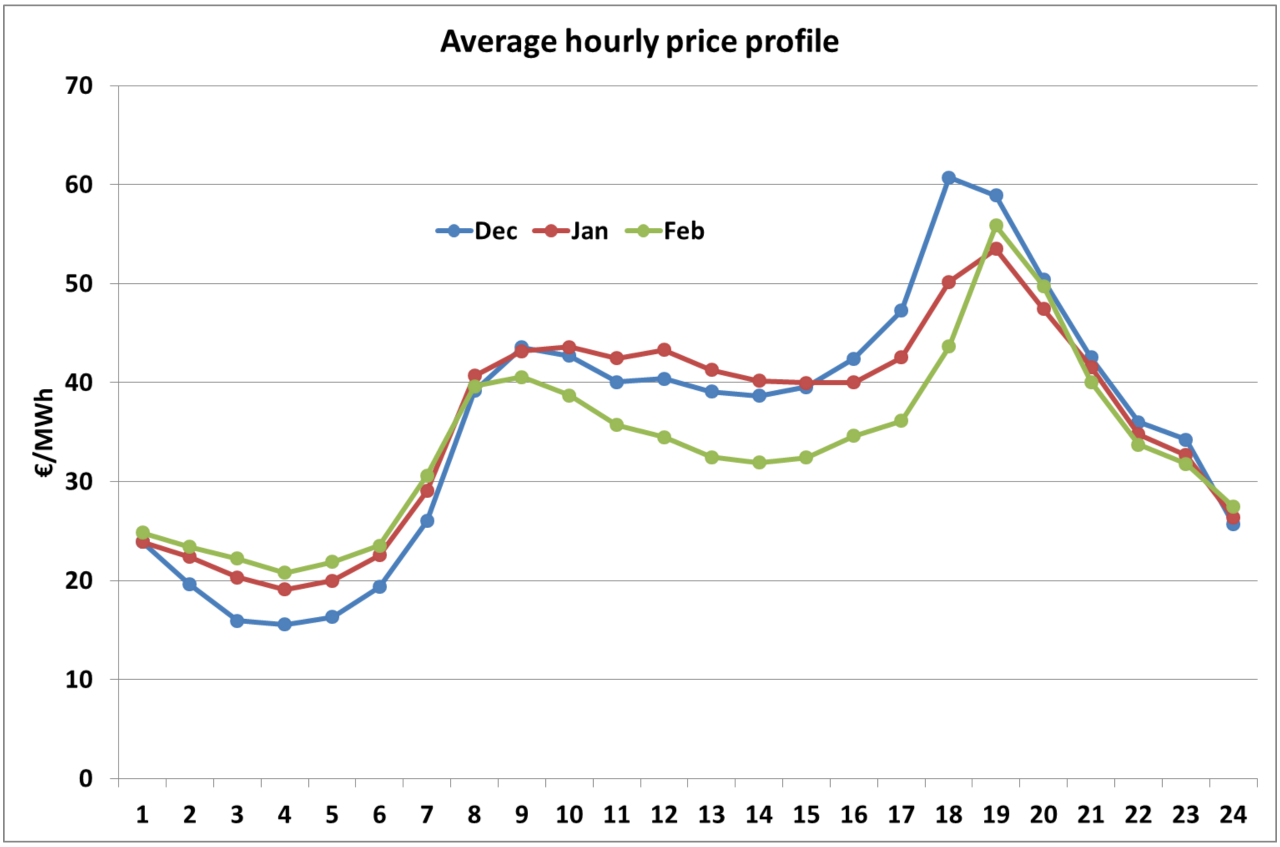

Figure Annex1-52: Average hourly price profile in December 2013 and in January and February 2014 (source: RSE elaboration on EPEX Spot data).

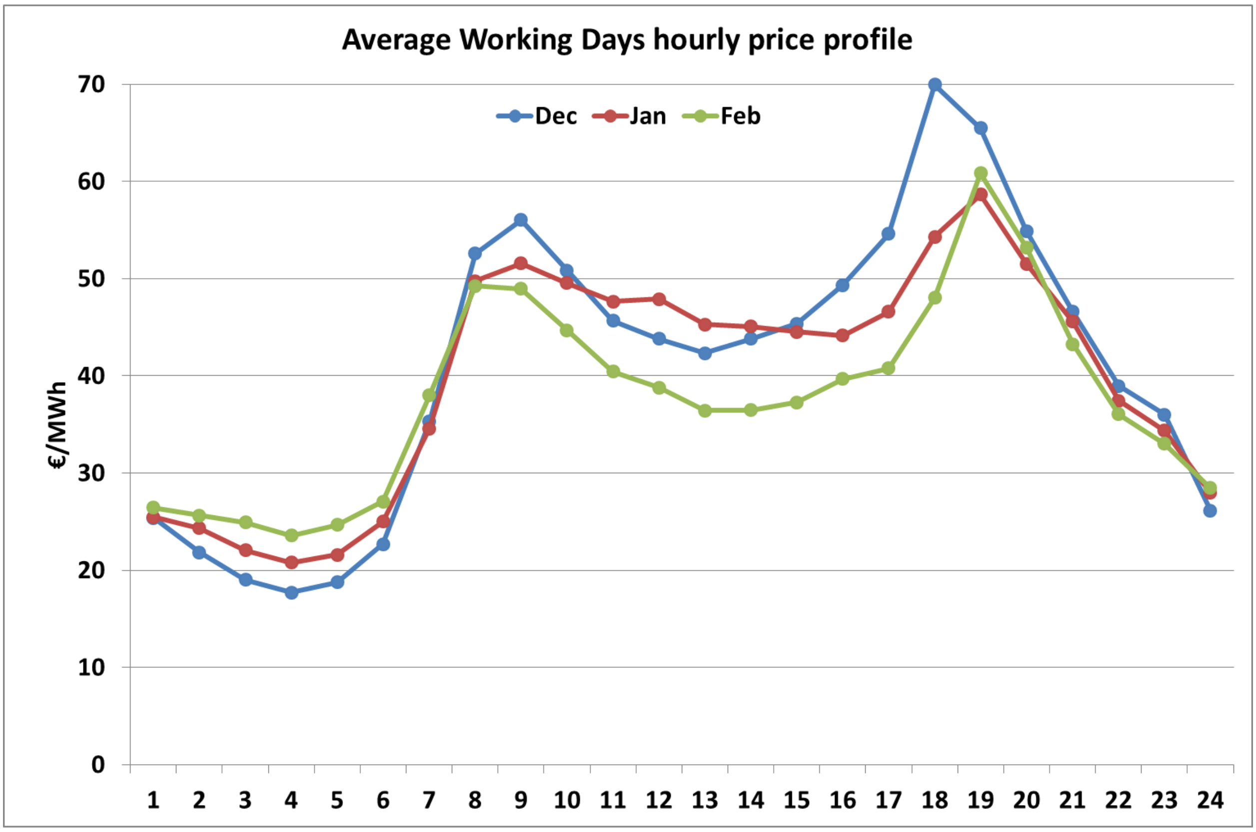

Figure Annex1-53: Average working days hourly price profile in December 2013 and in January and February 2014 (source: RSE elaboration on EPEX Spot data).

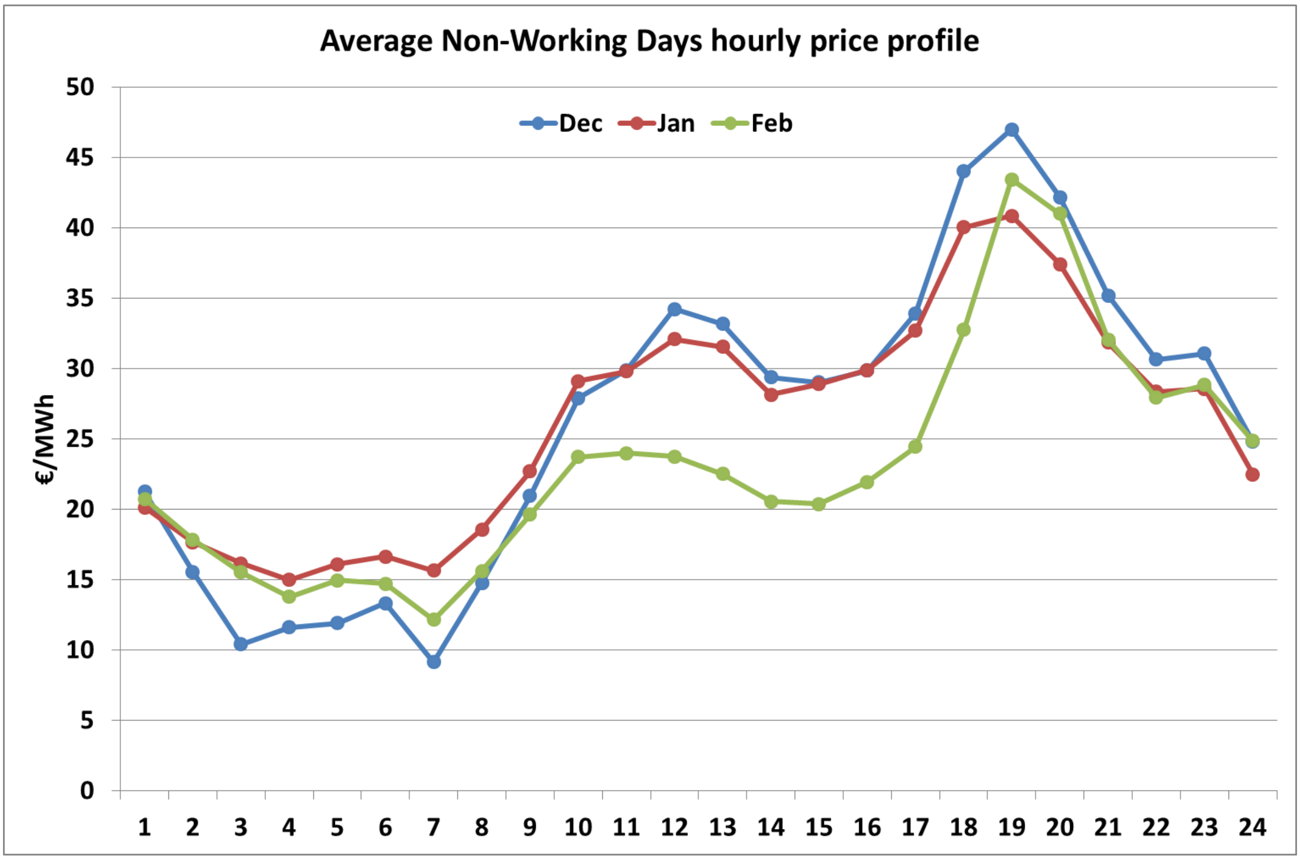

Figure Annex1-54: Average non-working days hourly price profile in December 2013 and in January and February 2014 (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-55, the average hourly price profiles in March, April and May 2014 are shown. The profiles in the three months are similar, except for the very high evening peak in March.

The profiles of working days, shown in Figure Annex1-56, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-57) show a much lower morning peak and significantly lower prices in the first hours of the afternoon, with price below 20 €/MWh and near 10 €/MWh in May.

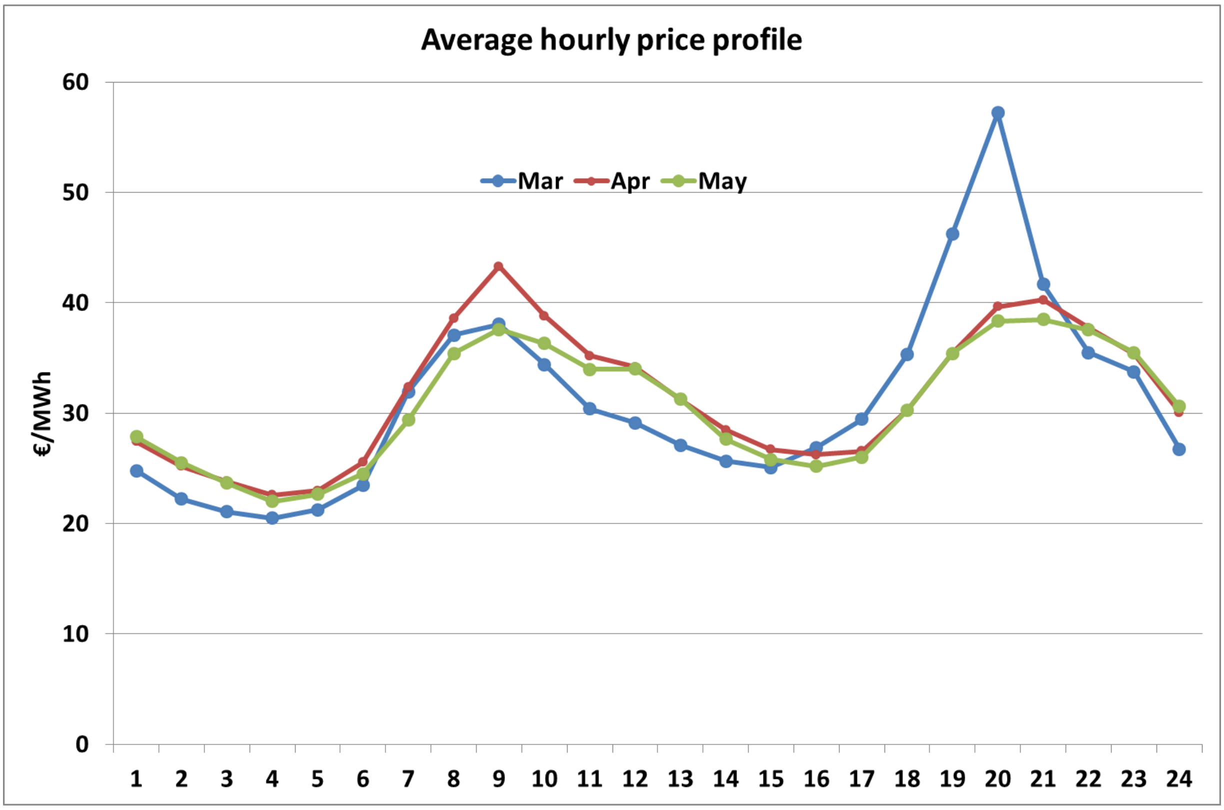

Figure Annex1-55: Average hourly price profile in March, April and May 2014 (source: RSE elaboration on EPEX Spot data).

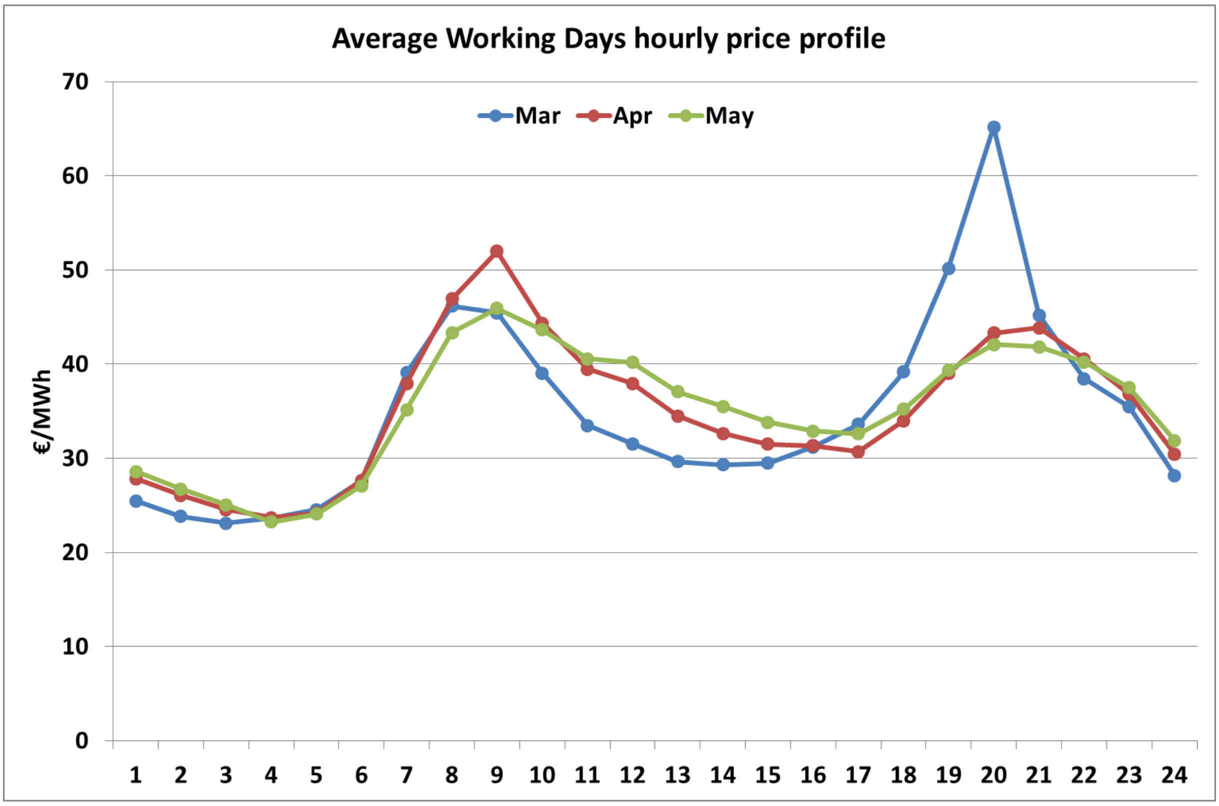

Figure Annex1-56: Average working days hourly price profile in March, April and May 2014 (source: RSE elaboration on EPEX Spot data).

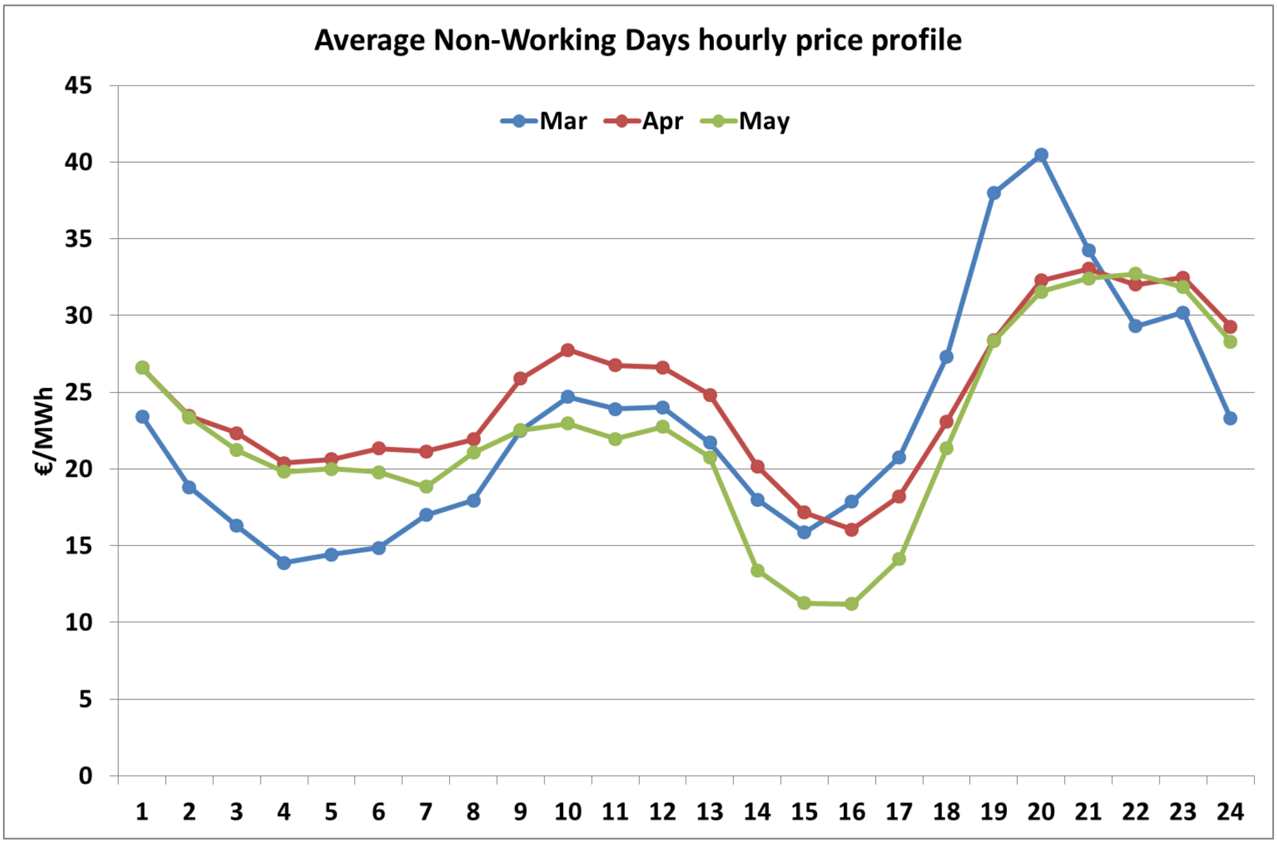

Figure Annex1-57: Average non-working days hourly price profile in March, April and May 2014 (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-58, the average hourly price profiles in June, July and August 2014 are shown. The profiles in the three months are similar and relatively “flat”: prices are almost always between 20 and 40 €/MWh.

The profiles of working days, shown in Figure Annex1-59, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-60) show a quite low morning peak and significantly lower prices in the first hours of the afternoon, with price in August below 10 €/MWh. On the contrary, the evening peak reaches higher values.

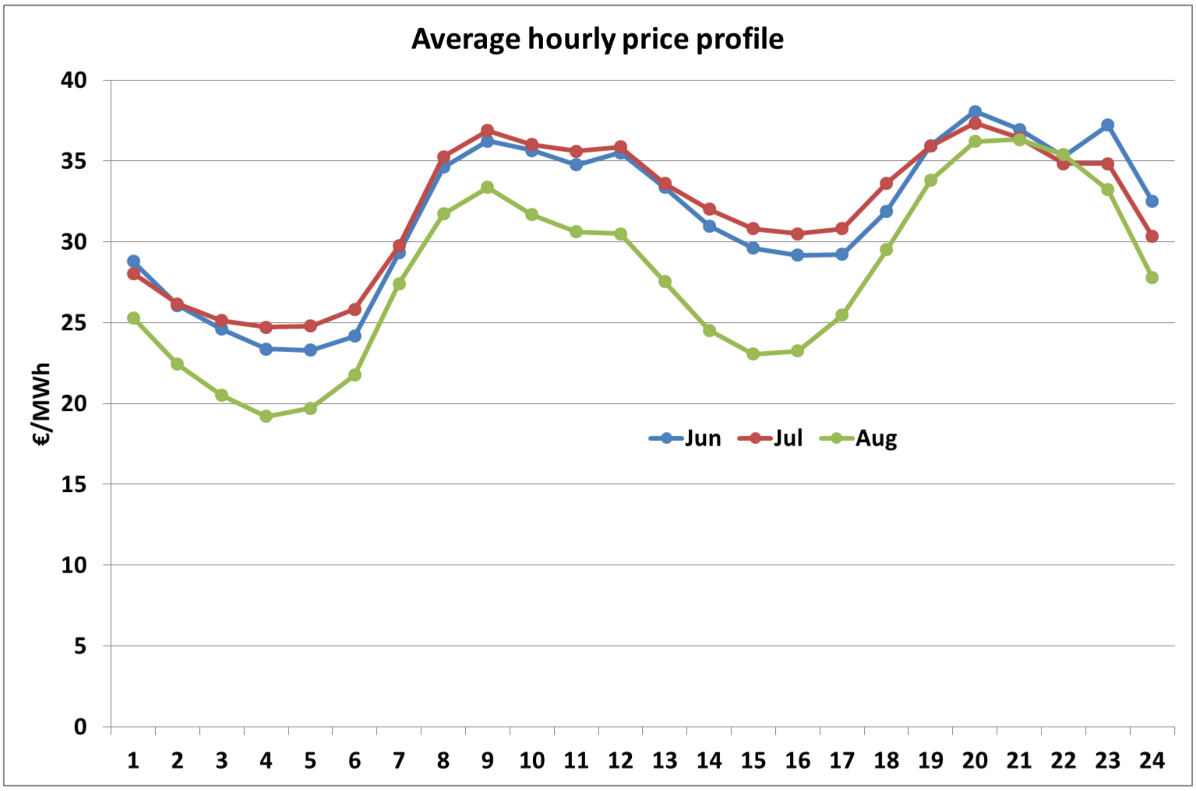

Figure Annex1-58: Average hourly price profile in June, July and August 2014 (source: RSE elaboration on EPEX Spot data).

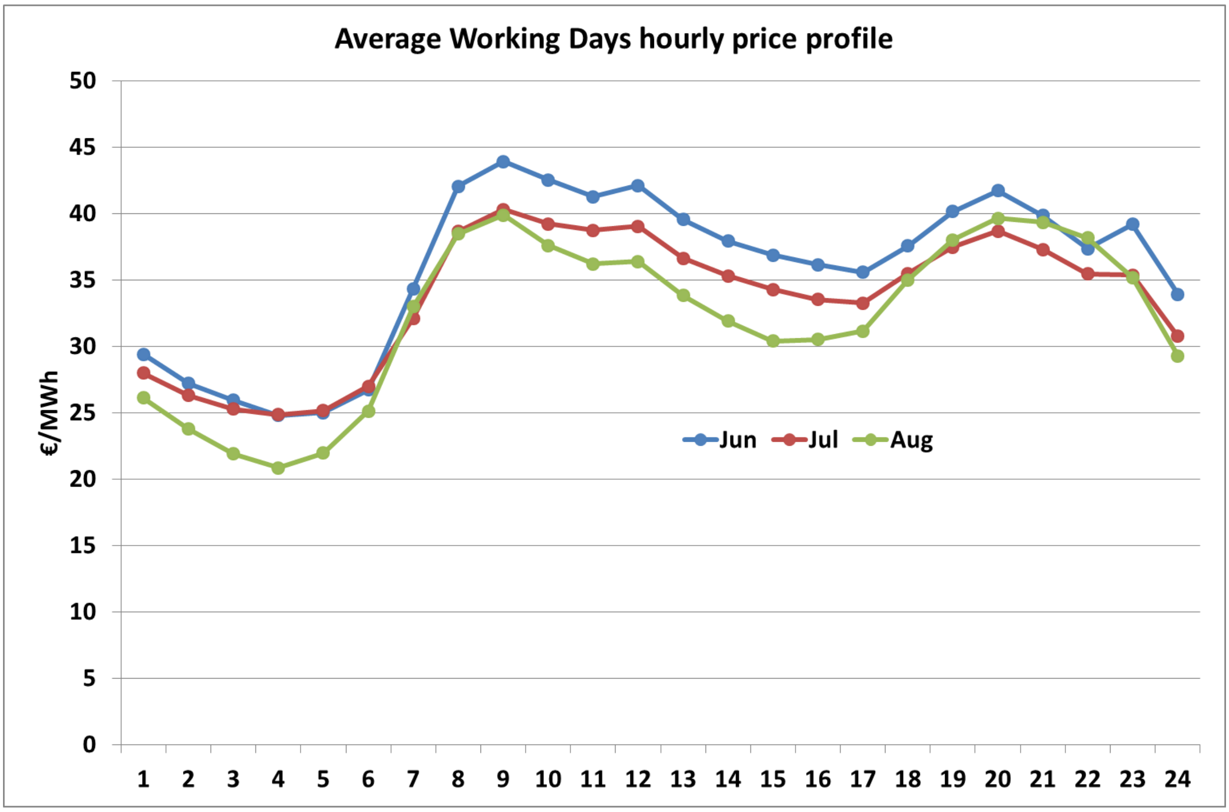

Figure Annex1-59: Average working days hourly price profile in June, July and August 2014 (source: RSE elaboration on EPEX Spot data).

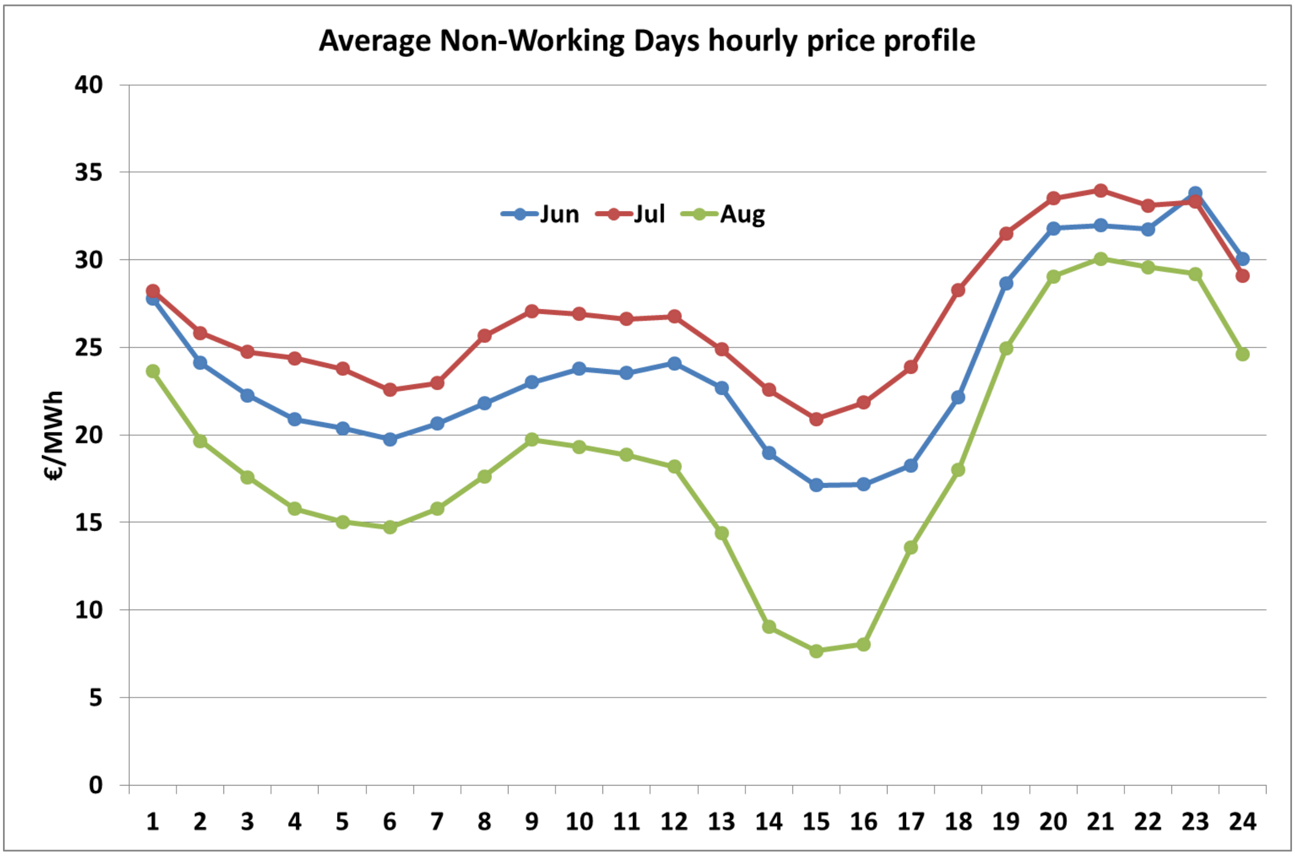

Figure Annex1-60: Average non-working days hourly price profile in June, July and August 2014 (source: RSE elaboration on EPEX Spot data).

In Figure Annex1-61, the average hourly price profiles in September, October and November 2014 are shown. In the first half of the day the profiles are similar, while in the second half of the day, profiles differentiate for the evening peak, that occurs earlier according to the sunset in the three months and is higher in November.

The profiles of working days, shown in Figure Annex1-62, are not so different from the overall ones, while profiles of non-working days (Figure Annex1-63) show a low morning peak (with much lower prices in November). The evening peak reaches values about 10 €/MWh lower than working days.

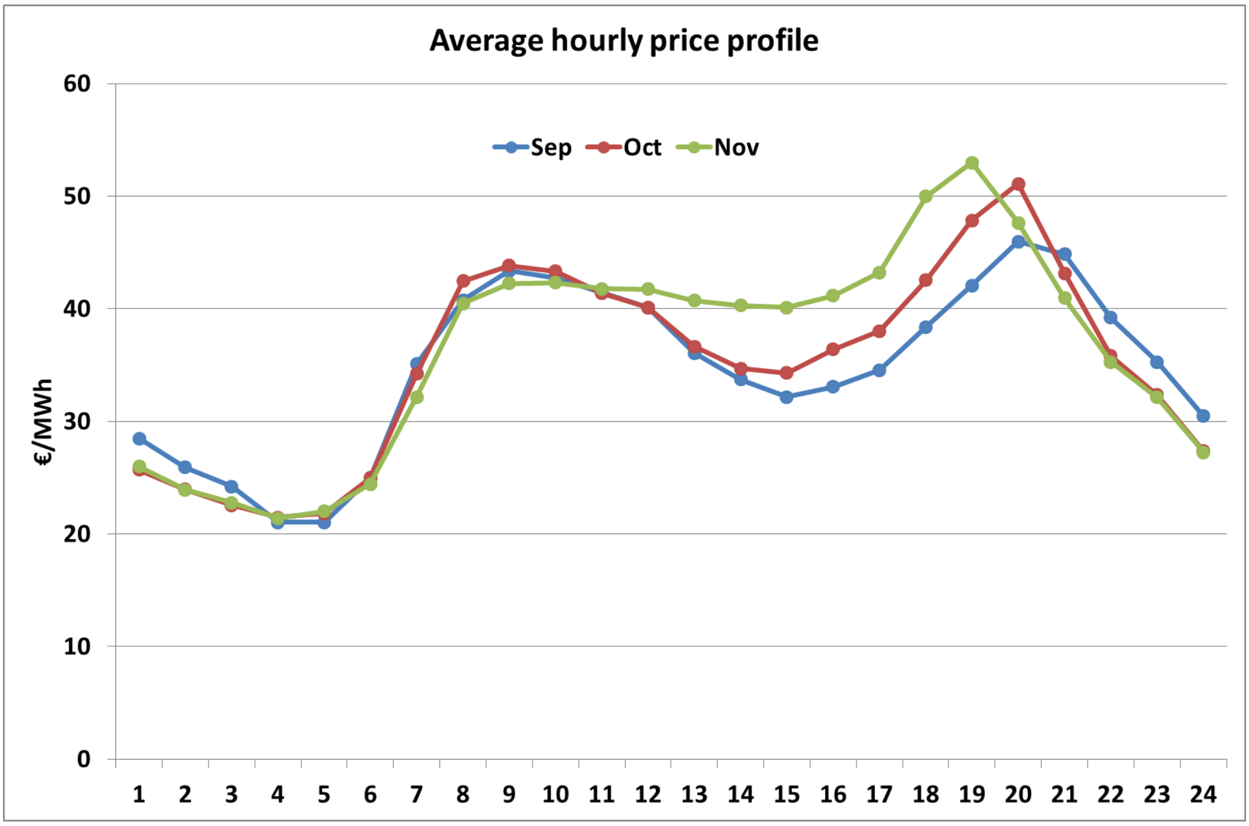

Figure Annex1-61: Average hourly price profile in September, October and November 2014 (source: RSE elaboration on EPEX Spot data).

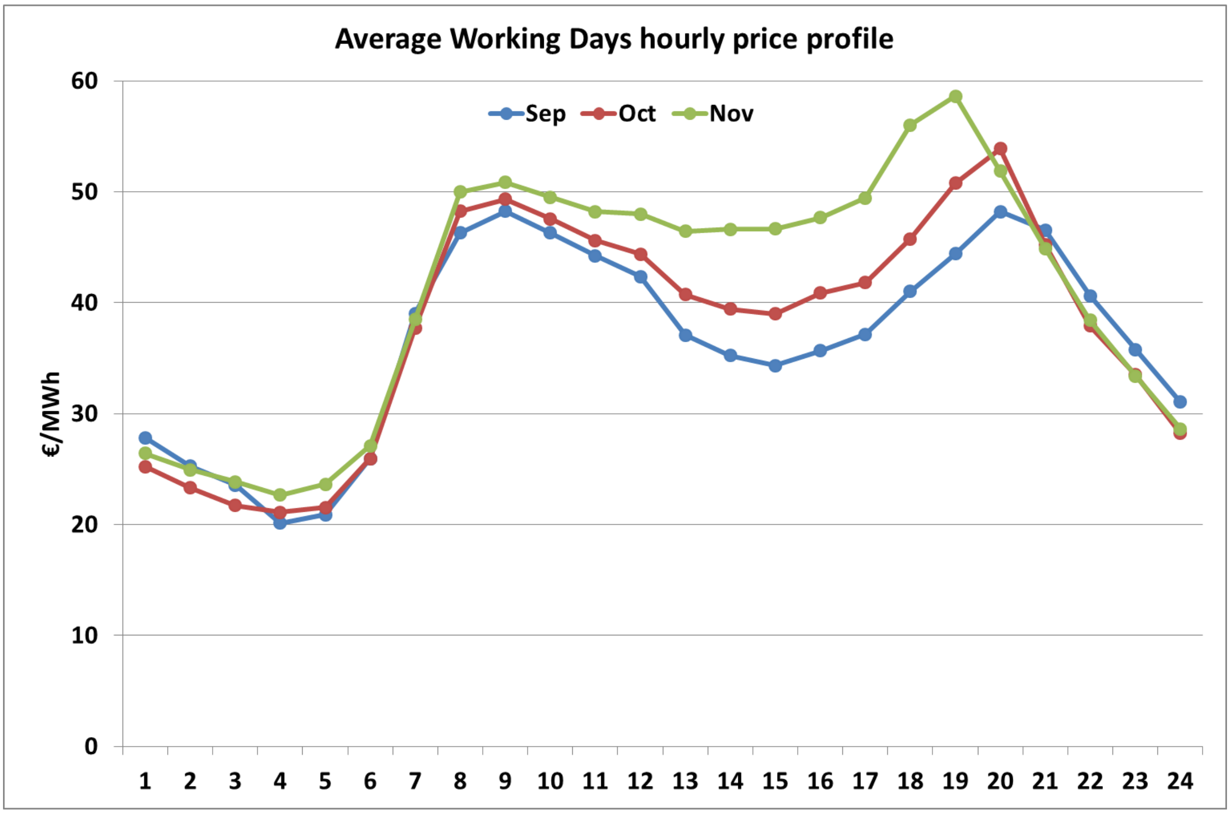

Figure Annex1-62: Average working days hourly price profile in September, October and November 2014 (source: RSE elaboration on EPEX Spot data).

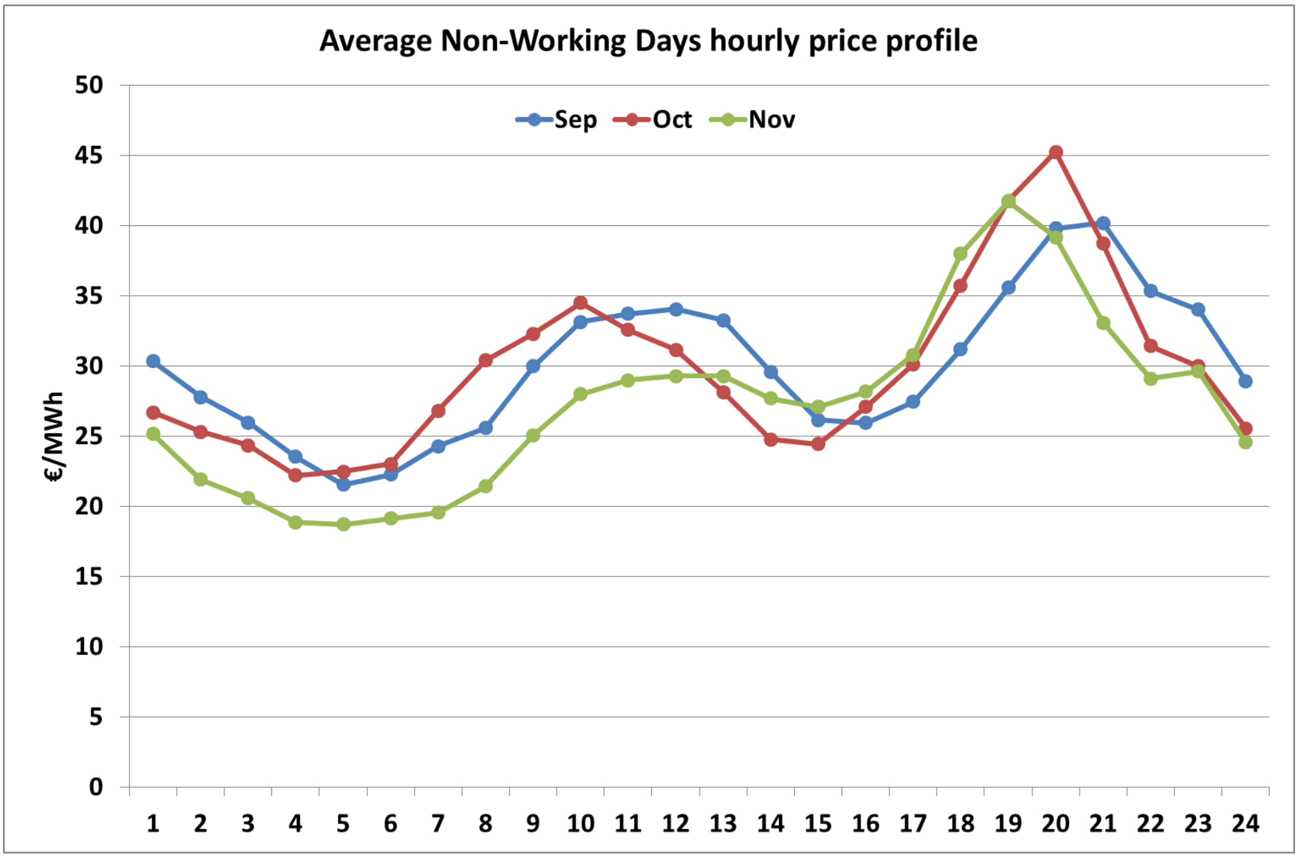

Figure Annex1-63: Average non-working days hourly price profile in September, October and November 2014 (source: RSE elaboration on EPEX Spot data).

3.2 Intra-day spot market

The intra-day spot market, whose sessions take place after the closure of the day-ahead market session, has the purpose of adjusting the schedule output of the day-ahead market, for several reasons.

For example, the day-ahead market schedule could violate some technical constraints of generation / consumption units (e.g. ramp rates, start-up / shut-down times, etc.), making it not feasible. Moreover, since the intra-day market sessions take place closer to real-time, market players could benefit from new information that has become available after the closure of the day-ahead market session (e.g. failures of plants, new forecasts of renewable generation or of consumption, etc.) and that would make necessary to adjust the day-ahead market schedule, in order to avoid imbalances.

For these reasons, the intra-day market typically deals with volumes much lower than the day-ahead ones.

In the following an analysis of the intra-day spot markets in Italy and in Germany is provided.

3.2.1 Italy

The Italian intra-day spot market is called Mercato Infragiornaliero – MI. The Italian Power Exchange, including the intra-day spot market, is managed by GME - Gestore dei Mercati Energetici (www.mercatoelettrico.org).

3.2.1.1 Market description

The intra-day market (MI) allows participants to change the schedules defined in the day-ahead market through additional demand bids or supply offers. In this way, a generator can sell additional energy or buy-back part of the energy already sold in the day-ahead market, while a load can buy additional energy or re-sell part of the energy already bought in the day-ahead market.

The MI consists of four sessions: MI1, MI2, MI3 and MI4. The sessions are organized in the form of implicit auctions of electric energy, like the day-ahead one, with different closure times and in sequence.

The session of MI1 takes place after the results of the day-ahead market have been published: it opens at 10:45 of the day before the day of delivery and closes at 12:30 of the same day. The results of MI1 are notified to participants and published by 13:00 of the day before the day of delivery.

The session of MI2, like MI1, opens at 10:45 of the day before the day of delivery, but closes at 14:40 of the same day. The results of MI2 are notified to participants and published by 15:10 of the day before the day of delivery.

The session of MI3 opens at 16:00 of the day before the day of delivery and closes at 07:30 of the day of delivery. Offers / bids refer to the hours from noon to midnight of the day of delivery. The results of MI3 are notified to participants and published by 8:00 of the day of delivery.

The session of MI4, like MI3, opens at 16:00 of the day before the day of delivery and closes at 11:45 of the day of delivery. Offers / bids refer to the hours from 4 p.m. to midnight of the day of delivery. The results of MI4 are notified to participants and published by 12:15 of the day of delivery.

The sessions of the intra-day market are based on price-setting rules that are consistent with those of the day-ahead market, including zonal prices and congestion management. Nevertheless, unlike in the day-ahead market, the PUN is not calculated and all purchases and sales are valued at the zonal price.

Nevertheless, in the intra-day, to replicate the effect of the application of the PUN to withdrawal points belonging to geographical zones, GME applies a non-arbitrage fee to all accepted bids / offers pertaining to such points.

In particular, for each purchase transaction concluded in the MI and pertaining to a withdrawal point belonging to a geographical zone, if the PUN set in the previous session of the day-ahead market was higher (lower) than the related zonal price, the market participant will pay (receive) a non-arbitrage fee equal to the difference between the PUN and the zonal price, applied to each MWh of the purchase transaction.

Vice versa, for each sale transaction concluded in the MI and pertaining to a withdrawal point belonging to a geographical zone, if the PUN in the previous session of the day-ahead market was lower (higher) than the related zonal price, the market participant will pay (receive) a non-arbitrage fee equal to the difference between the zonal price and the PUN, applied to each MWh of the sale transaction.

In the intra-day market it is also possible to submit the so-called “balanced offers”, composed of sale offers at a price equal to zero and purchase bids without price indication, submitted even by different market participants, but referring to the same hour and to “offer points” belonging to the same geographical or virtual zone, and such that the sold quantity is equal to the purchased one. “Balanced offers” are typically used by each large generation company to redispatch the amount of energy sold in the day-ahead market among its generators located in a specific zone, in order to better optimize its portfolio schedule.

After the closure of each session of the intra-day market, GME (as done after the closure of the day-ahead market) notifies the Italian TSO TERNA of the results that are relevant for dispatching: flows and updated injection and withdrawal schedules. These results are required by TERNA to determine information about residual transmission capacities between zones for subsequent market sessions.

3.2.1.2 Analysis of recent market results

In Figure Annex1-64 the volumes traded in each month of the last year in the four sessions of the intra-day market are shown, while in Figure Annex1-65 the average hourly volumes traded in 2014 (January÷November) in the day-ahead market (MGP) and in the four sessions of the intra-day market are reported.

The volumes traded in the intra-day market are about one tenth of the volumes traded in the day-ahead market.

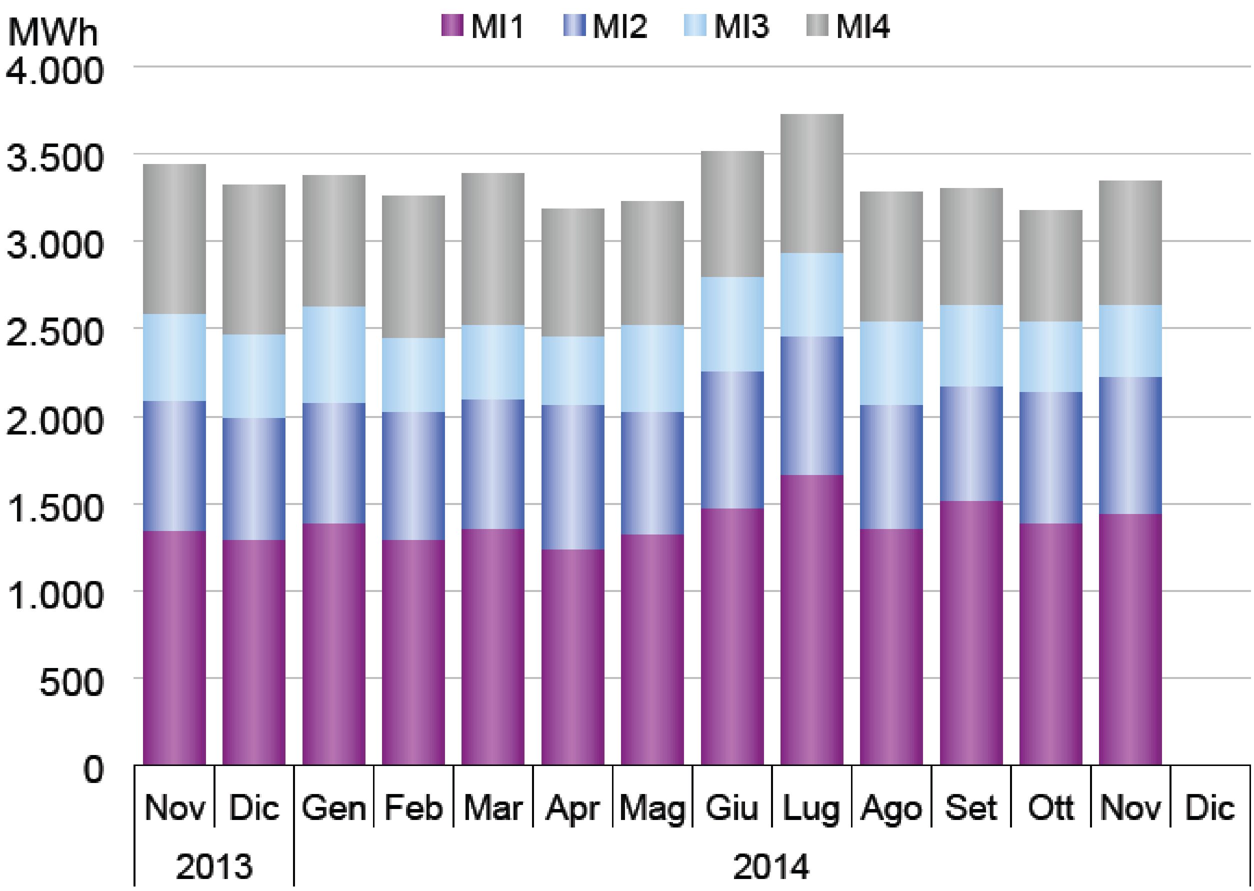

Figure Annex1-64: Volumes traded in each month of the last year in the four sessions of the intra-day market (source: GME).

Table Annex1-7: Average hourly volumes traded in 2014 (January÷November) in the day-ahead market (MGP) and in the four sessions of the intra-day market (source: GME),

MGP	MI1	MI2	MI3	MI4
32165 MWh	1449 MWh	778 MWh	421 MWh	696 MWh

In Figure Annex1-65 the monthly average of the hourly prices in the four sessions of the intra-day market is shown.

It can be noticed that the average prices of MI1 and of MI2 (that refer to all the 24 hours of the day of delivery) are quite similar to the average prices of the day-ahead market, reported in Figure Annex1-21, while the average prices of MI3 and of MI4 are higher, since they refer to set of hours (including the evening peak) characterized by a higher average price also in the day-ahead market.

As far as the hourly price profiles are concerned, they are quite similar to the day-ahead ones.

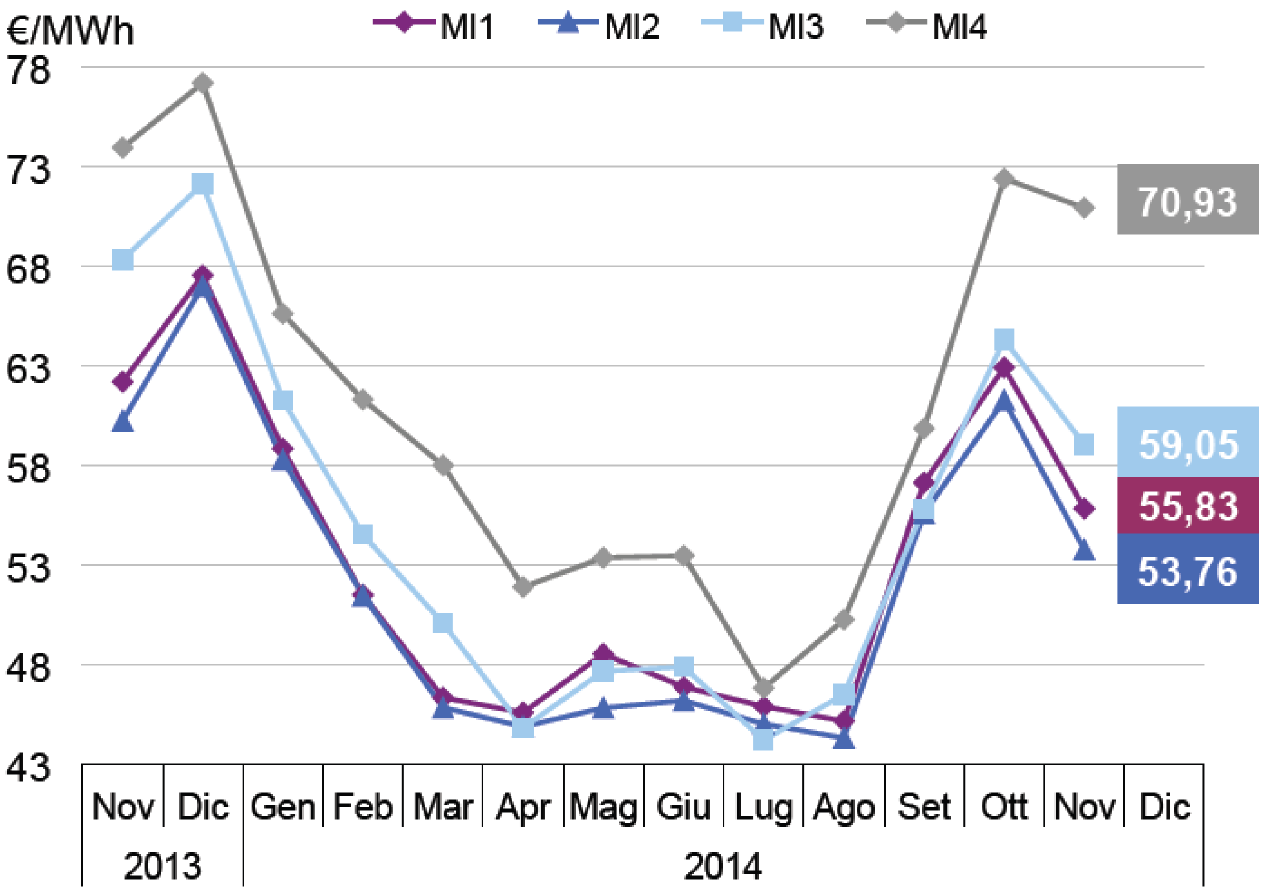

Figure Annex1-65: Monthly average of the hourly prices in the four sessions of the intra-day market (source: GME).

3.2.2 Germany

3.2.2.1 Market description

The intra-day market is the second pillar of the short-term power market. Trading happens continuously until 45 minutes before delivery. Trading participants send orders which can be matched and executed at any moment. All four EPEX SPOT's intra-day markets are connected through cross-border trading.

The intra-day market for power is available for the German, Austrian, French and Swiss market areas with the following characteristics:

- continuous trading and pricing (24/7),
- contracts tradable up to 45 minutes before the beginning of delivery,
- (Austria and Switzerland: 75 minutes),
- hour and block contracts available for trading,
- flexible portfolio balancing through 15 minute contracts on the German and Swiss markets,
- cross-border trading between Germany, Austria, France and Switzerland.

The intraday market has the following advantages:

- buying or selling of volumes which could not be traded in the auction,
- possibilities of very short-term portfolio optimisation, e.g. in the event of a power plant outage or changed weather conditions,
- lower balancing costs as a result of highly developed optimisation options and a more efficient utilisation of capacities,
- permits arbitrage between neighbouring countries and creates opportunities for cross-border trading.

The characteristics of the Intraday Auctions are summarized in Table Annex1-8.

Table Annex1-8: Intraday auctions by EPEXSpot for Germany.

Bid types	Place of delivery	Contract size	Tick size	Trading hours
Hours, blocks, fifteen-minute contracts (only DE and CH), Trade Registration for trades concluded off the exchange	Within the following TSO zones: 50Hertz Transmission GmbH, Amprion GmbH, TenneT TSO GmbH, TransnetBW GmbH	0.1 MW	€ 0.01 per MWh	24/7

3.2.2.2 Analysis of recent market results

The market results of the intraday market can be analysed for different periods of the year on the EPEXSpot website (http://www.epexspot.com/en/market-data/intradaycontinuous/intraday-table/). An example of the days 01-02.12.2014 is shown in Figure Annex1-66.

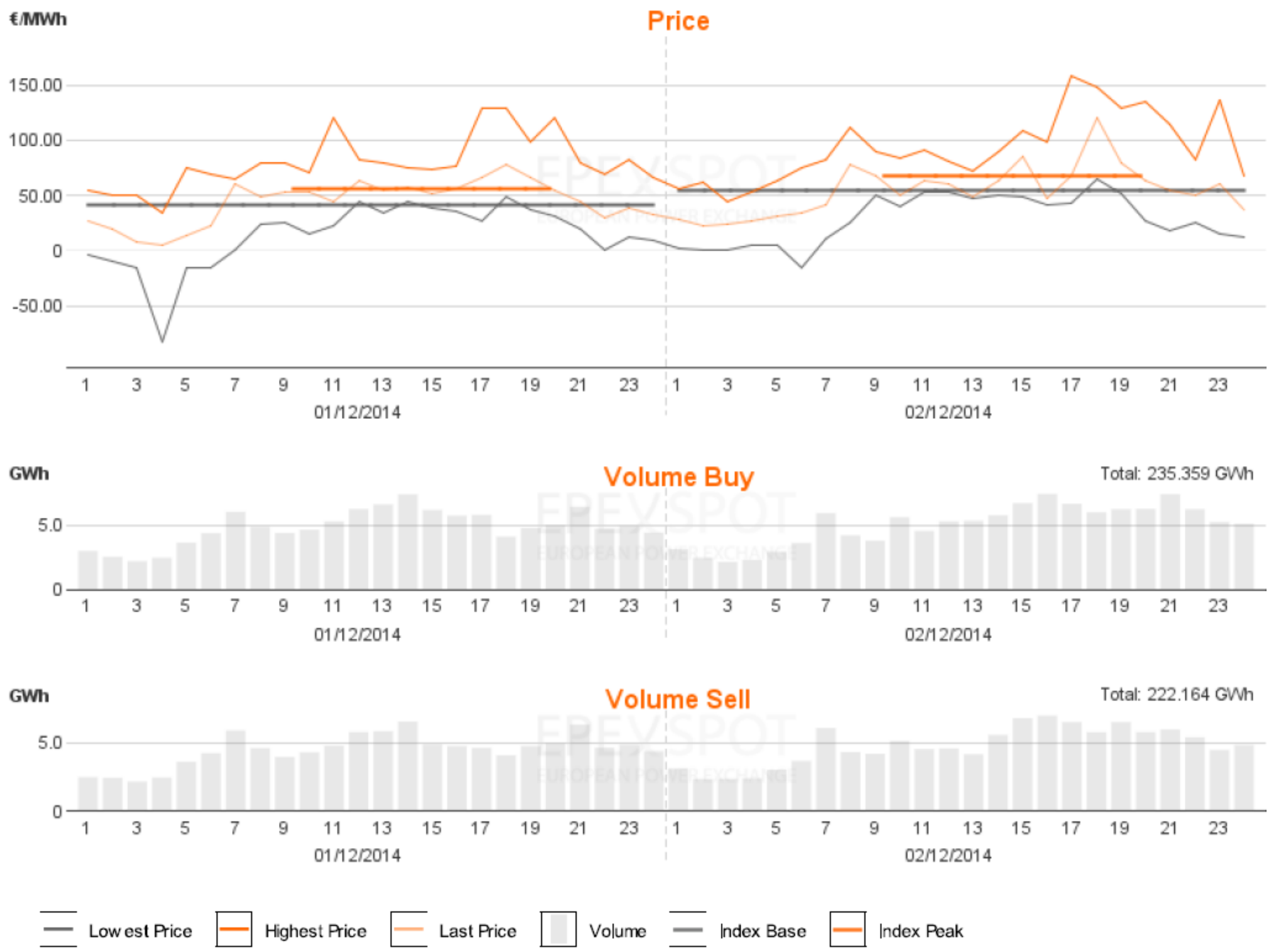

Figure Annex1-66: Results of the EPEXSpot intra-day power market (01-02.12.2014)

3.3 Opportunities for the participation of large industrial loads with flexible demand to the Power Exchange energy markets in Italy and in Germany

As above reported, short-term[26] electric energy purchases through the Power Exchange can be carried out in the day-ahead spot market, that is typically the most important one, in terms of volumes of energy traded and of significance of the clearing prices, or in the intra-day spot market, where adjustments to the day-ahead market schedule can be done, in order to tackle with changes in the situation that occurred after the closure of the day-ahead market session and to avoid imbalances. For these reasons, the intra-day market typically deals with volumes much lower than the day-ahead one.

Within this context, a detailed analysis of hourly price profiles in the period between December 2013 and November 2014 has been carried out for the day-ahead spot markets of the Italian Power Exchange (IPEX) and of the German one (EPEX Spot). Several charts have been included in the report, such as price hourly values, monthly average, hourly average (annual and for each month), for all the days of the year and for working-days and non-working days only.

The charts reported in Figure 2 and in Figure 3, showing the Italian and German day-ahead spot market price hourly average difference w.r.t. the overall annual average of the same type of day in working days and in weekends and holidays, are the most significant ones. They clearly show how cheaper or more expensive can be to consume energy in each hour of each different type of day.

Price differences w.r.t. the average can be significant, ranging from about -18 ÷ +23 €/MWh in Italy and from about -15 ÷ +12 €/MWh in Germany, showing that there is a great opportunity to take profit from demand flexibility in purchasing energy from the day-ahead spot market.

As for the intra-day spot market, the Italian one is characterized by price profiles similar to the day-ahead profiles, while in the German one, that is a continuous auction, price profiles can be different from the day-ahead ones.

[26] We focus on short-term (day-ahead / hours-ahead) since it is the typical time horizon over which demand flexibility can more effectively be exploited. For this reason, we did not consider longer-term forward and future contracts in the analysis.

4 Contracts with a supplier

In the following, a summary of the typical contractual arrangements for energy purchases in the steel industry is reported, with a focus on the degree of flexibility.

4.1 Italy

In the Italian steel industry energy is typically bought through a supplier, at an agreed price defined according to specific consumption profiles. The price is usually the day-ahead spot market price (PUN).

In such a case, the foreseen consumption profile has to be communicated to the supplier two days before the day of delivery, to allow the supplier itself to buy the energy on the day-ahead spot market, one day before the delivery. Of course this reduces the flexibility with respect to direct purchases on the Power Exchange.

In case of deviations of consumption from the program agreed with the supplier or deriving from Power Exchange purchases, imbalance energy must be settled at specific imbalance prices. In the Italian regulation, prices are penalizing or profitable according to the concordance or discordance of the imbalance sign with the sign of the overall imbalance of the zone where the consumer is located: see section 5.1 for details.

Apart from the cost of energy purchases and of possible imbalances, grid usage charges related to peak power consumption are very important, both in case of contracts with a supplier and of purchases on the PowerExchange. In Italy, the fee applied to the monthly peak power consumption measured in any quarter of an hour of each month is currently equal to 1.528 €/kW-month.

4.2 Germany

In the German steel industry a main part of the yearly electricity supply is purchased via the traditional forward market. Many companies directly buy their estimated yearly electricity supply with a risk surcharge (for deviations from the estimated consumption). Still, most of the bigger companies participate at the day-ahead market as well for a part of their more dynamic needs. Conclusively, a precise estimation of the daily electricity demands is mandatory to avoid imbalance fees, as specified in section 5.2.

The energy delivery contract consists of two parts:

- the grid usage, to be paid to the responsible TSO;
- the charge for the electricity delivered itself.

Normally, the yearly paid fee for grid usage depends on the electricity peak consumption of a company, resembling a sort of maximum-surveillance. in Germany the monthly fee ranges from 6 to 9.38 €/kW-month, or an annual fee can be paid, ranging from 35.99 to 60.79 €/kW-year.

This means that today a flat electricity consumption without big peaks is often desired. This is often accompanied by reducing the peak loads in form of intervention within the production cycle.

5 Economic regulation of imbalances in Italy and in Germany

5.1 Italy

According to the Italian regulation [19], imbalance fees in Italy are defined on the basis of the comparison of the sign of the imbalance of the "dispatching point" (i.e. the difference between the actual injection / withdrawal of electric energy and the schedule programmed on the markets of the Power Exchange or through bilateral contracts) with the sign of the aggregated imbalance of the "macrozone" including it.

The considered "macrozones" are two: the North geographical zone and the rest of Italy [27].

The aggregated imbalance of a macrozone is the algebraic sum, with the sign changed, of the volumes of electric energy traded by the Italian TSO TERNA for balancing purposes in the Dispatching Services Market, both in the programming phase and in real time, in a specific "relevant time period" and in the specific macrozone.

The volumes corresponding to sales / purchases by TERNA are accounted for with a positive / negative sign. The "relevant time period" for consumption units and for generation units not enabled to provide dispatching services is an hour, while for generation units enabled to provide dispatching services it is a quarter of an hour [21].

As far as "dispatching points" regarding consumption units (as well as generation units not enabled to provide dispatching services) are concerned, the prices that are used to value the imbalanced energy are the following:

- in each hour when the aggregated imbalance of the macrozone where the "dispatching point" is located is positive, the imbalance price is the minimum between:
    - the average price of purchase bids accepted in the Dispatching Services Market for real time balancing, weighted for the respective quantities, in that hour and in that macrozone;
    - the zonal sell price of the day-ahead market for that hour and for the zone where the "dispatching point" is located;
- in each hour when the aggregated imbalance of the macrozone where the "dispatching point" is located is negative, the imbalance price is the maximum between:
    - the average price of sale offers accepted in the Dispatching Services Market for real time balancing, weighted for the respective quantities, in that hour and in that macrozone;
    - the zonal sell price of the day-ahead market for that hour and for the zone where the "dispatching point" is located.

Since typically the average price of purchase bids / sale offers accepted in the Dispatching Services Market for real time balancing is lower / higher than the zonal sell price of the day-ahead market, if the imbalance of the "dispatching point" has the same the sign of the aggregated imbalance of the macrozone[28], the "dispatching point" is penalized, since it has to sell / buy the imbalanced energy at a price lower / higher than the one of the day-ahead market. Conversely, if

[27] AEEGSI Order no. 525/2014/R/eel: *"Modifiche e integrazioni alla disciplina degli sbilanciamenti effettivi di energia elettrica"*.

[28] I.e. the "dispatching point" contributes to the overall imbalance.

the imbalance of the "dispatching point" has the opposite sign of the aggregated imbalance of the macrozone[29], the "dispatching point" makes a profit, since it has to sell / buy the imbalanced energy at a price higher / lower than the one of the day-ahead market.

5.2 Germany

In Germany imbalance energy is settled, for each quarter of an hour, at the price obtained by dividing the control energy costs sustained by the TSO in the balancing market in that specific quarter of an hour, by the balance of the deployed amount of control energy in that same time interval.

[29] I.e. the "dispatching point" counteract the overall imbalance.

6 Comparison of the two options (Power Exchange vs. contracts with a supplier) in terms of possibilities to take profit from demand side management

Purchases in the Day-Ahead Market and in the Intra-Day Market of the Power Exchange are the most flexible option, since they allow to take full profit from hourly price differences and allow to change the consumption profile nearer to real-time.

Thus, demand side management would be more effective in case of purchases directly on the Power Exchange.

On the other hand, without forward contracts that fix the price for the bulk of energy consumption, a full exposure to the volatility of Power Exchange prices can be risky. Moreover, the direct participation to the Power Exchange requires an internal structure that only larger companies could afford.

Annex 2

D 1.2 Description of the grid characteristics (events, time response, etc.) and interaction with large consumers (Responsible RSE) (Mar 2015)

Summary

1 <u>Current and expected criticalities in the power system</u>

1.1 Italy

The large development of intermitted renewable sources, together with the reduction of power consumption due to the global economic crisis have led the Italian power system to a general condition of overcapacity. As shown in Figure Annex2-1, starting from 2009 the Italian system is undergoing a situation of large overcapacity, since the reserve margin is much higher than the typical values considered sufficient, around 10% – 15% of the peak load.

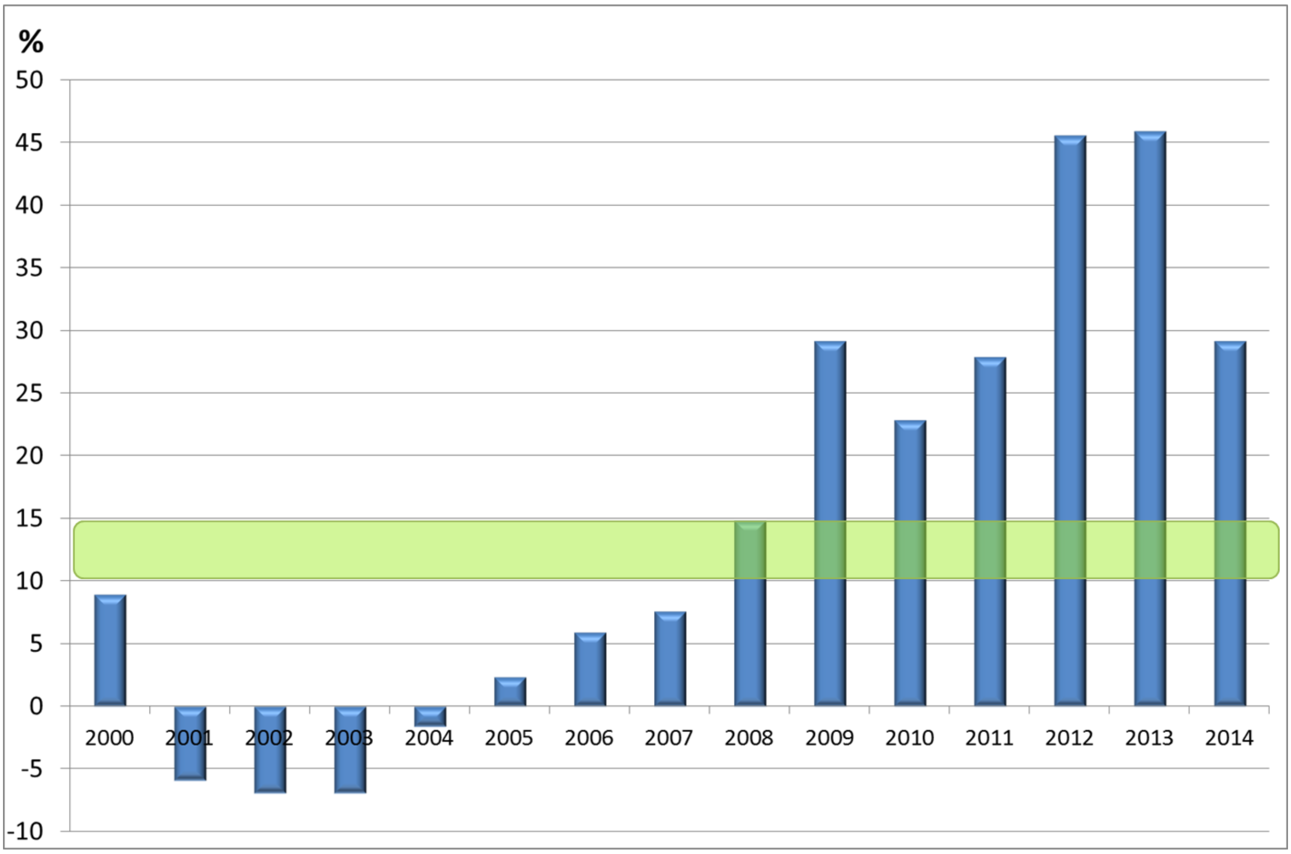

Figure Annex2-1: Reserve margin at peak load conditions in the Italian power system (in green the values typically considered sufficient).

This was due first to large investments in new combined cycle gas turbines (34 GW of additional generation capacity) and more recently by the huge development of renewable sources, especially photovoltaic and wind (Figure Annex2-2), that, due to incentives, gradually replaced thermal generation. The load factor of conventional power plants has then been decreasing dramatically in the last years, so that producers can hardly find a suitable coverage for their fixed costs.

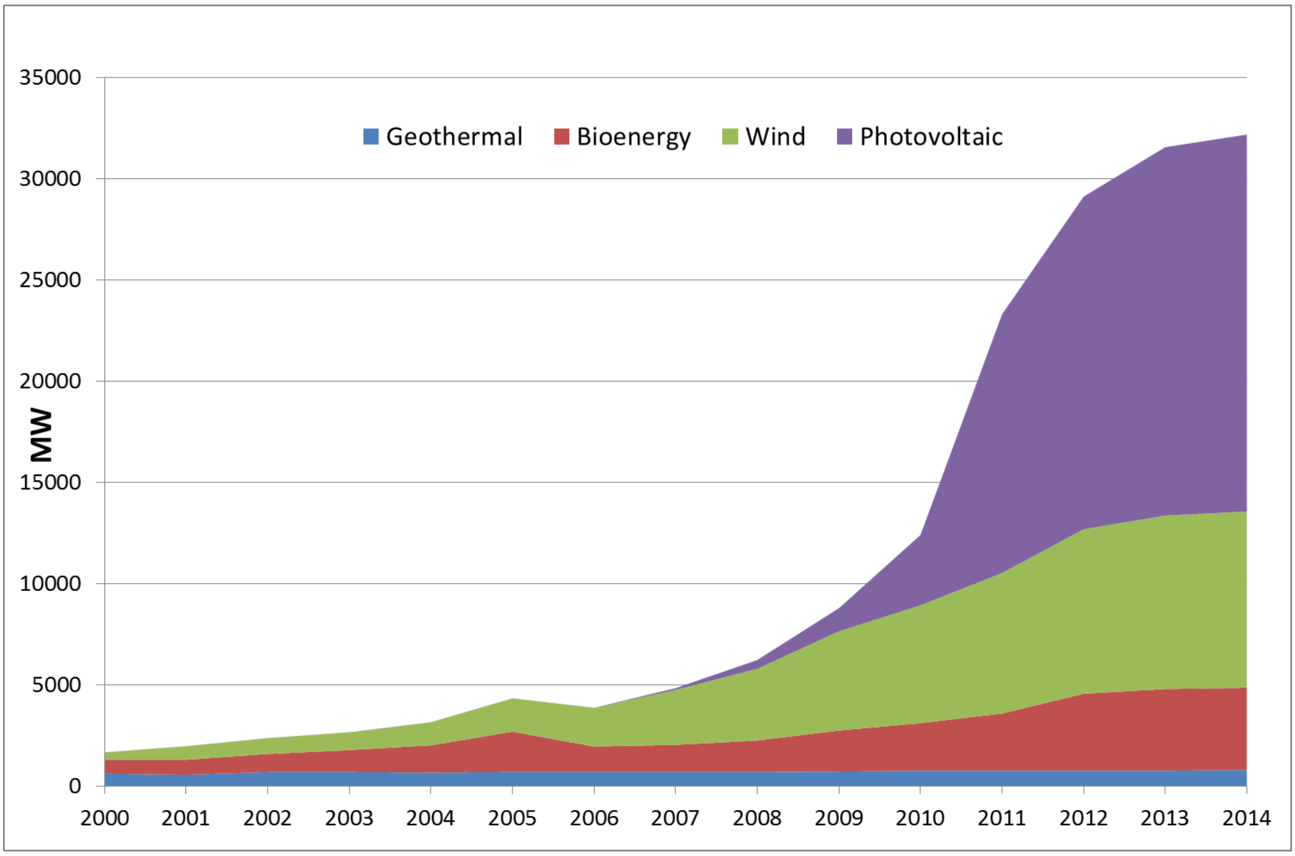

Figure Annex2-2: Development of renewable sources in the Italian power system (hydro excluded).

The main effect of intermittent renewables, mainly wind and solar PV, on the electricity market operation is related to the residual load profile that shall be covered by conventional power plants. The increase of renewable generation, mainly from PV source, introduces two effects: the reduction of residual load[30] during the central hours of the day and an increase of the ramp slope in the evening.

Figure Annex2-3 shows the evolution of the residual load resulting from the day ahead market in March and November of years 2011, 2012 and 2013. It can be noted that the effect of PV during the day increased in the considered years, with a remarkable reduction of residual load. The effect is more critical during the bank holidays in summer, when the total load is very low. Figure Annex2-4 shows the residual load profile on 18th August 2014: the minimum level reached in the hour 14 is about 5000 MW, when the total load was more than 20000 MW.

[30] I.e. the load to be supplied by dispatchable conventional generation.

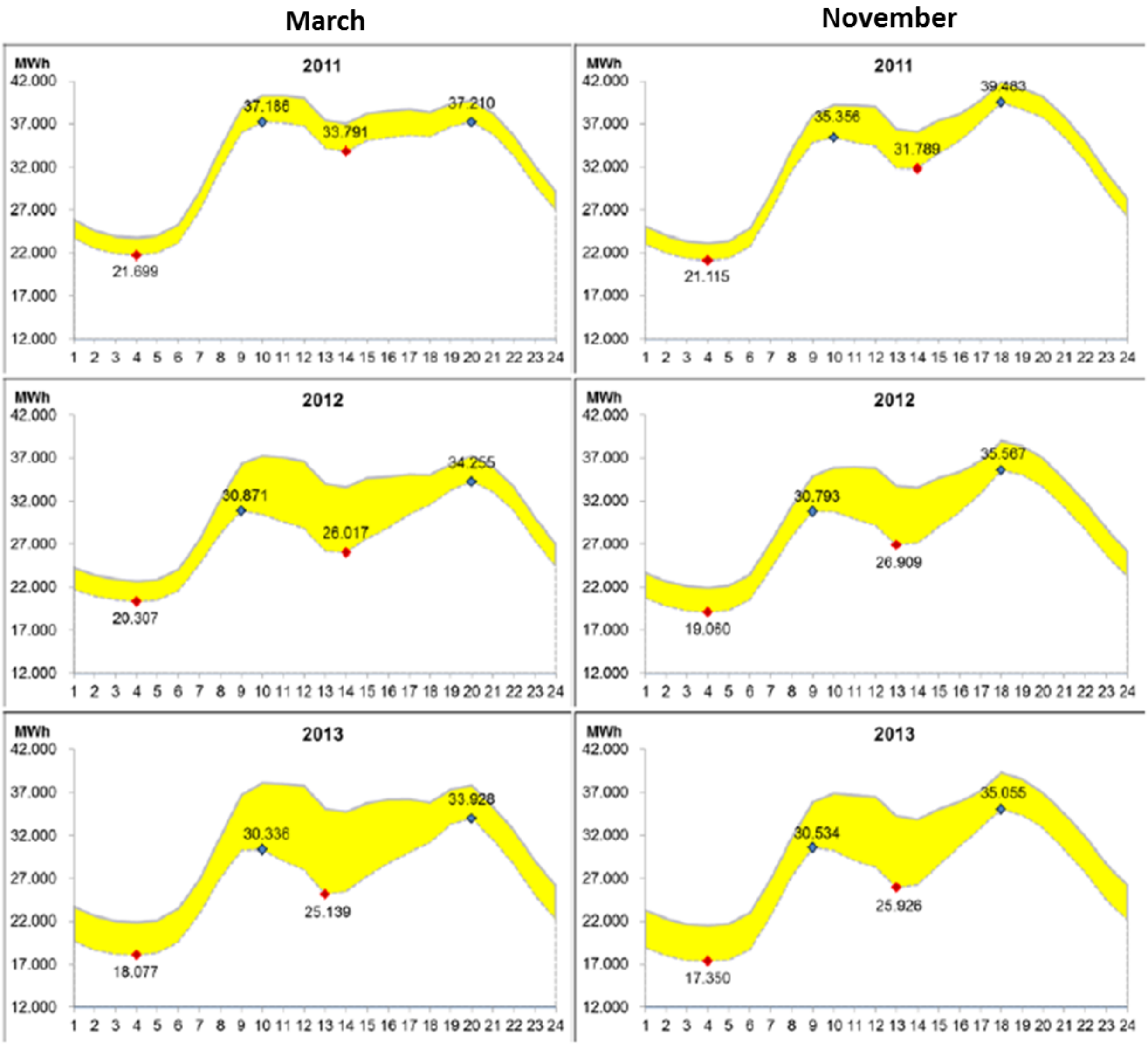

Figure Annex2-3: Evolution of residual load resulting from the day ahead market in the working days of March and November (comparison of years 2011 – 2013).

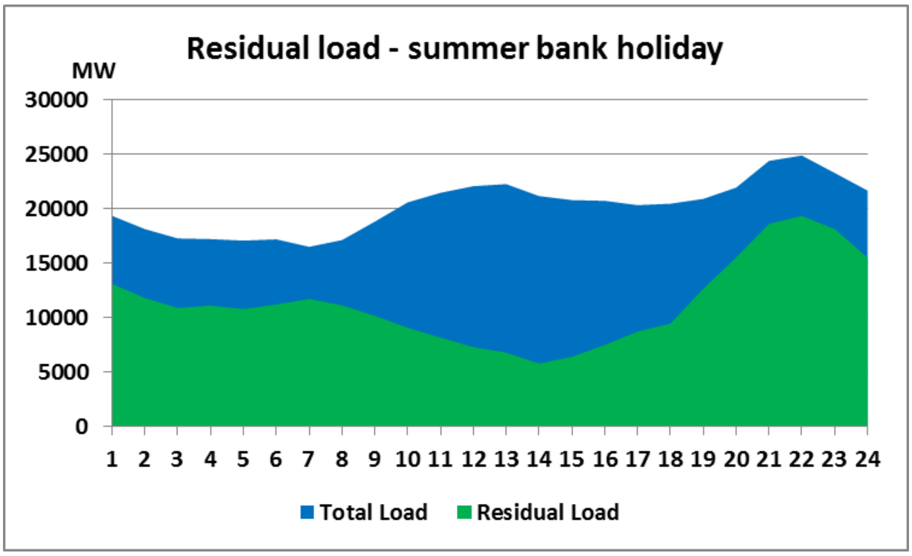

Figure Annex2-4: Residual load resulting from the day ahead market on 18th August 2014.

This effect impacts not only on the dispatchability of thermal power plants reducing their load factors, but also on day ahead prices resulting from the market. This further reduces the profitability of conventional plants that suffer a low production and prices too low to cover their costs.

Figure Annex2-5 shows the ratio between the average hourly day ahead price in 2007 and in 2014 and its minimum value (reach at hour 4 or 5), in order to get a “normalized” profile. The dramatic change of the price profile, especially during the central hours of the day, is quite clear.

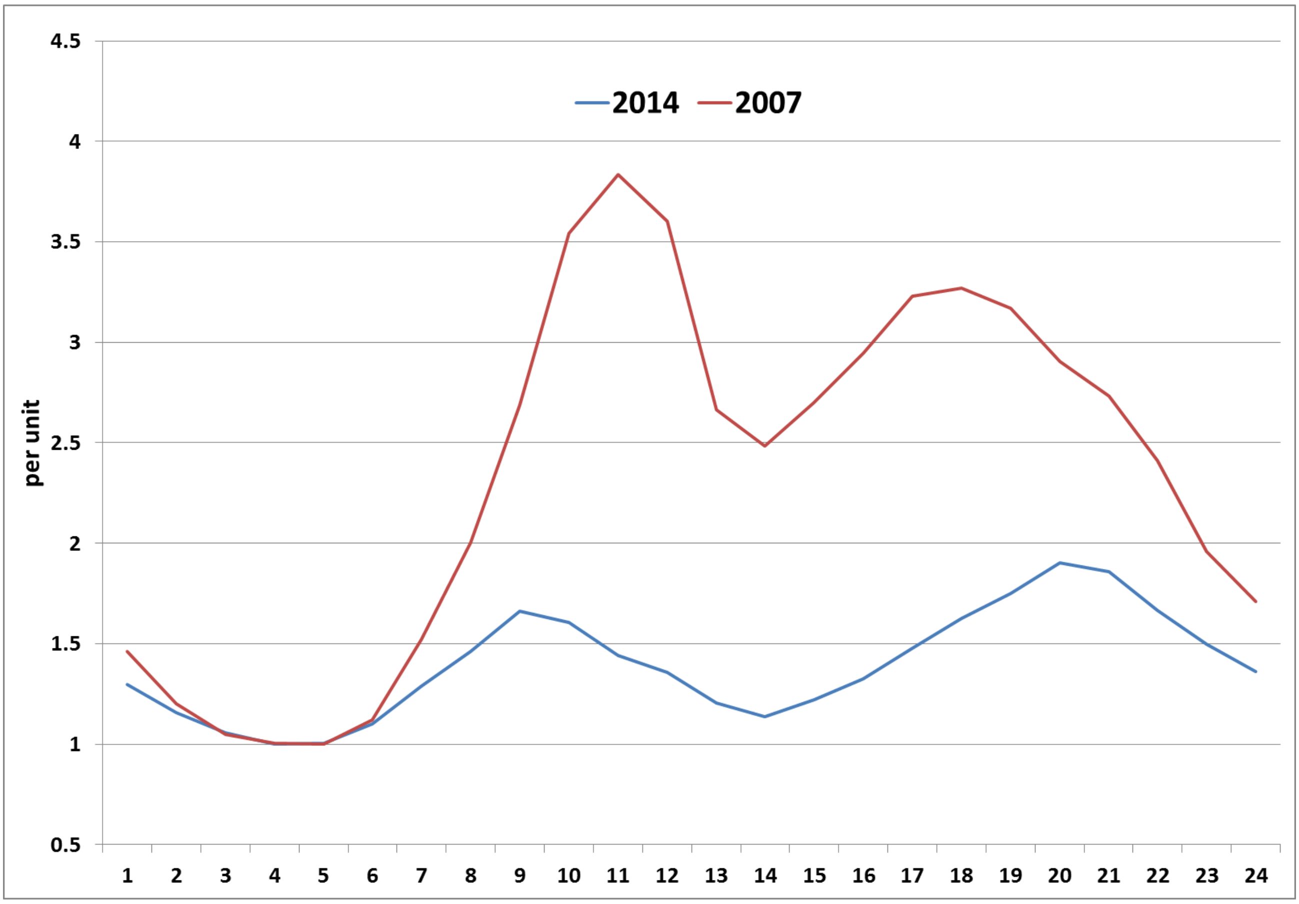

Figure Annex2-5: Change of day ahead average price profiles between 2007 and 2014.

The large development of intermittent renewable sources has an impact also on the ancillary services market and on the real time balancing market. The volatility of the RES requires an increase of system flexibility during the scheduling phase and the uncertainty related to power production forecasts forces the system operator to procure additional spinning reserve margins to guarantee a safe operation in real time. Thus controllable power plants with a high level of flexibility, demand side management and new devices such as energy storage systems able to quickly react to the changes of residual load are more and more required for future operation of the system.

Another element of criticality is related to the geographical location of renewable sources; in fact large part of RES production is located in the southern part of Italy, while the load is mainly in the North. This results in increasing energy flows from South to North that can be limited by transmission network constraints, causing congestion.

As for the future, the new targets of the 2030 EU climate and energy policy entail a further development of renewable sources, while demand is expected to slowly grow: this means that the above mentioned criticalities are here to stay.

To face all the criticalities that emerge in the power systems, in the next years several actions are planned by the policy makers and the regulatory authority. Among them the most relevant in the framework of the integration of renewable sources are:

- Market reform:
    - Complete the integration of the Italian market in the Internal Electricity Market with the market coupling mechanism.
    - Carry out a revision of the ancillary services markets in order to allow all potential suppliers of regulating reserve to participate to the market, thus including demand side response, energy storage, downward reserve from RES.
    - Introduce a more cost reflective mechanism for the settlement of imbalances.
    - Harmonize the market rules with the other EU countries for preventing inefficiencies.
- Capacity market:
    - Introduce an efficient and effective capacity market, compliant to the EU guidelines, in order to guarantee long term adequacy for the system.
    - Develop a specific branch of the capacity market with the aim of promoting flexibility in power generation.
- Network expansion:
    - Foster the network development to avoid congestion and RES curtailment.
    - Promote a better coordination between the TSO and DSOs for a more coordinated development and operation of networks.

1.2 Germany

The power system in Germany is undergoing a period of transition [31, 32]. Renewable energy will take on a greater role in the power supply as the use of nuclear energy in Germany will end in 2022 and the European markets for electricity will continue to grow together.

The power system must maintain a balance between power generation and consumption, especially in view of the fact that the shares of wind and solar energy in the power supply mix increase. Examples for this development are shown in Figure Annex2-6.

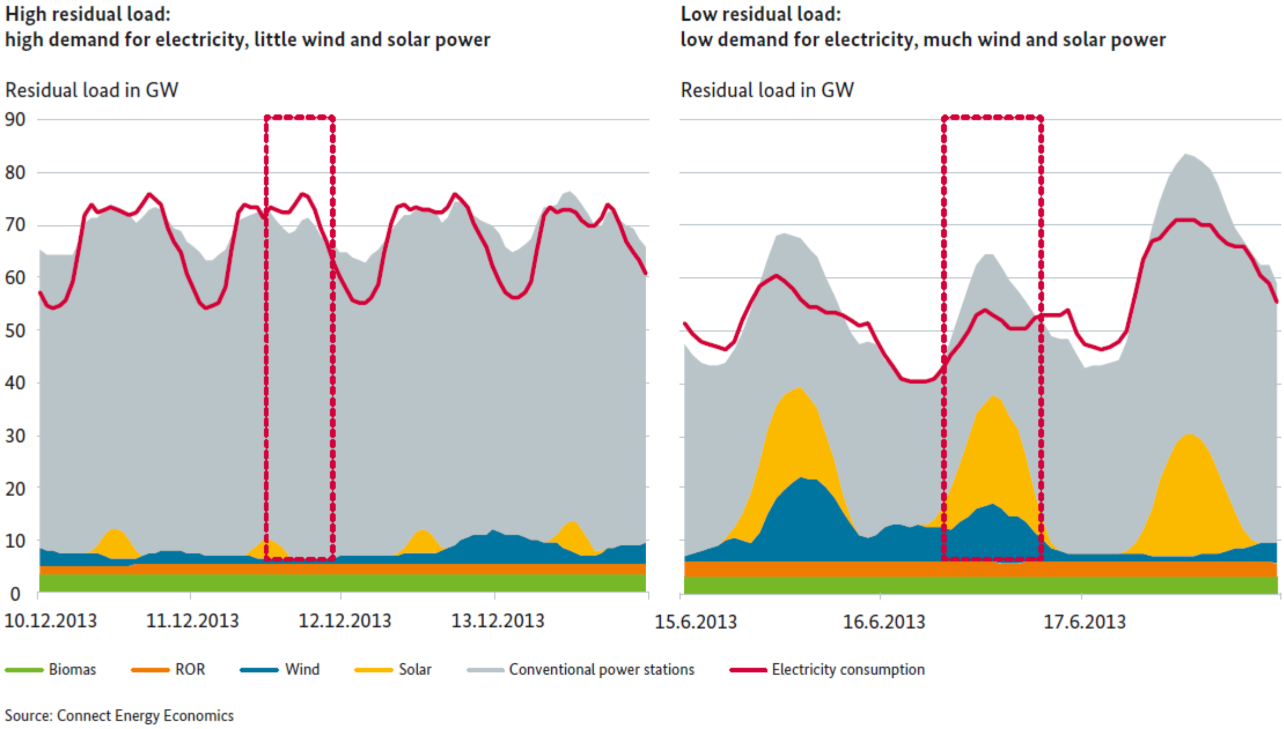

Figure Annex2-6: Examples of situations with high and low residual load [32].

To achieve the balance the market has to fulfil two tasks: firstly, it must ensure that sufficient capacity is available (i.e. reserve function) and secondly, that this capacity is used at the right time and to the extent necessary (i.e. dispatch function). The policy is therefore focusing on how to develop a future market design and a regulatory framework for the electricity sector that ensures that the power supply is secure, cost-efficient and environmentally friendly.

The main challenges of the German power system may be summarized as follows:

- Transition of the markets

[31] Federal Ministry for Economic Affairs and Energy (BMWi), Public Relations: Electricity Market for Germany's Energy Transition (Grünbuch). Berlin, October 2014.

[32] CONNECT Energy Economics GmbH: Leitstudie Strommarkt. Berlin, July 2014.

The electricity market is now liberalised. The European markets are largely coupled and continue to grow. Overcapacities and low CO_2 prices are driving down the prices for electricity. The nuclear power will phase-out until 2022 and the base-load will decrease. The expansion of renewables needs new flexible peak load technologies and a demand side management.

- <u>Flexibility options</u>
  In order to adjust the balance of the grids, new flexible mechanisms have to be developed. A flexible production of conventional and renewable energy as well as a flexible demand of consumers in industry and household is necessary. Furthermore the possibilities to store energy have to be developed.

- <u>Grid expansion</u>
  Powerful grids are needed that couple the regions with wind, solar or hydropower production to the consuming markets. The electricity is more and more produced in a decentralized way and the lay-out of the grids and voltage transformation has to be adapted to the future needs.

- <u>Market price signals</u>
  New mechanisms to adjust production and consumption of power have to be developed. Within the spot market a cost-effective synchronization of supply and demand takes place. Since 2011 a trade in 15-minute units takes place. Negative price signals are possible if the costs for a shut-down of power plants are too high. Additional incentives are necessary to stimulate the combined heat and power production and a competitive production of renewable energies.

The policies are intensifying the European co-operation and the cross-border trading of electricity, too. This will strengthen the security of power supply in Europe. Furthermore the environmental goals for climate protection and reduction of CO_2 will influence the power market in an essential way.

2 Technical regulation of ancillary services

2.1 Italy

In Italy the regulation that control the dispatching activity and the related ancillary services market is the deliberation 111/06 [[33]] of the national Regulatory Authority. The technical regulation for the operation of the system is instead provided by the Grid Code [[34]] for transmission, dispatching, development and security of grid issued by the TSO TERNA. This document provides all technical regulations for:

i) access to the grid;
ii) development, management and maintenance of the grid;
iii) performance of dispatching services;
iv) supply measurement and settlement services for financial charges connected to the aforementioned services;
v) security of national electricity system.

Concerning the provision of ancillary services, in Italy the generating units qualified to participate to the ancillary services market must have the following features:

- being a generating unit with a rated power greater than 10 MVA;
- not being a non-dispatchable renewable energy source;
- not being a generating units under test period;
- being able to increase/reduce at least 10 MW of power generation within 15 minutes from the start of the service;
- for reservoir hydro power plants: being able to produce at the maximum power for at least 4 hours.

The consumption units at the moment are not qualified to provide any form of ancillary service.

Further technical requirements are defined depending on the specific service provided:

- Primary control reserve (PCR): all the qualified generating units shall provide the PCR, responding to frequency variations with variations of the generated power within upward and downward bands equal to 1.5% of nominal power; half of the variation of the generated power requested to the unit must be supplied within 15 seconds and the full variation within 30 seconds; then, the new generation level must be kept for at least 15 minutes (in case there are no new frequency variations).
- Secondary control reserve (SCR): to provide SCR generating units shall be equipped with a control system able to automatically respond with variations of the generated power to the set point signal transmitted by the TSO. Each unit shall provide SCR within bands equal to ± 15% of the nominal power (for hydro plants) or equal to the maximum between ± 10 MW and ± 6% of nominal power for thermal power plants. The power corresponding to the whole band must be supplied within 200 seconds and kept for at least 2 hours.

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[33] Authority for Electric Energy, Gas and Hydro Services, Deliberation n° 111/06, 13 June 2006 and successive updates, http://www.autorita.energia.it/it/docs/06/111-06.htm.

[34] TERNA, Grid Code, http://www.terna.it/default/home_en/electric_system/grid_code.aspx

- Tertiary control reserve (TCR): all the qualified generating units that are able to supply the power variation requested by the TSO within 15 minutes with a ramp rate of at least 50 MW/min can provide the "*ready reserve"* TCR service. All the generating units that are able to supply the power variation requested by the TSO within 2 hours without any time limitation are qualified for the *"substitution reserve"* provision.

Further technical details and limitations for the provision of ancillary services can be found in the grid code of the Italian TSO TERNA [[34]].

2.2 Germany

The legal and regulatory framework for providing and transmitting electric power and sustaining a balanced load-frequency in Germany is complex and interwoven by different national and international regulations. On European level the European Network of Transmission System Operators for Electricity (ENTSO-E) elaborated a common valid grid code which will come in force. Until now a collection of principles for system operation for the European TSO's is comprised within an Operation Handbook [[35]].

The German national legal framework is mainly devoted to reserve and balancing energy topics and is included in the Energy Industry Act (EnWG) [[36]] and the German Renewable Energy Sources Act (EEG) [[37]]. Additional regulatory decrees can be introduced and changed by the German Network Agency which also provides different market rules for control reserve segments. The German Network Agency (Bundesnetzagentur) acts as an additional regulator by determining market rules and access conditions for each control-reserve quality after consulting the TSOs and bidders. For the allocation of control energy actual data concerning the control tariffs can be found and downloaded on a specific website [[38]].

Further requirements focusing on technical issues are included in the latest version of the German TSOs' grid code which has been set to work in 2007 [[39]].

In this document the German TSOs define the rules for the access to the national grid, while also considering and satisfying the boundary conditions of the European electricity transmission grid.

Main topics are:

- Connection conditions, technical requirements and approaches for the connection and parallel operation of generating plants within the high voltage network, grid frequency stability (PCR/SCR/TCR), active/reactive power generation, grid protection in case of faults, accounting.
- Grid usage (transmission losses, bottlenecks, costs of EEG).
- TSO system services in addition to transmission of energy, regarding quality of supply (frequency and grid stability, grid restoration after failures, transmission management).
- Network development describing possible means for capacity and architecture of new grids to ensure low risk of failures and a high guarantee of supply (e.g. implementation of grid redundancies).
- Operational planning and system management to define coordinative and organization tasks of TSOs (definition of daily load schedules, maintenance schedule of energy generation plants, technical organization of grid management for maintaining frequency stability, count and charging of transmitted and feed electricity).

This framework ensures an open and transparent access to the grid as a prerequisite for a free market. Furthermore, it targets to guarantee grid stability even in times of highly fluctuating feed-in

[35] ENTSO-E: "UCTE Operation Handbook (OH)", v2.5 draft, 24.06.2004

[36] Federal Ministry of Justice: „Energiewirtschaftsgesetz - EnWG", 07.07.05

[37] Federal Ministry of Justice: „Renewable Energy Sources Act – EEG 2014", 21.07.14

[38] www.regelleistung.net/ip/action/abrufwert

[39] Verband der Netzbetreiber (VDN) e.V. beim VDEW: "TransmissionCode 2007 – Network and System Rules of the German Transmission System Operators", August 2007.

of electricity. The TSOs have thereby "developed a common understanding concerning the implementation of their responsibility for the system" [[40]].

3 Dispatching services market / balancing market

3.1 Italy

The Ancillary Services Market (Mercato per il Servizio di Dispacciamento - MSD) is the market where TERNA - as Transmission System Operator - procures the resources needed to manage, operate, monitor and control the power system (relief of intra-zonal congestions, creation of power reserve, real-time balancing). In the MSD, TERNA enters into purchase and sale contracts with a view to obtaining resources for dispatching services and acts as central counterpart to the transactions.

Bids/offers must refer to offer points (i.e. generation units) qualified to provide ancillary services in the MSD and must be submitted by the respective dispatching users directly (without agents acting on their behalf). All accepted bids/offers are remunerated at the offered price (pay-as-bid methodology).

The MSD consists of a scheduling stage (ex-ante MSD) and a real time stage, the Balancing Market (MB).

In the ex-ante MSD, TERNA accepts energy demand bids and supply offers in order to relieve residual intra-zonal[41] congestions and create reserve margins. In particular, the ex-ante MSD consists of four scheduling sub-stages: MSD1, MSD2, MSD3 and MSD4. In this phase the Italian TSO accepts tertiary reserve bids and offers to define an optimal scheduling, relieving network congestions and creating suitable secondary and tertiary reserve margins for the real time operation.

The Balancing Market (MB) takes place in different sessions, during which TERNA selects bids/offers for the groups of hours of the same day on which the related MB session takes place. At present, the MB consists of 5 sessions. In the MB, TERNA accepts energy demand bids and supply offers in order to provide secondary regulation and to balance energy injections and withdrawals into/from the grid in real time.

3.1.1 Market description

Unlike other markets in Europe, the main ancillary services in Italy are traded on the MSD spot market (that takes place in different stages) and are remunerated only on the basis of the energy, without any remuneration for the capacity made available. In the following a brief description of the dispatching services trading is provided[42].

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[40] Verband der Netzbetreiber (VDN) e.V. beim VDEW: "TransmissionCode 2007 – Network and System Rules of the German Transmission System Operators", August 2007, p.3

[41] Inter-zonal congestion have already been managed by the previous sessions of the day ahead and of the intra-day markets: see deliverable D1.1 *"Description of the general and local electricity markets and tariffs in Italy and in Germany"*.

[42] Primary control reserve (PCR) is not offered in a competitive market: the supplied regulating energy is remunerated on the basis of a tariff defined by the Italian Regulatory Authority, provided that the unit is equipped with an adequate metering system.

Secondary control reserve: SCR is automatically activated through the regulation signal sent by the TSO to each unit. The amount of energy is selected by a *pro-rata* criterion and remunerated according to the price offered by the producer in the MSD (pay-as-bid mechanism).

Tertiary control reserve: TCR is activated by the TSO by means of specific dispatching orders sent to the generating units. The amount of energy is selected on the basis of a common merit order and remunerated according to the price offered by the producer in the MSD (pay-as-bid mechanism).

Table Annex2-1 summarizes the main characteristics of the products traded in the ancillary services market for balancing purpose.

Table Annex2-1: Main characteristics of the products traded in the ancillary services market for balancing purpose.

Service	Product	Time slice	Selection of bid	Remuneration
SCR	2 products (upward and downward) for each hour	1 hour	Energy price merit order	Energy pay as bid
TCR	2 products (upward and downward) for each hour. Bids between minimum and maximum power can be divided into up to 4 steps with different prices.	1 hour	Energy price merit order	Energy pay as bid
	1 minimum power bid (increase from zero to minimum power) for each hour	1 hour	Energy price merit order	Energy pay as bid
	1 shut-down bid (reduction from minimum power to zero) for each hour	1 hour	Energy price merit order	Energy pay as bid
	1 start-up bid for each hour (only CCGT and OCGT)	-	Merit order	Token compensation
	1 change of configuration (only CCGT with two gas turbines)	-	Merit order	Token compensation

According to the central-dispatching design of the Italian market, energy imbalances are computed and settled for each generating and consumer unit, with different prices depending on the unit classification. The imbalance settlement for an aggregate portfolio is not allowed.

For the qualified generating units, energy imbalances are priced according to a dual price mechanism, depending on the sign of the control area imbalance. On the other hand, imbalances of consumers and of all the generating units not qualified for providing ancillary services are priced with a single price mechanism, depending on the sign of the control area imbalance. Table Annex2-2 and Table Annex2-3 shows respectively the dual price mechanism applied to qualified units and the single price mechanism for the non-qualified units. The energy imbalances are settled with reference to different time periods: for qualified units the relevant time frame is 15 minutes, for non-qualified units it is 1 hour.

The imbalance prices, both for qualified and non-qualified units, are computed on zonal basis for two macro-areas: North (equivalent to the Northern zone of the day ahead market) and South (that includes all the other market zones).

For non-dispatchable renewable energy sources the current regulation fixes an imbalance threshold for each energy sources (wind, PV, RoR hydro), within which the cost of imbalances is aggregated and equally divided among all generating units of a specific source. The net imbalance of a unit exceeding the threshold is then priced according to the non-qualified unit regulation.

Table Annex2-2: Dual price mechanism for imbalances of qualified units.

Sign of control area imbalance	Sign of unit imbalance	Price for qualified unit
+	+	Minimum between: - day ahead price - min price of downward bids accepted
+	-	Day ahead price
-	+	Day ahead price
-	-	Maximum between: - day ahead price - max price of upward bids accepted

Table Annex2-3: Single pricing mechanism for imbalances of non-qualified units.

Sign of control area imbalance	Price for non-qualified unit
+	Minimum between: - day ahead price - average price of downward bids accepted
-	Maximum between: - day ahead price - average price of upward bids accepted

3.1.2 Analysis of recent market results

Figure Annex2-7 shows the trend between years 2008 and 2013 of the annual volume of ancillary services provided in Italy, detailed for type of service (SCR/TCR) and type of regulation (upward/downward). Such volumes include both the scheduling phase (ex-ante MSD) and the real time operation (MB).

During the considered period volumes of control reserves significantly changed, because of several reasons: improvements in scheduling and operation of the system and several market reforms have contributed to enhance the real time control and balancing of the system, leading also to a better economic performance.

Figure Annex2-8 shows the monthly amount of balancing energy provided only in real time operation for each type of services in the year between December 2013 and November 2014[43] and Figure Annex2-9 shows the corresponding prices. It can be noted that in real time the energy used for downward services is almost twice than the upward energy. This is a consequence of the large development of intermittent RES that introduce more uncertainties in the balance of the system; in order to face uncertainties the TSO in the scheduling phase procures additional reserve that is then balanced by downward energy in real time, if not used.

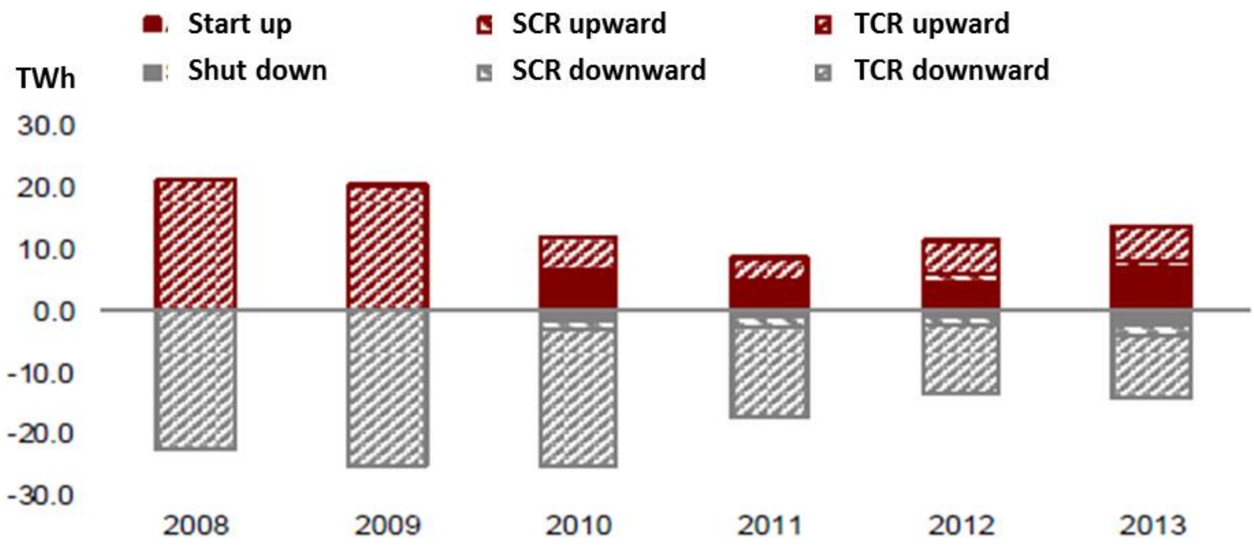

Figure Annex2-7: Annual volume of balancing reserve provided in years 2008-2013.

[43] The same period considered for the analysis of the energy markets reported in deliverable D1.1.

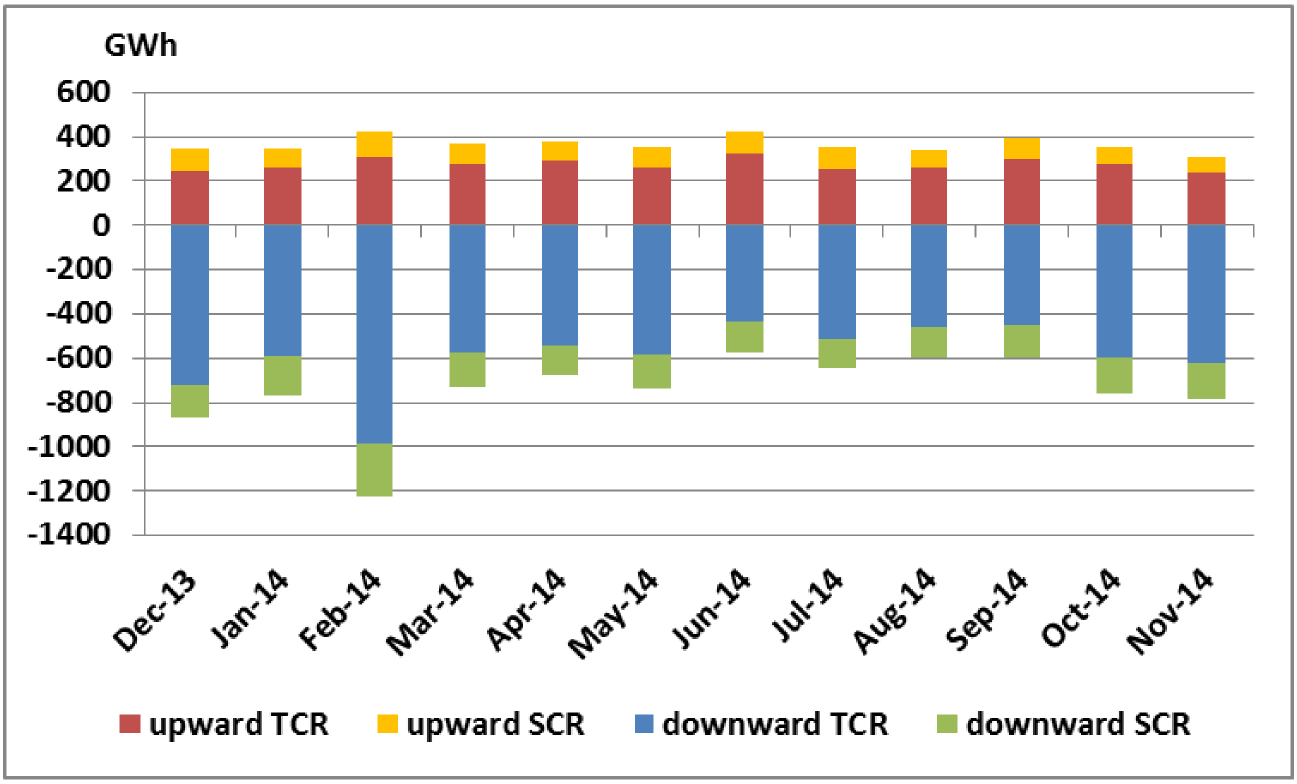

Figure Annex2-8: Monthly volume of balancing energy provided for each type of services.

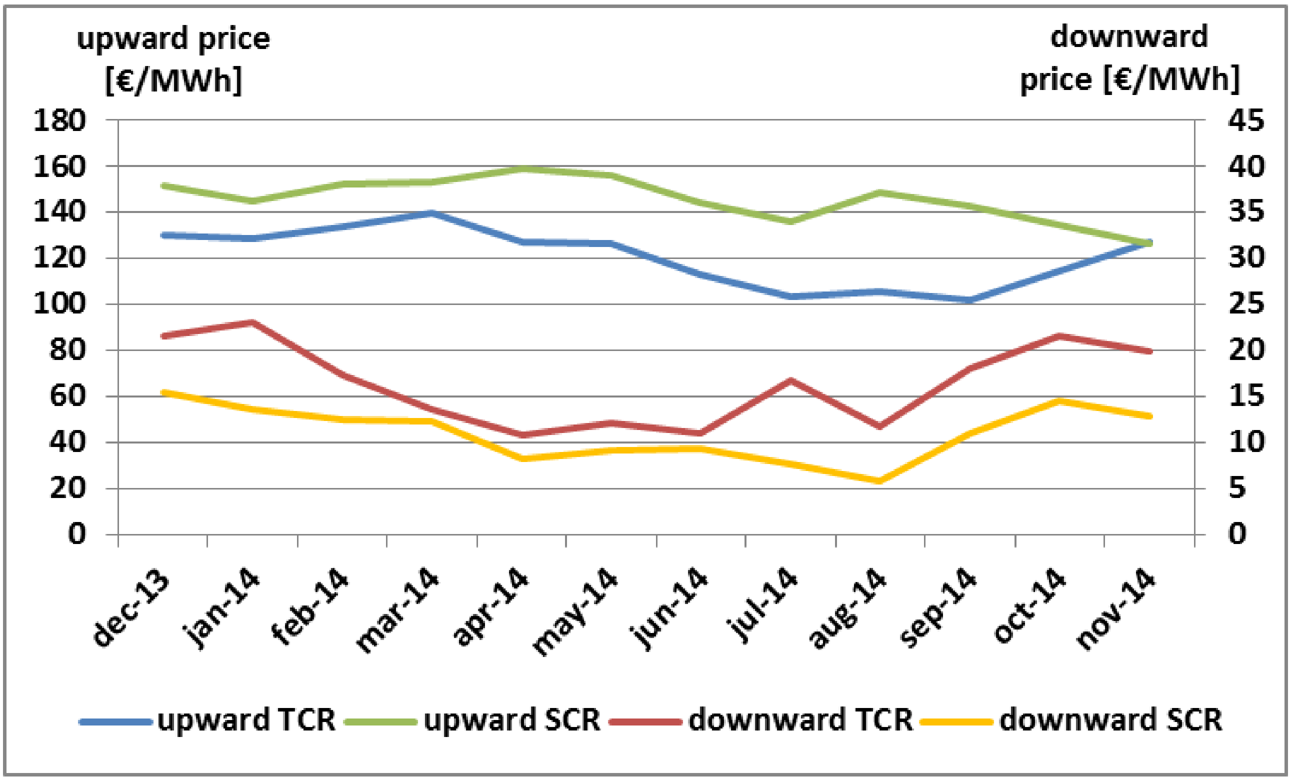

Figure Annex2-9: Monthly weighted average of balancing energy prices.

Typical prices of upward reserves are higher than the day ahead energy price, while the downward reserve price is lower. This means that operating on the balancing market can be much more remunerative than operating only on the day ahead market.

Prices of control reserves reflect also the value of the two distinct services: SCR and TCR. Since SCR is a faster service and not all the market participants are able to provide it, it is the most valuable product, with higher prices for increasing generation and lower prices for reducing generation[44].

Figure Annex2-10 and Figure Annex2-11 respectively show the hourly balancing energy provided and the corresponding prices. It can be noted that the volumes of balancing energy depend also on the residual load profiles and in particular on the direction of the ramp.

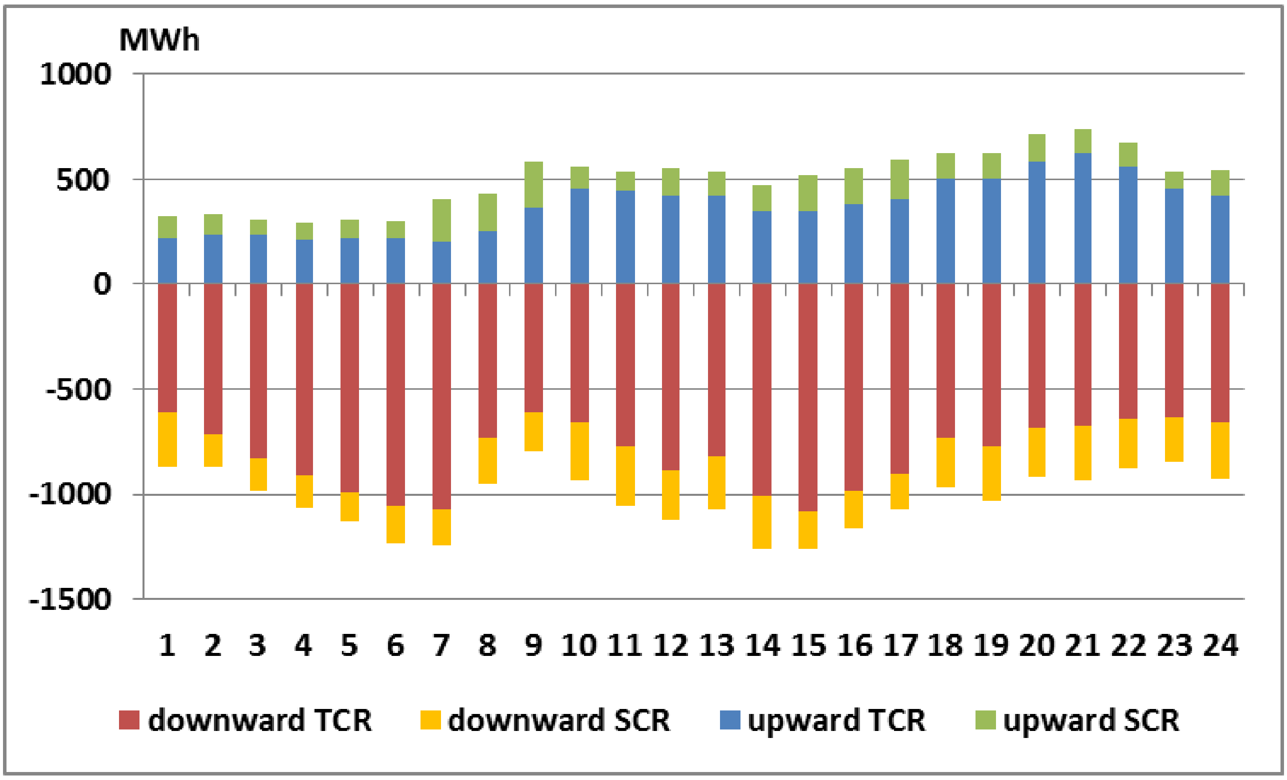

Figure Annex2-10: Hourly average of balancing energy provided for each type of service.

[44] Currently in Italy negative prices are not allowed. The price for downward service is the price at which the producer buys back its own energy: this results in a net expenditure for the producer.

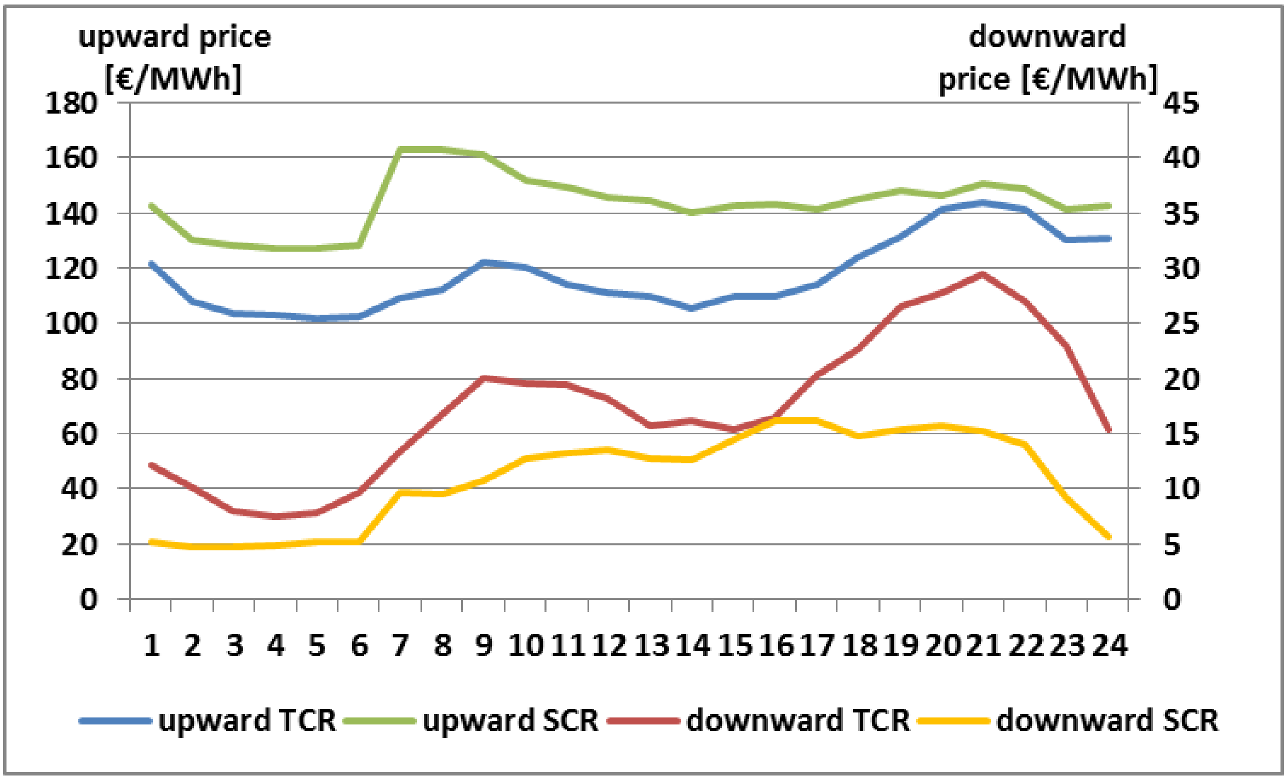

Figure Annex2-11: Hourly weighted average of balancing energy prices.

In order to better understand the market framework where the Italian industrial partners (ORI Martin and AST) involved in the project can potentially participate, in the following a more detailed analysis of the historical results of the Balancing Market in the two market zones where their steel plants are located is presented. The two market zones are NORTH and CENTER-NORTH (CNORTH) and the analysis is focused on the TCR used for real time balancing in the period December 2013 – November 2014.

Figure Annex2-12 reports the hourly average amount of TCR provided in the NORTH market zone for upward and downward regulation. Even in this case the hourly profile of services provision depends on the residual load profile and follows the general trend already shown for the whole Italian market (Figure Annex2-10).

Figure Annex2-13 shows the same volumes provided in the CNORTH market zone; in this case the average volumes are significantly lower than in the NORTH zone. This is due to the lack of resources that can provide TCR.

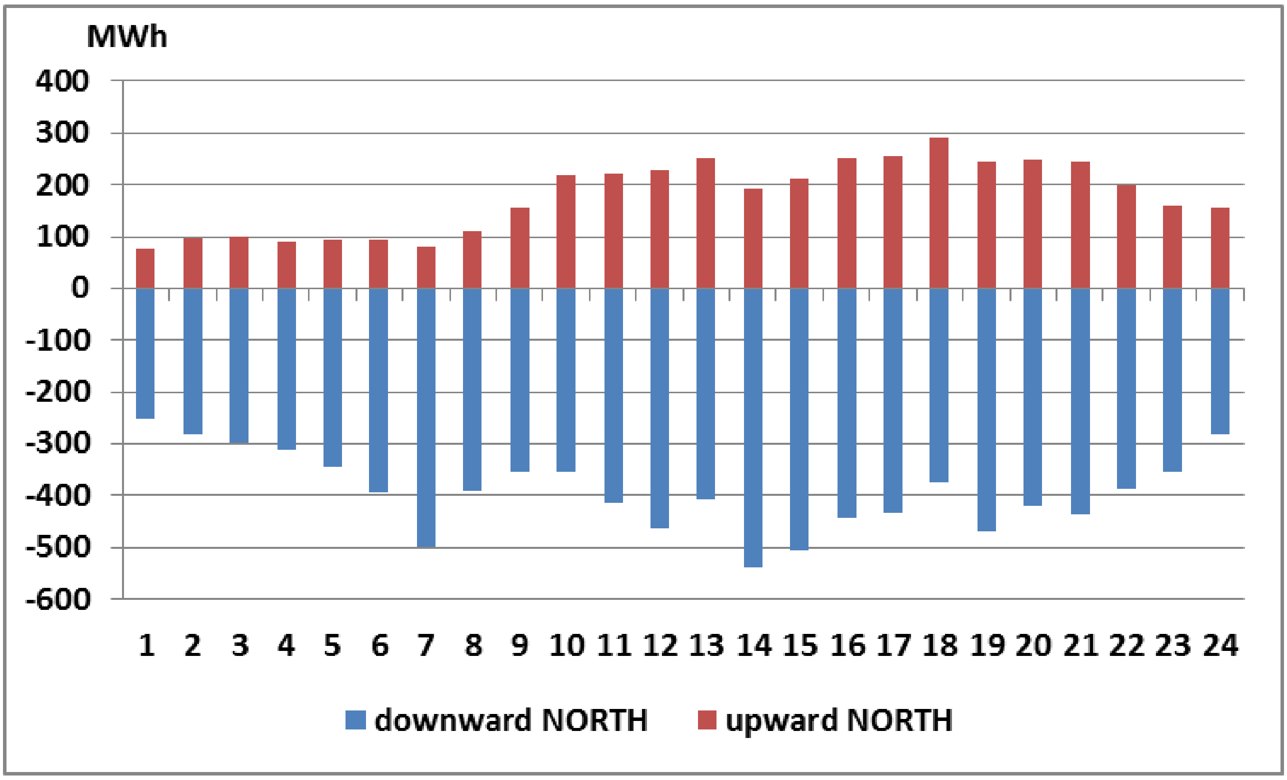

Figure Annex2-12: Hourly average balancing energy for TCR provided in the NORTH zone.

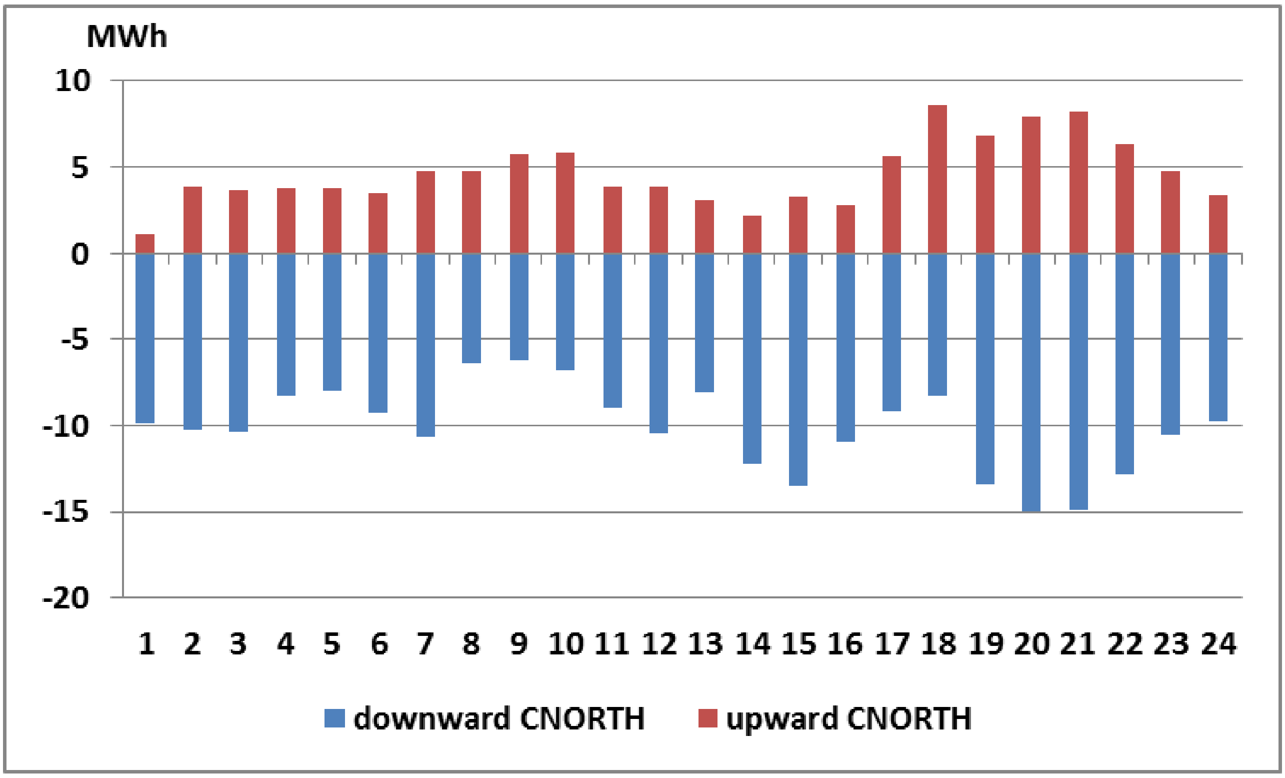

Figure Annex2-13: Hourly average balancing energy for TCR provided in the CNORTH zone.

Figure Annex2-14 and Figure Annex2-15 show the hourly average price for TCR in both market zones. It can be noted that prices for TCR in the NORTH zone are quite constant along the day, while in the CNORTH zone there is a price spike for upward service in correspondence to the evening load ramp. This is coherent with the reduced volumes traded and indicates a shortage of TCR for upward service in that market zone.

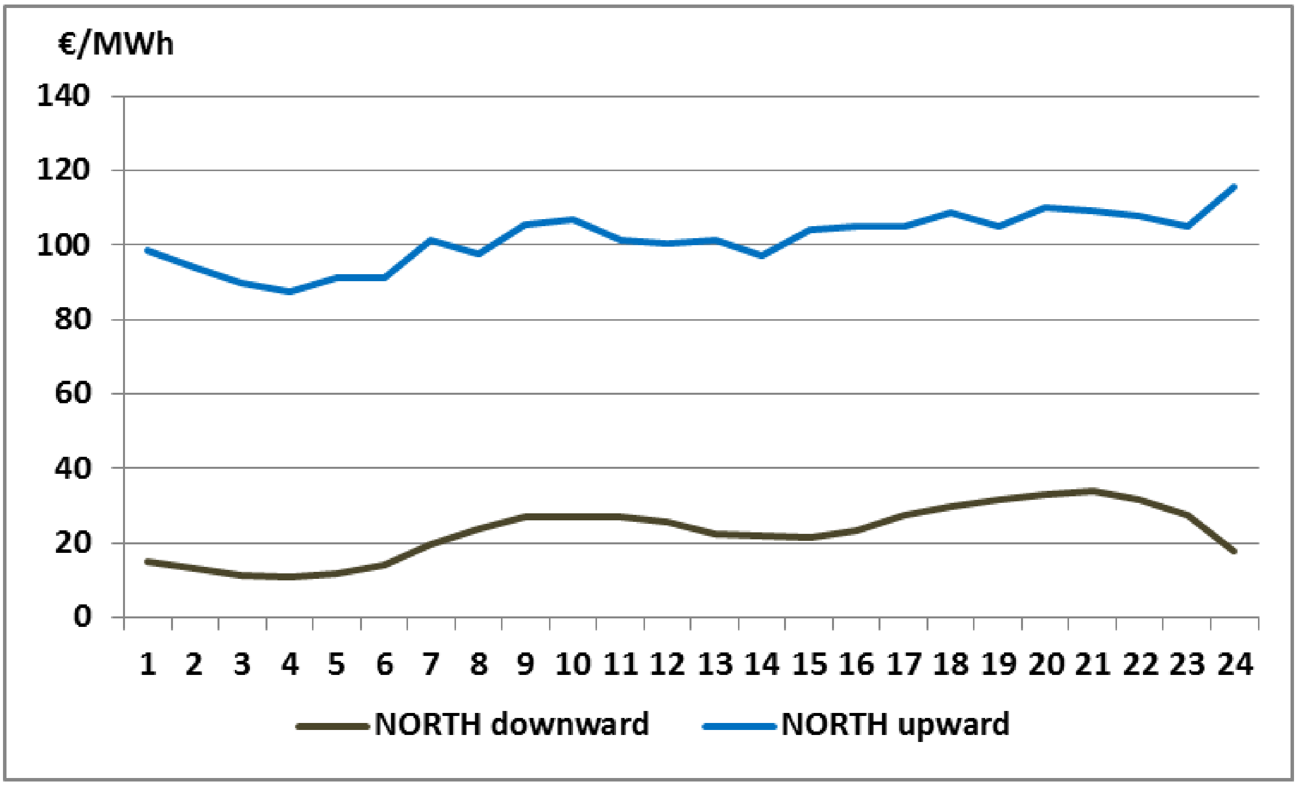

Figure Annex2-14: Hourly average price of TCR in the NORTH zone.

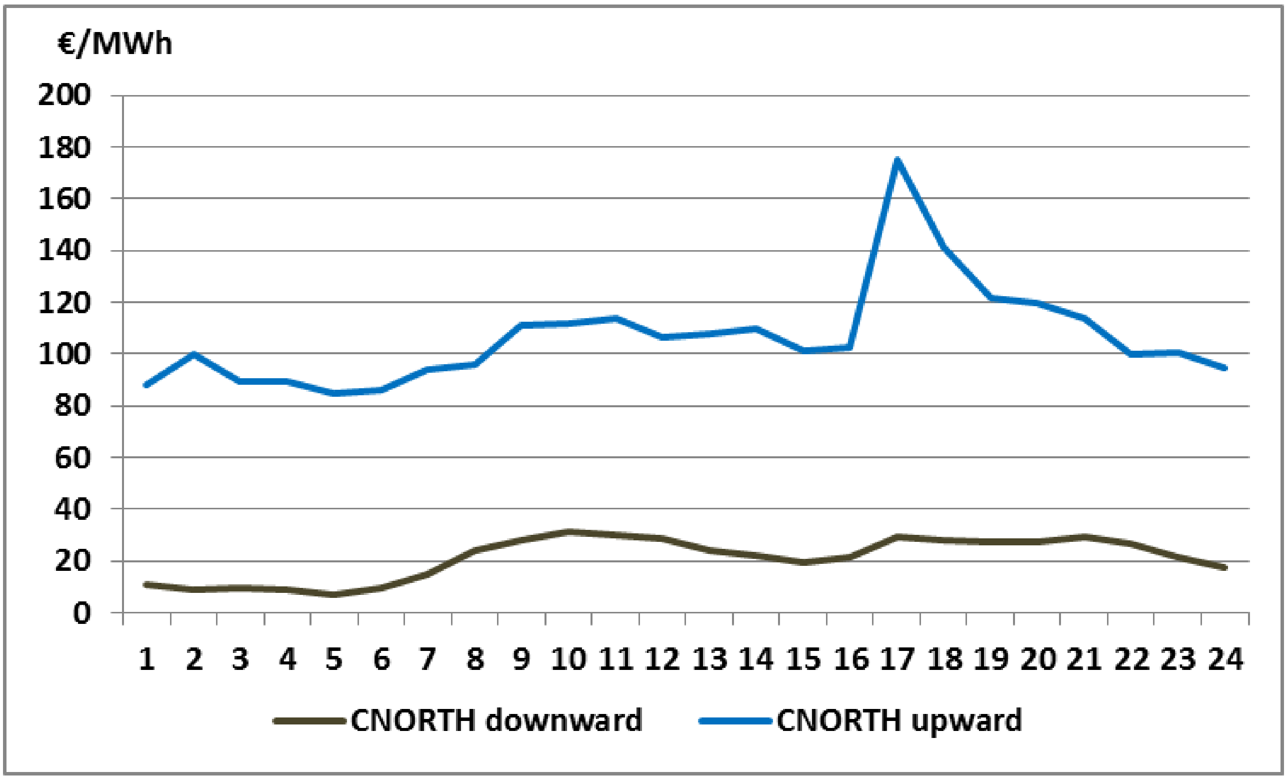

Figure Annex2-15: Hourly average price of TCR in the CNORTH zone.

Figure Annex2-16 and Figure Annex2-17 show the monthly average of daily values of TCR procured respectively in the NORTH and in the CNORTH zone, while Figure Annex2-18 shows the corresponding prices. The price spike that occur in April in the CNORTH zone can be explained with the lack of TCR occurred in that month (see Figure Annex2-17).

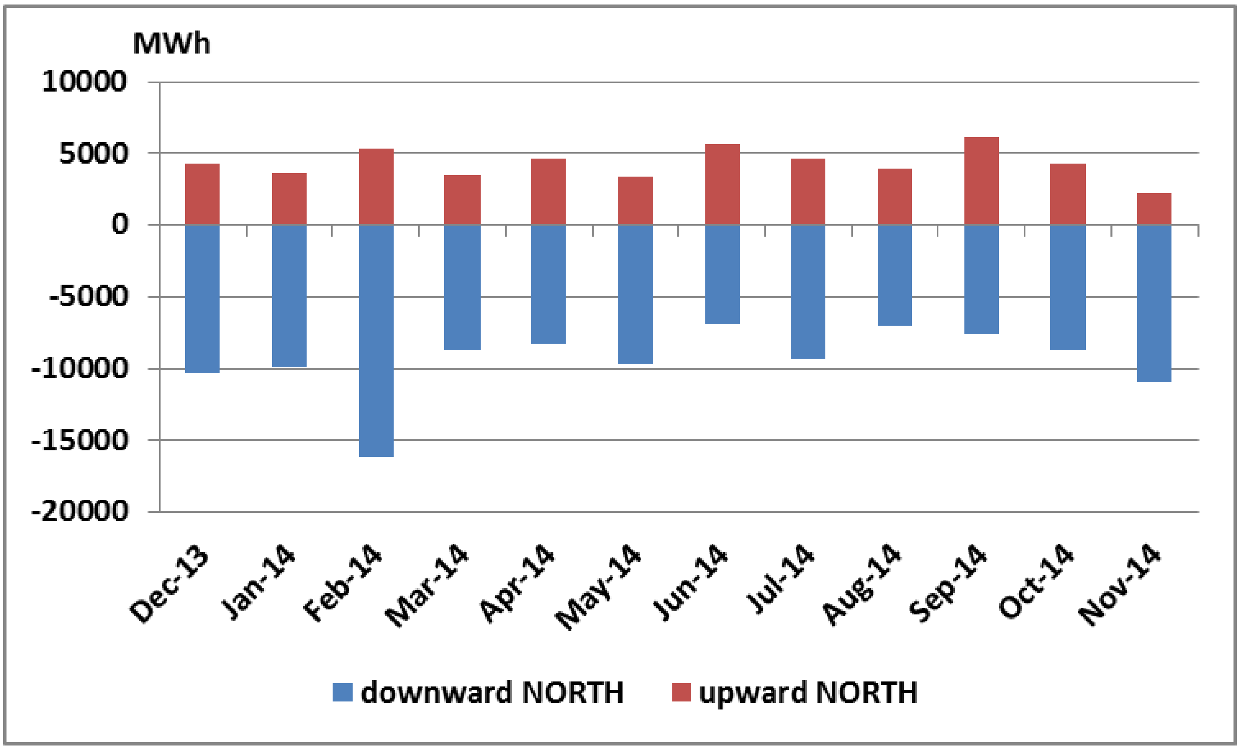

Figure Annex2-16: Monthly average of daily balancing energy for TCR provided in the NORTH zone.

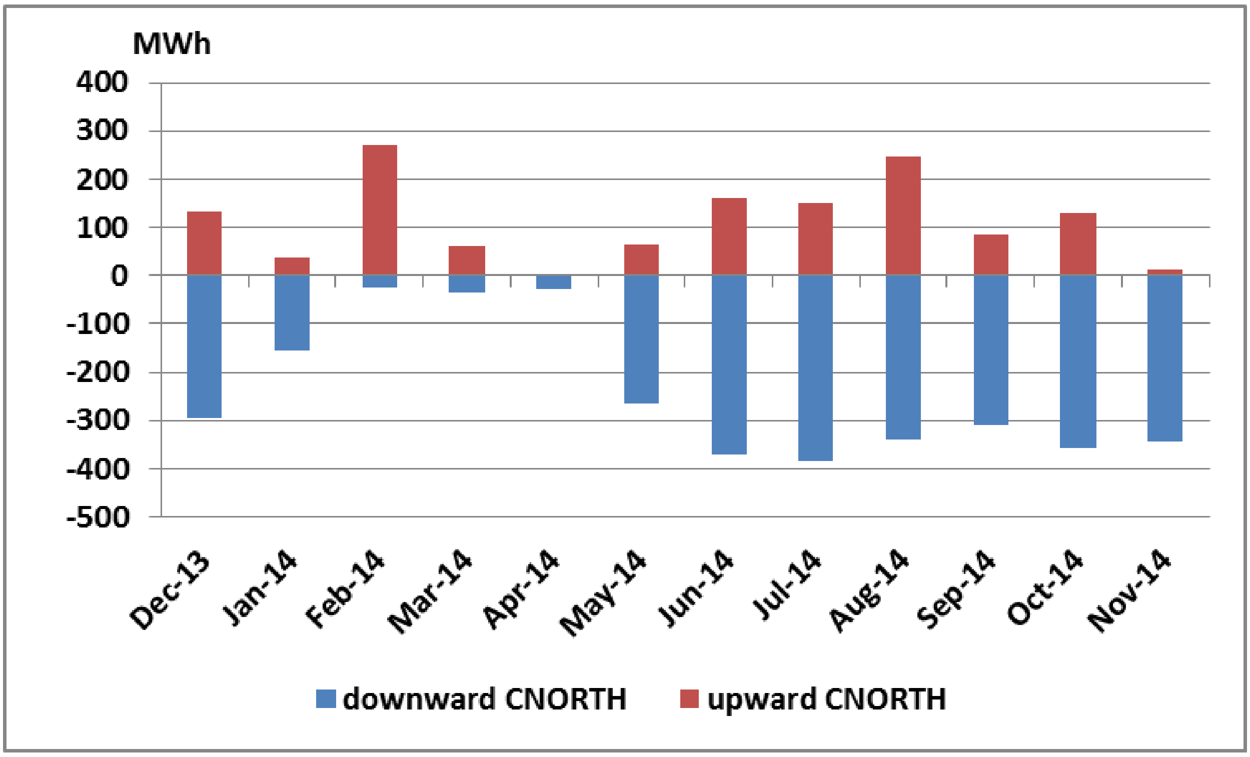

Figure Annex2-17: Monthly average of daily balancing energy for TCR provided in the CNORTH zone.

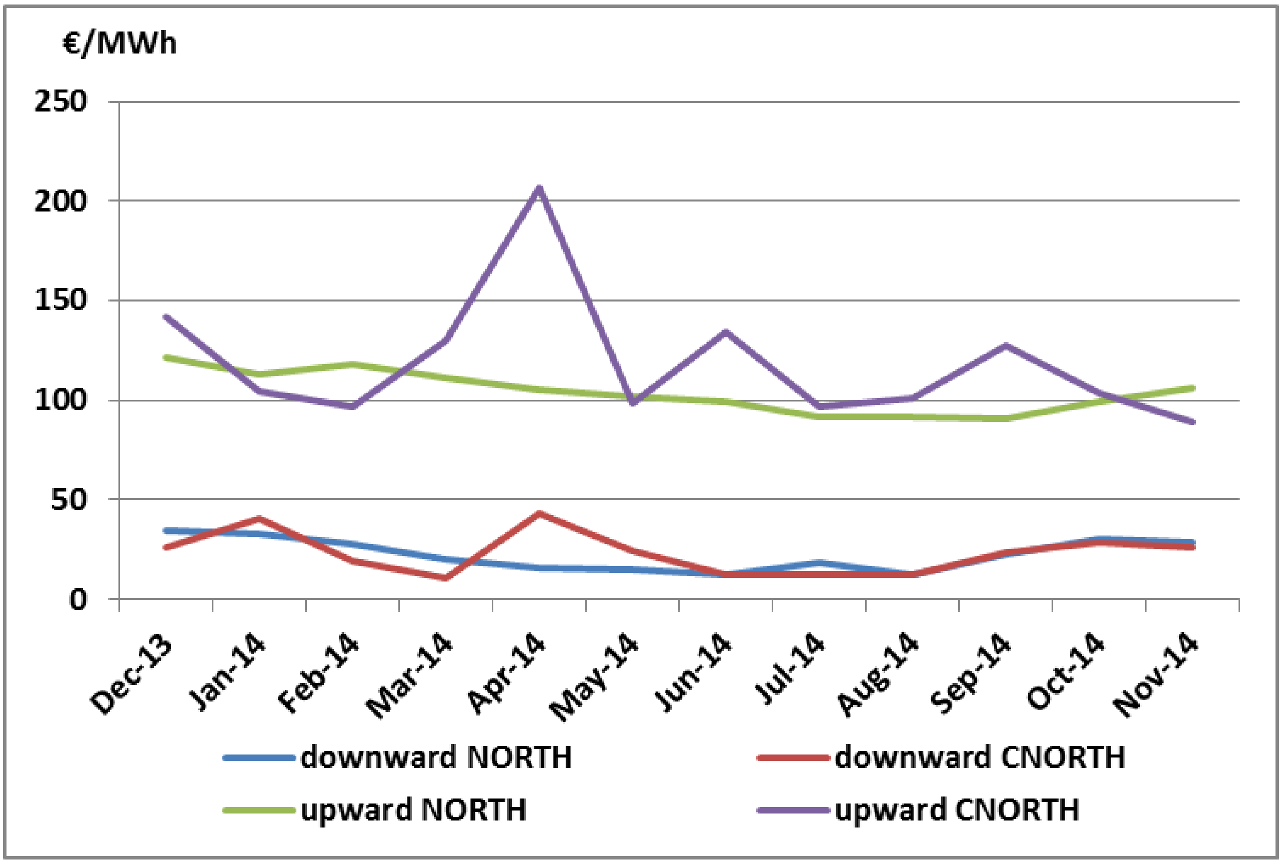

Figure Annex2-18: Monthly weighted average of TCR prices in the NORTH and CNORTH zones.

Another interesting aspect is the difference between TCR procured during working days and non-working days. Figure Annex2-19 through Figure Annex2-22 clearly show that the average volumes procured during working days are significantly higher than in non-working days, in both market zones and both for upward and downward regulation. This is mainly due to the typical load reduction during weekend.

On the contrary, while in the day ahead market the energy price in non-working days is lower because of a reduction of traded volumes, in the ancillary services market the prices of TCR are almost constant in working and non-working days, as shown in Figure Annex2-23 and Figure Annex2-24. Indeed there is a slight increase of the upward price, especially in the CNORTH market zone, proof of the scarce availability of regulating resources.

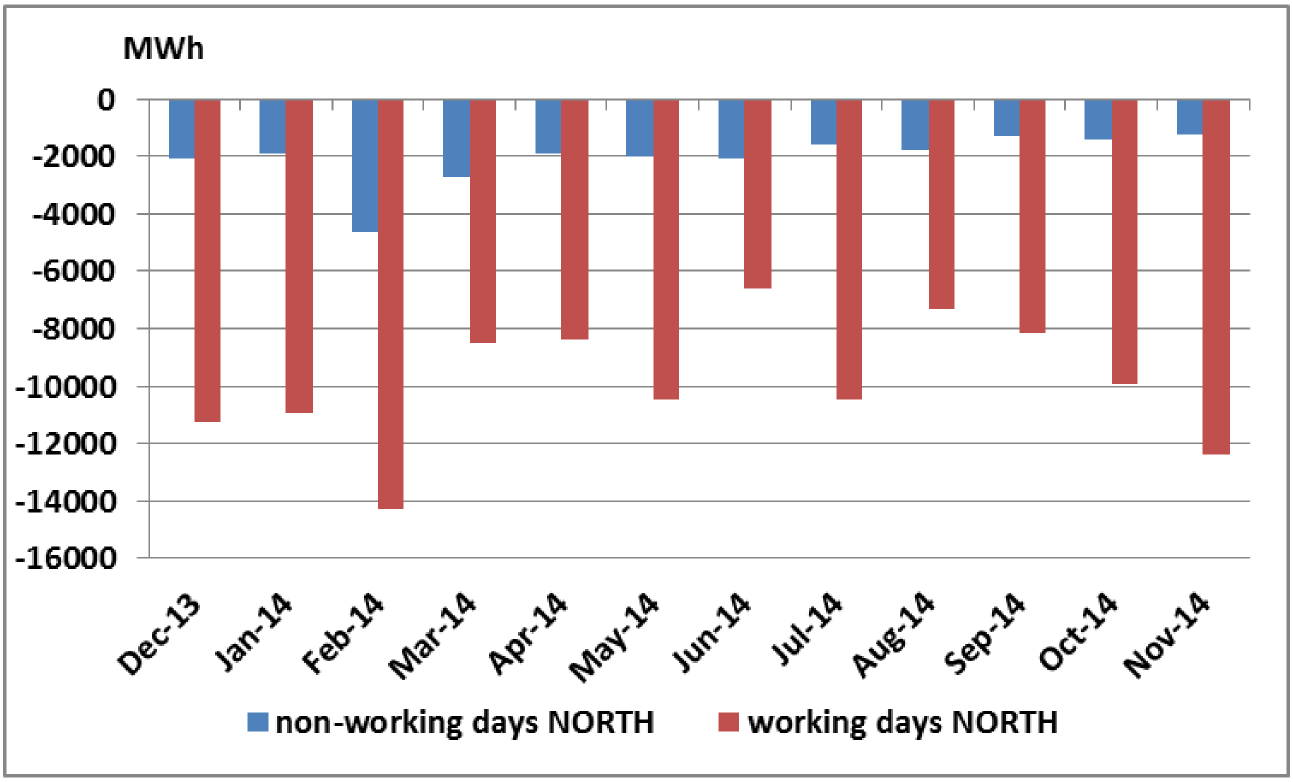

Figure Annex2-19: Monthly average of daily downward balancing energy for TCR provided in the NORTH zone in working and non-working days.

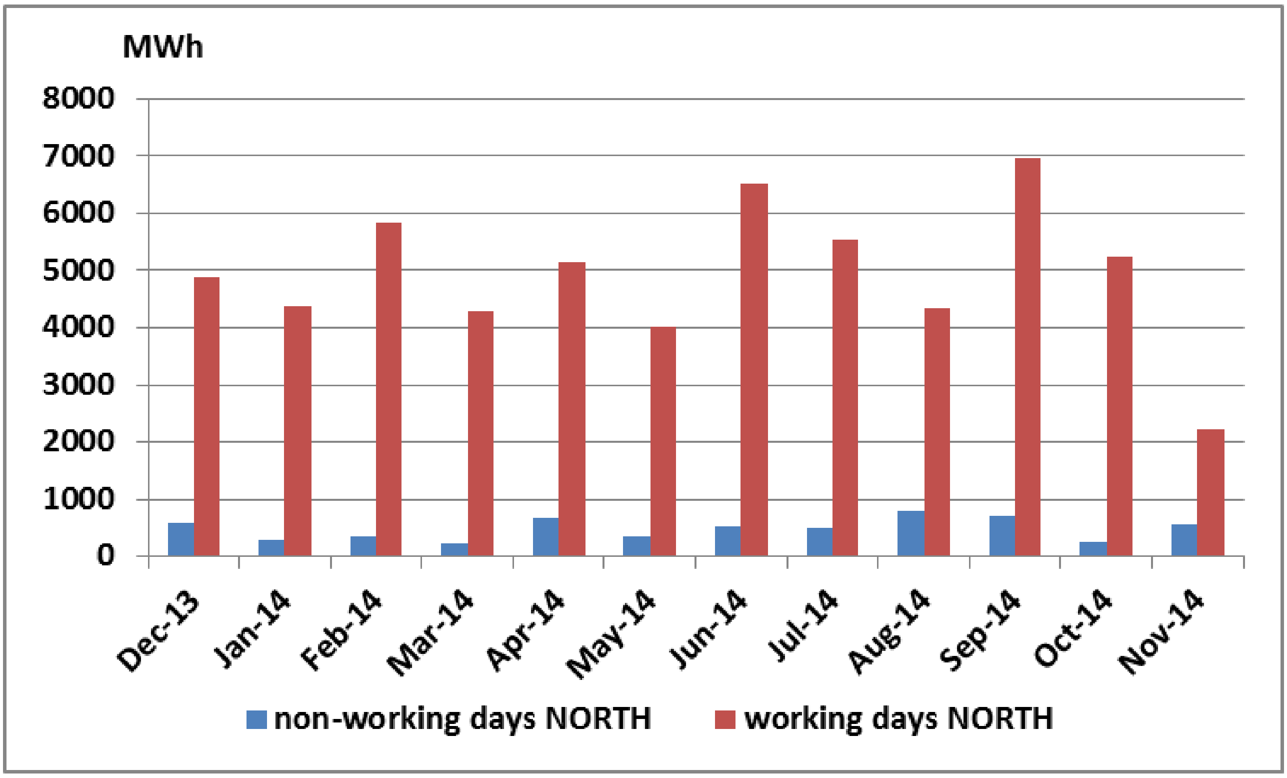

Figure Annex2-20: Monthly average of daily upward balancing energy for TCR provided in the NORTH zone in working and non-working days.

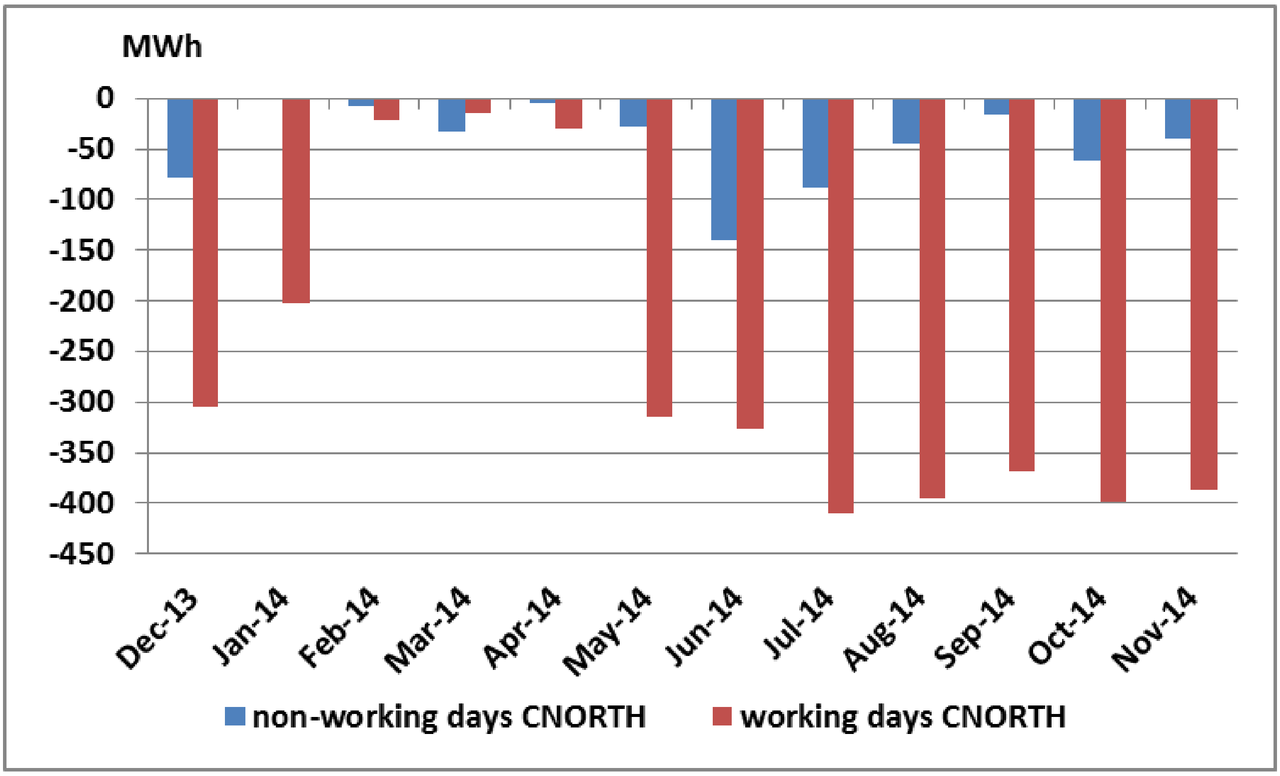

Figure Annex2-21: Monthly average of daily downward balancing energy for TCR provided in the CNORTH zone in working and non-working days.

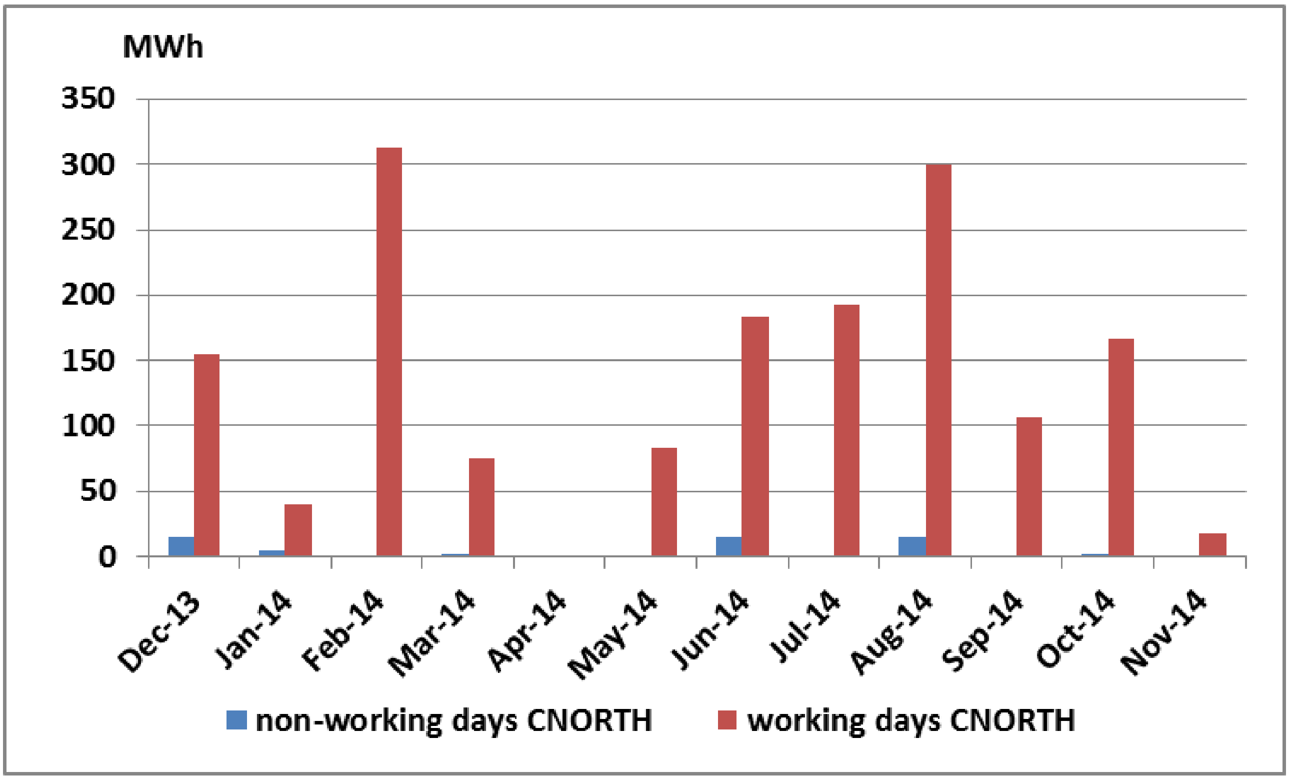

Figure Annex2-22: Monthly average of daily upward balancing energy for TCR provided in the CNORTH zone in working and non-working days.

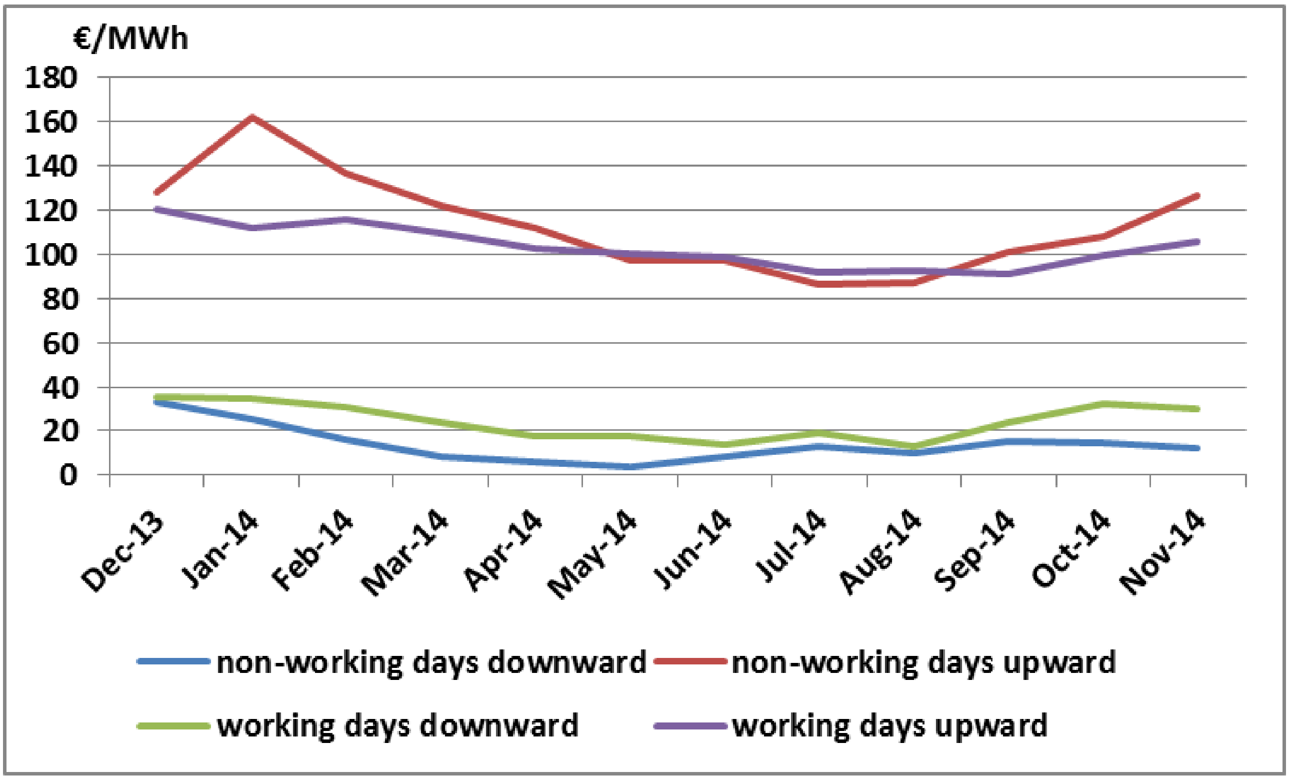

Figure Annex2-23: Monthly weighted average of TCR prices in the NORTH zone for upward and downward regulation in working and non-working days.

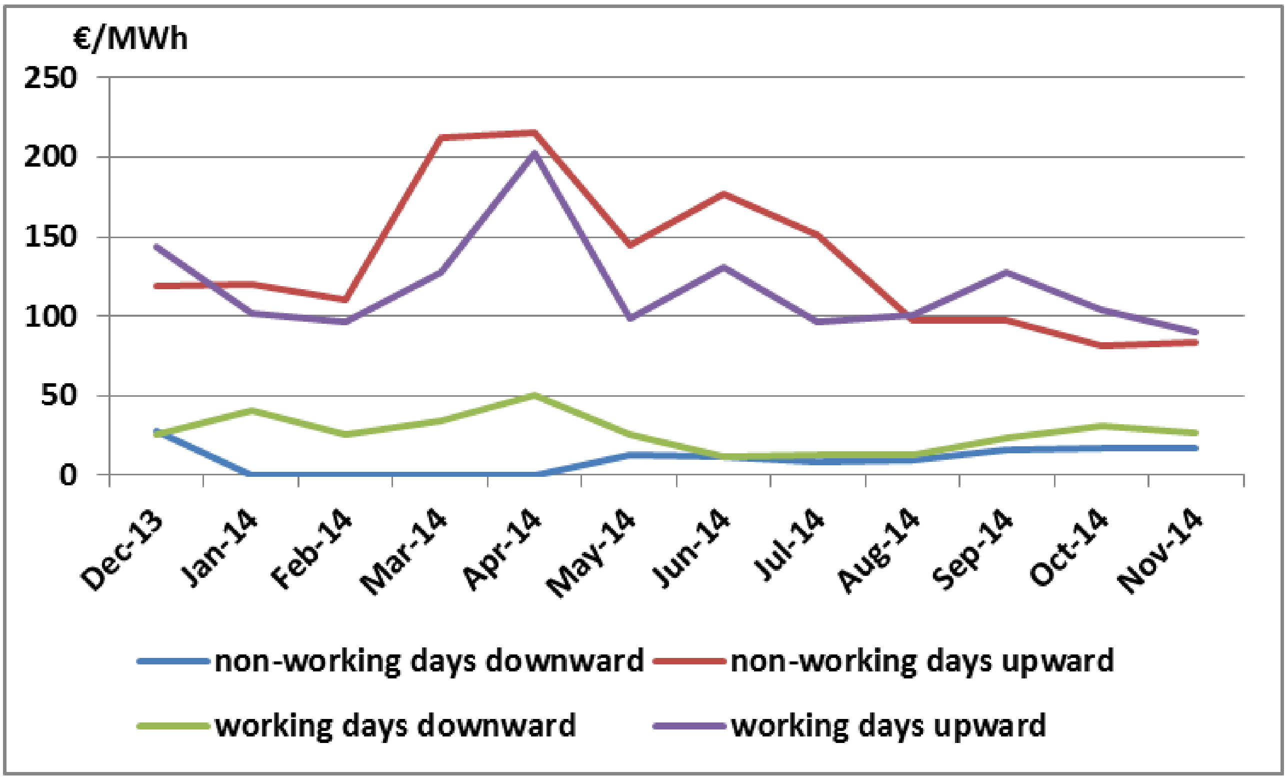

Figure Annex2-24 - Monthly weighted average of TCR prices in the CNORTH zone for upward and downward services in working and non-working days.

3.2 Germany

In Germany larger electricity customers cover their energy demands via the traditional energy market. Therefore, contracts with a power company are concluded. These contracts mostly comprise a fixed base price combined with a demand rate. When exceeding a threshold, defined as a maximum averaged quarter of an hour achievement, the customer is financially fined.

Additionally, there is the possibility for larger companies to cover a part of their electricity demand via the European Electricity Exchange (EEX). To stabilize the electricity grid larger electricity customers can participate solitarily or as a part of a pool of customers at the electricity control market, the German Control Reserve Market.

3.2.1 Market description

This control market assists the so called Netzregelverbund (NRV) as a supplementary tool to guarantee the grid-stability in the context of flexible electricity generation and demand. The NRV is an incorporation of all German and several international transmission grid operators (TSOs) for electricity. In this network all control zones are optimized with respect to economic advantages and grid-stability, by exchanging required information. In case of imbalances, control energy is activated. Major impacts on the actual grid situation are the stochastic load behavior, regenerative electricity supply, failures of conventional power stations as well as the electricity wholesale trade.

There are three types of control power which can be differentiated by their activation speed and principle of activation. Primary control reserve (PCR), secondary control reserve (SCR), as well as tertiary control reserve (TCR). They can be defined as positive (shutdown of aggregates) as well as negative (cut-in of aggregates).

The PCR is quantified by ENTSO-E which directly cooperates with the NRV within the International Grid Control Cooperation (IGCC). It stabilizes the grid as fast as possible and will not be considered further in this analysis.

The SCR is an automatically activated control reserve and only activated where imbalances occur, slower than the PCR. SCR minimizes deviations of network frequency as well as unscheduled energy flows. SCR has a limited duration, therefore for longer lasting imbalances in the system it must be replaced by the slower TCR. The requirements for the TCR are lower than for the other two.

The overall situation for German industrial consumers is depicted in Figure Annex2-25.

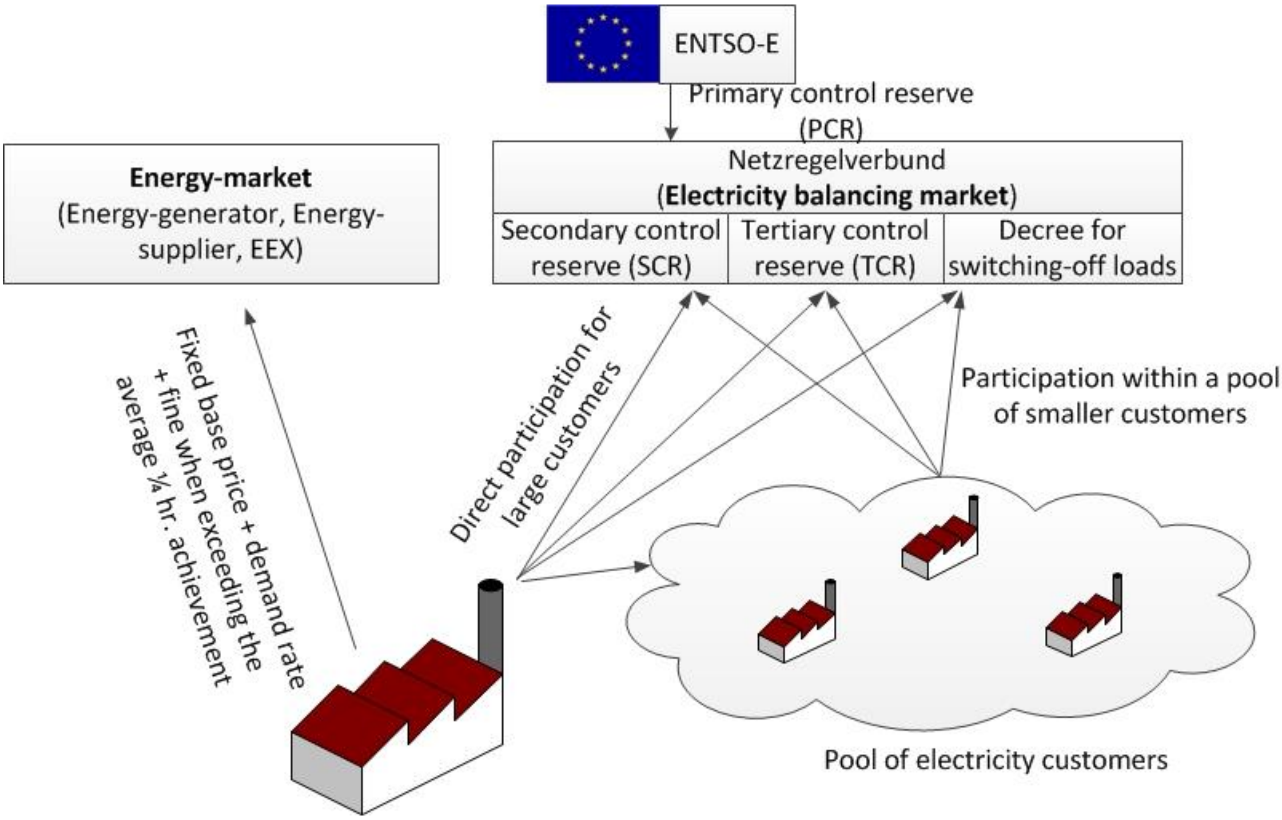

Figure Annex2-25: General overview of the German electricity market for industrial consumers.

Since 1st December 2006, the minute reserve (TCR) required by the four TSOs has been procured via a joint cooperation. For this purpose, a TSOs' common Internet platform is available [[45]]. A joint tender for the procurement of primary and secondary control reserve was introduced one year later on 1st December 2007 and is also processed via this internet-platform.

Control reserve and control energy have to be procured within a common (cross-control area) and anonymized and strictly regulated tendering process. Supplementary information on IGCC is provided there as well by detailing energy exchanges between the various IGCC partners. A study commissioned by the German TSOs dealing in more detail with *"The description of load-frequency*

[45] www.regelleistung.net

control concept and market for control reserves" enables a sufficiently deep and complete insight into this topic [[46]].

The main characteristics of control reserve products in Germany are listed in Table Annex2-4.

[46] Consentec: *"The description of load-frequency control concept and market for control reserves"*, study commissioned by the German TSO's, 27.02.14, http://www.consentec.de/wp-content/uploads/2014/08/Consentec_50Hertz_Regelleistungsmarkt_en__20140227.pdf

Table Annex2-4: Main characteristics of control reserve products in Germany [46]

	PCR	SCR	TCR
tender period	weekly	weekly	daily
tender time	as a rule on Tuesdays (W-1)	as a rule on Wednesdays (W-1)	as a rule Mo-Fri, 10 a.m.
product time-slice	none (total week)	peak: Mo-Fri, 8 a.m. to 8 p.m., without public holiday off-peak: residual period	6 x 4 blocks of hour
product differentiation	none (symmetric product)	positive / negative SCRL	positive / negative TCR
minimum bid amount	1 MW	5 MW	5 MW (submission of bid for a block of max. 25 MW possible)
increment of bid	1 MW	1 MW	1 MW
call for tender	capacity price merit-order	energy price merit-order	energy price merit-order
remuneration	pay-as-bid (capacity price)	pay-as-bid (capacity price and energy price)	pay-as-bid (capacity price and energy price)

In general, bidders are chosen on the basis of the merit order (based on costs for procured control reserve) of capacity prices. Energy prices bids are solely considered where bids have identical capacity prices. All chosen bidders are paid according to their individual capacity-price bid (pay-as-bid). For a more detailed insight into the control power market and the control power concepts see [47], where the legal and regulatory framework, the network access model, the realization of power-frequency control, pre-qualification of suppliers and provision and use of control reserve as well as the determination and settlement of control energy is analyzed. PCR and SCR are procured in weekly tenders, whereas TCR is provided in daily tenders.

For SCR and TCR it is essential that two different biddings for provided reserves as well as an energy price bid for deployed reserves and capacities which become valid in case of a possible activation have to be made.

A uniform balancing energy price, the so called “reBAP”, has been introduced as a single uniform price for the whole of Germany, changing every 15-minute interval [46]. The imbalance price is symmetric, i.e. it is used both for offtake of balancing energy out of the system by a player having a shortage of energy (positive balancing energy: e.g. a customer with a higher consumption than the scheduled amount) and for feed-in of balancing energy into the system by a player having a surplus of energy (negative balancing energy: e.g. a customer with a lower consumption than the scheduled amount).

The reBap is determined by dividing the energy costs arising in each specific quarter of an hour by the balance of the deployed amount of control energy within the same time interval. Since control energy costs can be either positive or negative, the reBAP can also be positive or negative. A positive reBAP means that the player pays the TSO for the balancing energy offtaken from the

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[47] www.regelleistung.net

system (i.e. in case of shortage), and that it is paid by the TSO for the balancing energy fed into the system (i.e. in case of surplus). If the reBAP is negative, the payment flows are in the opposite directions. Table Annex2-5 shows the payment flows for balancing energy in the different possible cases.

Table Annex2-5: Payment flows for balancing energy in the different possible cases.

Type of imbalance	Flow of balancing energy	Sign of reBAP	Effect for the player
shortage	offtake from the system	positive	pays
shortage	offtake from the system	negative	gets paid
surplus	feed-in to the system	positive	gets paid
surplus	feed-in to the system	negative	pays

As far as loads are concerned, Table Annex2-6 shows the main characteristics of SCR (Seconds Reserve Load – SRL), TCR (Minutes Reserve Load – MRL), as well as of the service regarding interruptible loads (AbLaV) [[48]].

Table Annex2-6: Main characteristics of control reserve products in Germany for loads [[49]]

	SRL	MRL	AblaV
Load alteration	+/- 5 MW	+/- 5 MW	+ 50 -200 MW
Call for bids	weekly	daily	monthly
Announcing time	Wednesday, 15:00 for next week	10:00 for next day	15. of month for the next month
Reaction time	< 5 min	< 15 min	SOL: 1 sec SNL: < 15 min
Holding period	up to 15 min	up to 4 hours	1, 4, 8 hours
Compensation	Addition: per kW Call: per kWh	Addition: per kW Call: per kWh	2.500 €/MW LP 100-400 €/MWh AP
Call	automatically	automatically, manually, by telephone, by schedule	SOL: automatically SNL: controlled by grid operator
Time slots	a) Mo-Fr 8-20 b) Mo-Fr 20-8, Sa, So, H	6 x 4 h	different times

[48] https://www.transnetbw.com/en/energy-market/ancillary-services/interruptible-loads
[49] FOREnergy: Flexibilisierung der Energienachfrage von industrieellen Verbrauchern, Jan. 2015

3.2.2 Analysis of recent market results

The necessary provision of control reserve is calculated every quarter of an hour and is based on historical data and estimations concerning relevant factors. It can be seen from Figure Annex2-26 that the tendered volume has undergone a significant change within the years.

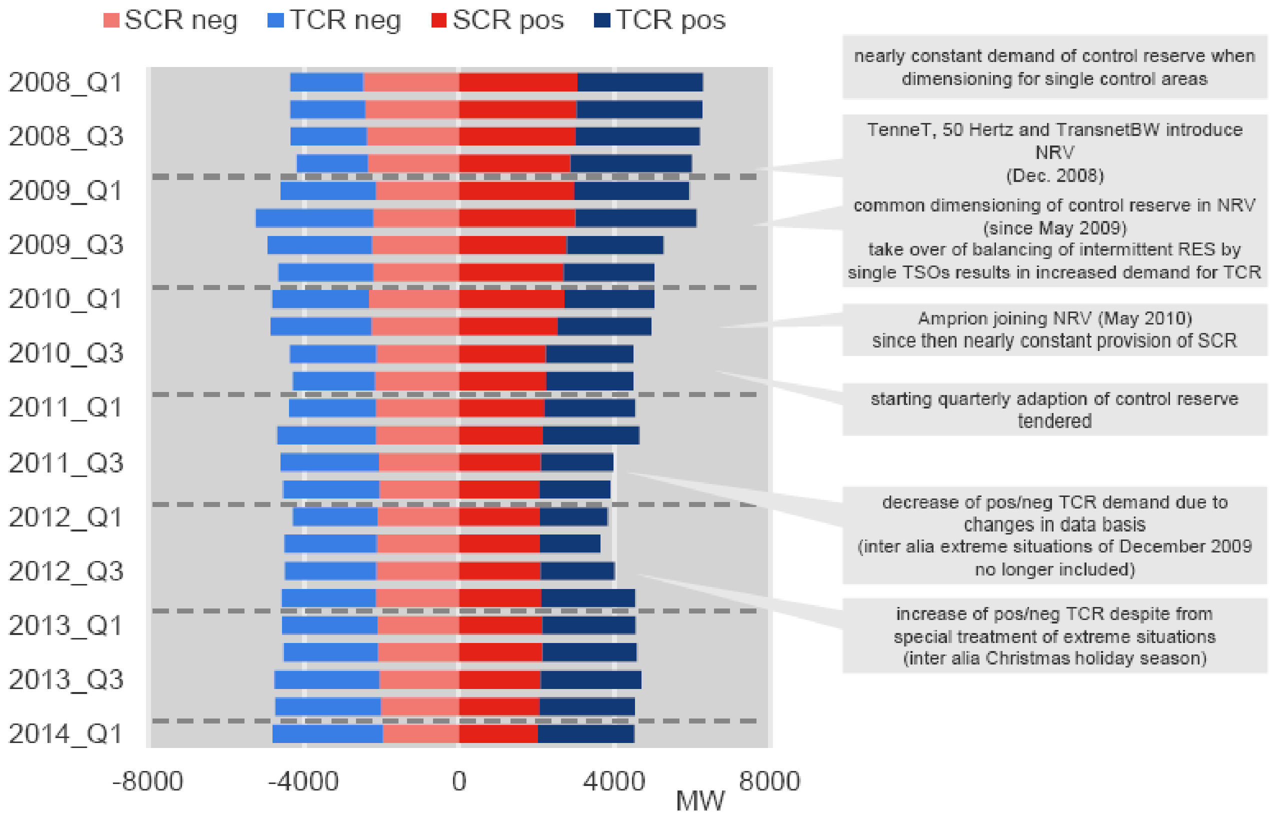

Figure Annex2-26: Quarterly averaged values of control reserve tendered (data base www.regelleistung.net) [46].

This is mainly based on changing behavior of the energy consumers as well as on structural changes of load-frequency control in Germany as e.g. the introduction of the NRV.

A nice historical overview condensing the overall development of tendered SCR and TCR is depicted in Figure Annex2-27 for SCR and Figure 7 for TCR.

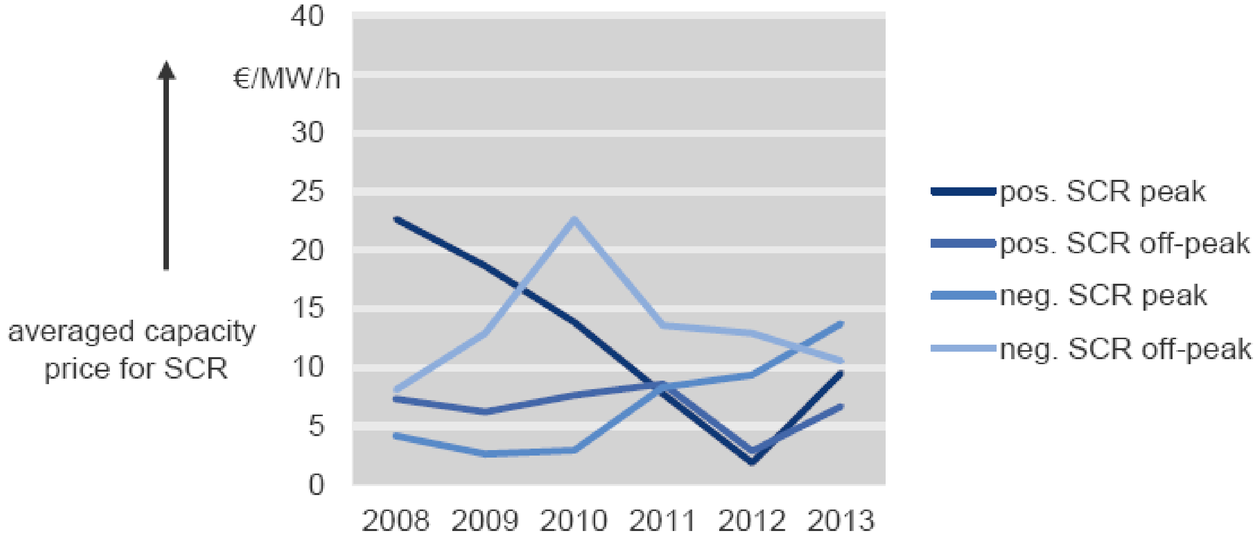

Figure Annex2-27: Evolution of averaged capacity price of accepted bids for SCR (data base www.regelleistung.net) [46].

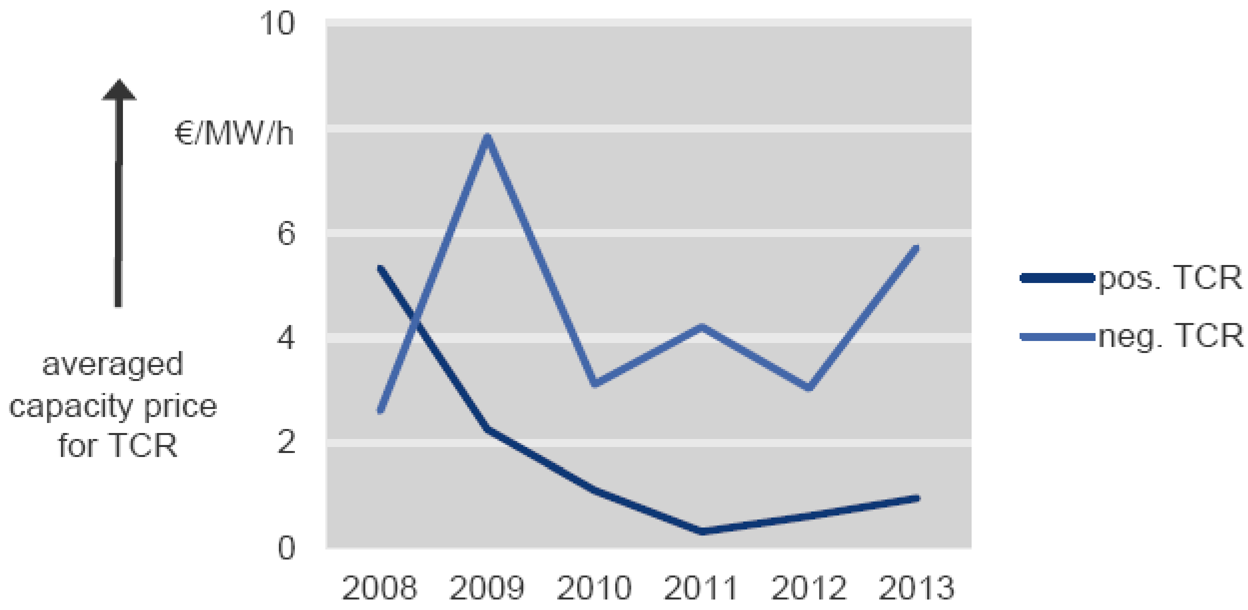

Figure Annex2-28: Development of averaged capacity price of accepted bids for TCR (data base www.regelleistung.net) [46].

These prices result from the overall provided control reserve.

It is not feasible to apply these figures to single use cases directly, since the capacity price strongly varies according to offered boundary conditions of the industrial plant. These requirements comprise:

Time response for providing balancing power (positive/negative)

Amount of balancing power offered in total

Possible duration of activation time

Allowable amount of possible activations (per week/month/year)

Robustness during possible activation (rejection rate, acceptance rate)

4 <u>Non market-based services, remunerated on the basis of a tariff</u>

4.1 Italy

In Italy the primary regulation service (PCR) for frequency regulation is a mandatory service to be provided by all generators with rated power greater than 10 MVA and compliant to specific requirements defined in the grid code. The primary regulation service consists in the provision of an upward and downward regulation capacity band, equal to 1.5% of the rated power, subject to the automatic control during real time operation, according to the frequency measured at the connection point of the plant with the grid.

In the past the primary control energy was settled as a deviation from the scheduled profile, like imbalances: this was penalizing for generating units that provided the primary control service. For this reason from 2014 a mechanism for the remuneration of this service has been introduced, avoiding the accounting of primary control energy as imbalances. The mechanism is optional and generating units that want to be remunerated must install a specific metering system. By means of such systems the TSO TERNA can measure the amount of primary control energy provided by the unit every 15 minutes. This amount is subtracted to the net power imbalances and remunerated with a price defined as:

- for upward regulation: hourly day ahead market zonal price plus 50% of the difference between the annual average price of bids accepted for upward secondary regulation and the annual average zonal price of the day ahead market (both average values refer to the previous year);
- for downward regulation: hourly day ahead market zonal price minus 50% of the difference between the annual average zonal price of the day ahead market and the annual average price of bids accepted for downward secondary regulation (both average values refer to the previous year).

5 Other current business opportunities for large industrial loads in providing ancillary services

5.1 Italy

Large industrial loads in Italy can participate to the provision of a service for switching off their consumption, if required by the TSO for security reasons. According to the grid code, the interruptible loads are classified in:

- Instantaneous switch-off (within 200 ms after the control signal)
- Emergency switch-off (within 5 s after the control signal)

The current regulation in force is order no. 301/14 of the Italian regulatory Authority [[50]] that regulates the period 2015-2017. The amount of interruptible loads to be supplied in the 3-year-period is 3300 MW, that the TSO TERNA shall buy by means of a Dutch auction mechanism, starting from a price of 105000 €/MW/year for Instantaneous switch-off and 60000 €/MW/year for Emergency switch-off.

The standard products traded in this auction include:

- 3-year-period product (¾ of the total amount to be provided should be covered by this product)
- Annual product, that accounts for the residual capacity after the 3-year-period allocation
- Monthly product, that accounts for the residual capacity after the previous long term allocations

In addition to the capacity compensation, during the annual operation, interruptible loads receive an additional compensation of 3000 €/MW for each interruption ordered by the TSO.

The requirements for a consumer for participating to the auction include the minimum size of the load equal to 1 MW, the capability to switch-off the consumption according to the required timing, the presence in the site of an automatic device for processing the control signal issued by the TSO.

The whole amount required for the period 2015-2017 has been provided through the Instantaneous switch-off service with 3-year-period product, with a marginal price of 88899 €/MW/year. Almost 300 consumers participated to the auction for the period 2015-2017 and several of them belong to the steel industry.

[50] Italian regulatory Authority for Electric Energy, Gas and Hydro Services: *"Disciplina delle procedure per l'approvvigionamento a termine delle risorse elettriche interrompibili e proroga semestrale dei contratti vigenti"*, order n° 301/14, June 19th 2014.

5.2 Germany

Larger customers and pools of smaller customers can participate at the electricity control market by making an application to their transmission system operator with respect to the governmentally introduced decree for switching-off loads [48].

The decree for switching-off loads [51] within industrial branches possessing high electricity demands is a governmental decree introduced to stabilize the electric transmission grids and thereby enhancing the security of supply. It will be valid until the end of 2015 with a potential for prolongation. The participation can be comparably performed via the official homepage responsible for collecting the bids for balancing energy [52].

A main drawback of the main energy-intensive processes within the steel industry (e.g. hot rolling, cold rolling, sinter blower, hot-dip galvanizing) is the discontinuous process behaviour and strict boundary conditions. Under these restrictions it is yet nearly impossible for the German steel producing industry to participate in this field.

[51] German federal ministry of justice: "Verordnung über Vereinbarung zu abschaltbaren Lasten (AbLaV)", 28.12.12

[52] https://www.regelleistung.net/ip/action/static/ausschreibungAbLa

6 <u>Synthesis</u>

6.1 Opportunities for large industrial loads in the current regulatory/market/tariff context

In Italy, according to the current Grid Code by the TSO TERNA, loads of any size are not enabled to provide ancillary services. Nevertheless, the Italian Regulatory Authority intends to remove soon this limitation, as stated in recent consultation documents, in line with the provisions of the European directive 2012/27/EU on energy efficiency. Considering the current prices of the Italian ancillary services market, this opportunity could be particularly profitable.

The only opportunity today available for large industrial loads is the provision of the interruptible load service, by means of multi-year contracts that remunerate the capacity made available for switching off the consumption. Such contracts are established with the TSO through an auction and are bound to large industrial loads that can guarantee at least 1 MW of switch-off capacity. Currently, among the industrial loads that participate at the auction there are also consumers from the steel industry.

On the contrary in Germany the ancillary services market is not precluded to any entity of the power system, thus loads and consumers can participate to the provision of regulating reserve, even in a pooled way. Because of the strict requirements for the provision of PCR and SCR, TCR seems to be the most attractive service that can be provided by large industrial loads. At the moment 1 MW balancing capacity is a rough number at which it gets interesting to participate at the balancing market or at least for companies offering demand response services.

Besides the ancillary services market, as well as in Italy, large consumers can participate at the auctions for the provision of interruptible load. However, as above mentioned, the discontinuous process behaviour and strict boundary conditions of the steel production process make nearly impossible for the German steel producing industry to participate in this field.

6.2 Proposals for improvements of the current context to make it more favorable for large industrial loads

The main improvement that should be put in place in the Italian context is the removal of the barrier for consumers to participate to the ancillary services market, since many industrial loads and aggregations of consumers are today ready to contribute to the balancing market.

For example, all the industrial loads enabled to provide interruptible load services are equipped with automatic devices for a fast switch-off and this makes them also compatible with a balancing reserve service both for the scheduling phase and in real time.

Allowing loads and consumers to participate to the ancillary services market would increase the balancing energy available to the system, increasing also the competition in the market. Since the Italian approach for the system operation is based on central dispatch and thus each point of the network is responsible for its own injection/withdrawal and cannot benefit from a portfolio aggregation, the most suitable service that can be provided by loads is the tertiary reserve, while the PCR and SCR are faster, automatic and more flexible services provided by generating units.

In the context of demand side response, the new interaction between TSO and DSOs should be regulated, since DSOs will be able in the next future to provide a contribution to the balancing service thanks to the controllable loads located in their network.

With the participation of large industrial loads to the ancillary services market, the service provided by interruptible loads can be reduced or even removed, since the flexibility provided by loads would be properly remunerated by the market.

Finally, in order to allow market participants to express the value of the flexibility offered, negative prices should be introduced, as already happens in many EU countries.

The Italian framework for system dispatching has been designed when the generation mix was mainly based on controllable conventional power plants and the power consumption was inelastic. Today the general conditions have changed, following the large development of new technologies such as intermittent renewable sources, distributed generation, demand side management and storage systems. For this reason the Italian Regulatory Authority has launched a process with the objective of reforming the electricity market in line with this new context, in order to exploit every potential resource able to provide control reserve and other ancillary services to support a secure and effective system operation.

On the other hand, the German market framework seems more open and favorable for large industrial loads, since they can participate to the provision of control reserve.

The balancing mechanism based on the balance responsible parties makes more flexible the participation of loads to the ancillary services market. Further improvements in this context could be a more effective dissemination of information about the potential participation of industrial loads to the ancillary services market, making clear:

- What are the main contents of a separate electricity contract concerning balancing energy?
- Will there be extra grid usage fees?
- How is it affecting the off-balance financing of the energy supplier?
- How will the usage of extra electricity be integrated (valid activation) ?

Finally, in order to allow steel industries to participate to the interruptible load service, tradable products with less binding constraints could be introduced, to account for the discontinuous process behaviour that characterizes them.

More in general, energy supply contracts should change putting flexibility more into the focus, due to the not constant energy consumption of the production process and taking into account the opportunity to exploit the flexibility to provide ancillary services to the network.

Annex 3

Statistical Imbalance Data Analysis
(Responsible SSSA)

Summary

In this section some detail arguments and results, concerning with statistical data analysis lead from SSSA in Task 2.3, are listed.

1 An example of the dataset build with data from TERNA

A dataset has been created for each macro zone (NORTH and SOUTH) with data collected from TERNA and through data pre-processing and aggregation. The macro zone dataset has been represented by a matrix, where each row corresponds to one hour of a day, in the reference period, while columns correspond to the different types of collected information.

An example of the dataset organization is shown in Figure Annex3-1.

	Input Data						Target Data		
	Hour	Month	Is Non Working Day	Wind Power Prevision [MWh]	Actual Energy Production (Renewable sources) [MWh]	Actual Power Requirement MGP [MWh]	Sign of network unbalance	Average Selling Price MSD [€/MWh]	Average Purchase Price MSD [€/MWh]
2014110101	1	11	1	4.085	1508.00	14013.00	+1	79.959	10.975
....	...	...	...	.....	.....	.....	.....	.....	.....
2014110124	24	11	1	0.440	1505.00	12130.00	-1	128.582	12.876
2014110201	1	11	1	0.388	1378.00	11521.00	+1	194.258	9.688
....	...	...	....	.....	.....	.....	.....	.....	.....
2014110224	24	11	1	1.5070	1860.00	12981.00	+1	168.932	21.022
....	...	...	...	.....	.....	.....	.....	.....	.....
2015093024	24	9	0	.....	.....	.....	+1	140.679	20.081

Figure Annex3-1: Example of dataset matrix for a macro zone

The dataset has been divided into two parts: input data and target data. The target variables correspond to the variables to be predicted:

- Hourly sign of imbalance of the National Transmission Network
- Hourly average selling price at the Dispatching Services Market
- Hourly average purchase price at the Dispatching Services Market

2 Markov chain results in imbalance sign analysis

In the context of network imbalance sign analysis, the network imbalance sign is the target variable and its possible values are '+1' for positive imbalance and '-1' for negative imbalance. Markov chain can be used to calculate the probability to remain in the same state or to move into the other one at the time t+K, knowing only the state at the time t.

Considering K=10, we have obtained the results shown Table Annex3-1 and Table Annex3-2. In particular, Table Annex3-1 (a) and Table Annex3-2 (a) show the results obtained by considering a positive starting state, while Table Annex3-1 (b) and Table

Annex3-2 (b) represent the probability related to a negative starting state in the NORTH and SOUTH macro zone.

+	State Positive	State Negative
K=1	0.87	0.13
K=2	0.78	0.22
K=3	0.72	0.28
K=4	0.68	0.32
K=5	0.65	0.35
K=6	0.64	0.36
K=7	0.62	0.38
K=8	0.62	0.38
K=9	0.61	0.39
K=10	0.61	0.39

(a)

-	State Positive	State Negative
K=1	0.20	0.80
K=2	0.33	0.67
K=3	0.42	0.58
K=4	0.48	0.52
K=5	0.52	0.48
K=6	0.54	0.46
K=7	0.56	0.44
K=8	0.57	0.43
K=9	0.58	0.42
K=10	0.59	0.41

(b)

Table Annex3-1: Probabilities related to the positive (a) and negative state (b) in the NORTH macro zone

Table Annex3-1, related to the NORTH macro zone, demonstrate that, if the imbalance sign at the time t is positive, it is more probable that the sign remains positive rather than to move to the negative state until the time t + 10, while, if the sign of the imbalance at the time t is negative, it is more probable to remain negative until the instant t + 4, after which it is more probable to have a change of state.

+	State Positive	State Negative
K=1	0.80	0.20
K=2	0.68	0.32
K=3	0.60	0.40
K=4	0.54	0.46
K=5	0.50	0.50
K=6	0.48	0.52
K=7	0.73	0.53
K=8	0.46	0.54
K=9	0.45	0.55
K=10	0.44	0.56

(a)

-	State Positive	State Negative
K=1	0.15	0.85
K=2	0.25	0.75
K=3	0.31	0.69
K=4	0.35	0.65
K=5	0.38	0.62
K=6	0.40	0.60
K=7	0.41	0.59
K=8	0.42	0.58
K=9	0.43	0.57
K=10	0.43	0.57

(b)

Table Annex3-2: Probabilities related to the positive (a) and negative (b) state in the SOUTH macro zone

Table Annex3-2, related to the SOUTH macro zone, demonstrates that, if the imbalance sign at the time t is positive, it is more probable that the sign remains positive rather than to move to the negative state until the time t + 4, while, if the sign of the imbalance at the time t is negative, it is more probable to remain negative until the instant t + 10. It is interesting to note the opposite behaviour of NORTH and SOUTH.

3 Classification performance through the Balanced Classification Rate

The performance of a classifier has been computed by means of a performance indicator, the Balanced Classification Rate (BCR), also known as Area Under Curve (AUC)[53].

The BCR is defined by the following equation:

$$BCR = \frac{1}{2}\left[\frac{TP}{TP+FN} + \frac{TN}{TN+FP}\right]$$

where the ratios TP/(TP+FN) and TN/(TN+FP) are also called as sensitivity and specificity, respectively.

The performance of the classifier is expressed in terms of four counts, well-represented in the confusion matrix, shown in Table Annex3-3.

	Classified as positive	Classified as negative
Actual positive	**TP**	**FN**
Actual negative	**FP**	**TN**

Table Annex3-3: Confusion matrix for binary classification

The meaning of the four counts in the confusion matrix is the following:

- True Positive (TP): percentage of correctly classified positive samples.
- False Negative (FN): percentage of positive samples incorrectly classified as belonging to the negative class;
- False Positive (FP): percentage of negative samples incorrectly classified as belonging to the positive class;
- True Negative (TN): percentage of negative samples correctly classified.

The BCR is an appropriate measure for imbalanced data[54], since it takes into account the balance between the two classes. For these reasons, in this work the BCR has been used to evaluate the classifier performance.

[53] Sokolova, M. and Lapalme, G. 2009. A systematic analysis of performance measures for classification tasks. Inf. Process. Manage. 45, 4 (Jul. 2009), 427-437

[54] Vannucci, M. Colla, V. Novel classification method for sensitive problems and uneven datasets based on neural networks and fuzzy logic. Applied Soft computing Journal, 11(2), 2011, pp. 2383-2390.

4 Performance functions

For a variable vector X, made of n scalar observations, the Root Mean Square Error is defined as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \widehat{X_i})^2}{n}}$$

where X_i is the measured value at time i, $\widehat{X_i}$ is the value predicted by the model at time i and n is the number of observations.

The Normalized Square Root Mean Square Error is defined as follows:

$$NSRMSE = \frac{RMSE}{\sigma}$$

where σ is the standard deviation of X.

The Mean Absolute Error is defined as the average difference, in absolute value, between the predicted and measured sample. It is not relevant in this analysis, because it is the amount of physical error in a measurement.

The Mean Relative Error is defined as the average ratio between the absolute error and the measured value. It is more interesting than the absolute error because it gives an indication of how good a measurement is relative to the measured value.

5 Multi-step-ahead prediction results on selling and purchase price

SSSA experimented the multi-step-ahead prediction algorithm, described in Task 2.3, to make predictions on the selling and purchase prices.

The multi-step-ahead prediction algorithm has been applied by using the different statistical techniques NARX and NAR neural networks, respectively to implement the model with and without exogenous inputs. Initially, the results achieved with NAR are explained.

Graphic visualizations with NAR

A graphic visualization of measured and predicted price values has been produced by the algorithm for each of the next ten hours, for both selling and purchase prices and for each macro zone. The measured values are represented in blue color, while the predicted ones in red color.

Another form of visualization of measured and predicted price values is the one where the x-coordinate represents measured values, while the y-coordinate represents predicted values. Each blue point represents a couple made of a measured value and the corresponding predicted value. Therefore, the closer to the bisector line (in green color) a point is, the better the prediction accuracy is.

Only graphics related to the first and the second hour and to the North macro zone are shown in the following Figure Annex3-2, Figure Annex3-3, Figure Annex3-4 and Figure Annex3-5.

The figures show that, for both selling and purchase prices, the predictions of the price are quite good and satisfactory for the first hour and start to decrease for the second hour. Furthermore, starting from the third hour, the results are less meaningful and the predicted values tend, always more, towards the mean price value.

The plots generated for South macro zone, not here represented, show similar trends.

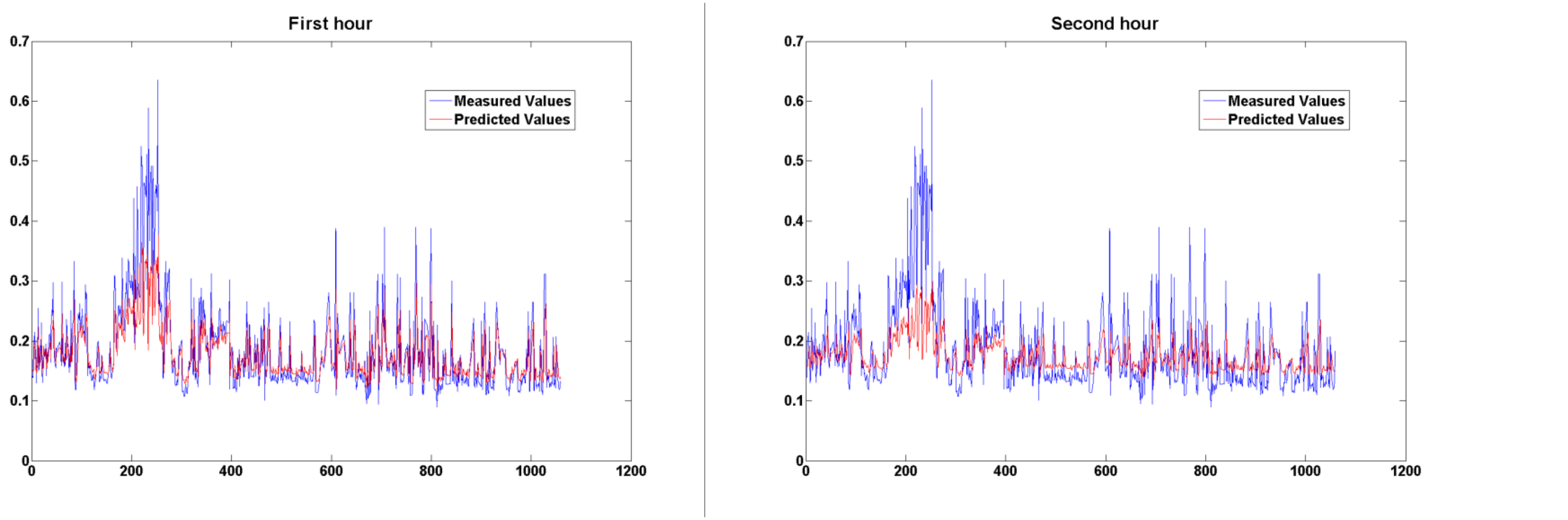

Figure Annex3-2: North Selling Price – Measured values (blue) and Predicted (red) for the first and second hour

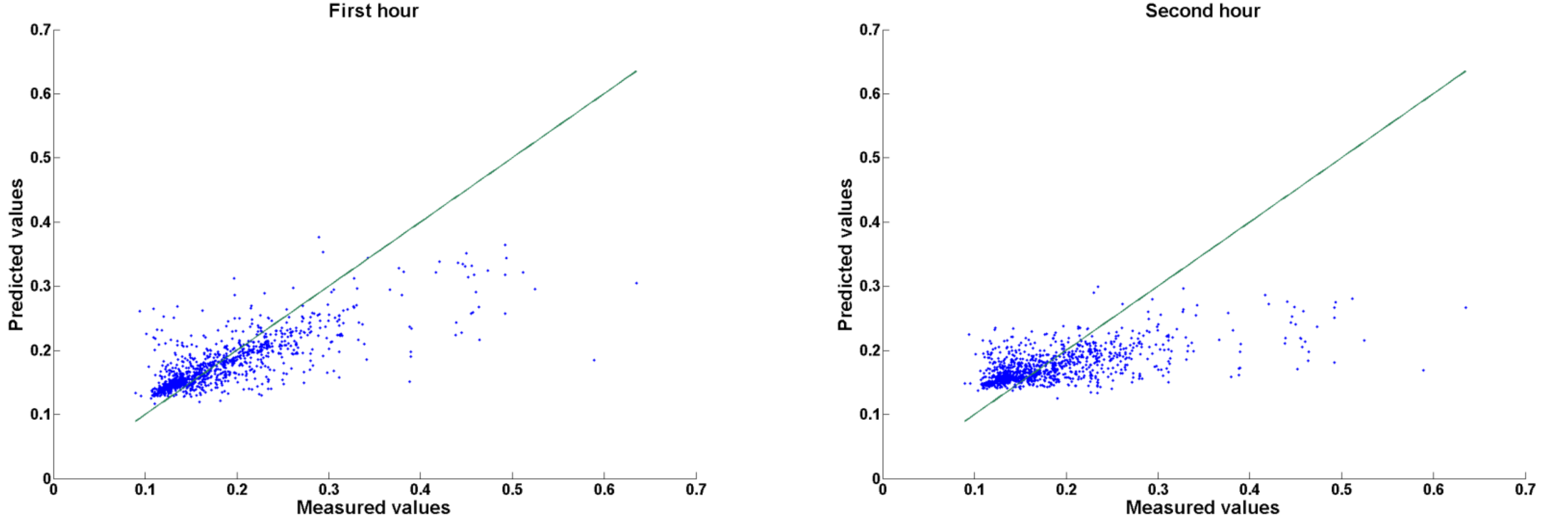

Figure Annex3-3: North Selling Price - Measured values towards predicted values for the first and second hour

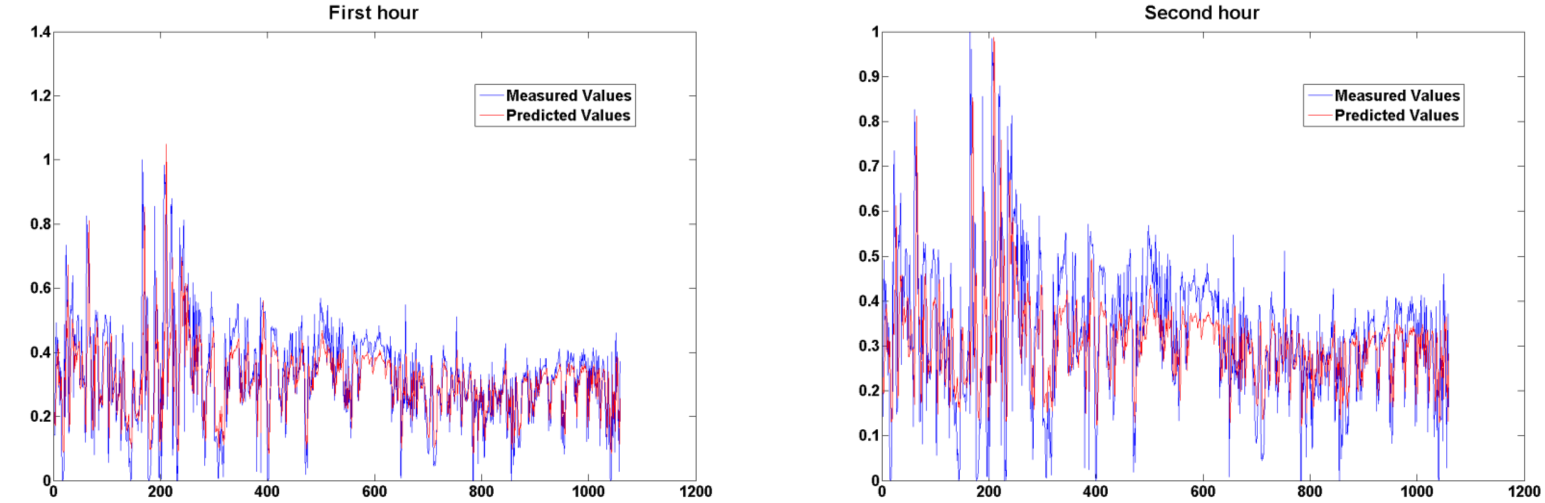

Figure Annex3-4: North Purchase Price – Measured values (blue) and Predicted (red) for the first and second hour

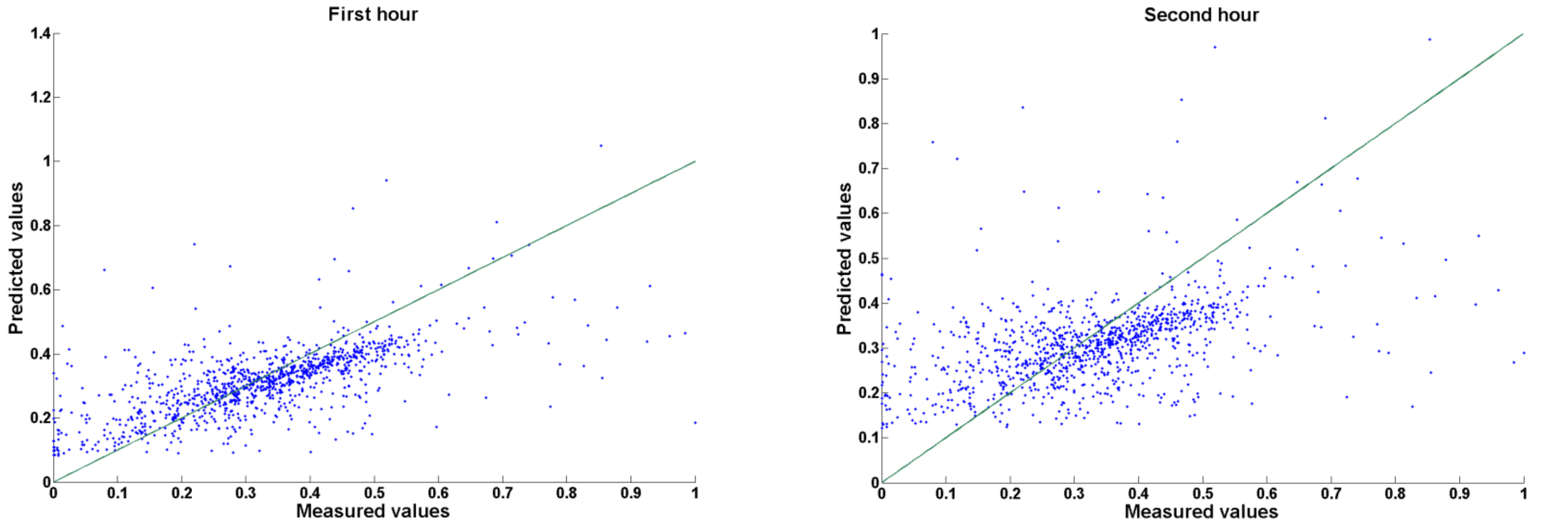

Figure Annex3-5: North Purchase Price - Measured values towards predicted values for the first and second hour

Multi-step-ahead prediction performance results with NAR

NAR performance results for prediction of the selling price for the next hours are shown in Table Annex3-4, for North and South macro zone.

	NORTH			SOUTH		
Hour	*NSRMSE*	*Relative Error*	*Absolute Error*	*NSRMSE*	*Relative Error*	*Absolute Error*
1	0.6731	0.1535	0.0303	0.6680	0.1902	0.0348
2	0.8389	0.2022	0.0400	0.8441	0.2651	0.0471
3	0.9254	0.2239	0.0444	0.9365	0.3038	0.0533
4	0.9716	0.2378	0.0472	0.9774	0.3218	0.0561
5	1.0022	0.2450	0.0486	0.9954	0.3301	0.0574
6	1.0083	0.2485	0.0492	1.0044	0.3324	0.0578
7	1.0088	0.2520	0.0496	1.0047	0.3337	0.0579
8	1.0072	0.2551	0.0499	1.0053	0.3342	0.0580
9	1.0054	0.2574	0.0501	1.0058	0.3342	0.0580
10	1.0048	0.2585	0.0502	1.0056	0.3343	0.0579

Table Annex3-4: Selling Price – Multi step ahead prediction results with NAR

NAR performance results for prediction of the purchase price for the next hours are shown in Table Annex3-5, for North and South macro zone.

	NORTH			SOUTH		
Hour	*NSRMSE*	*Relative Error*	*Absolute Error*	*NSRMSE*	*Relative Error*	*Absolute Error*
1	0.7767	-	0.0828	0.7388	-	0.0726
2	0.9202	-	0.1029	0.8927	-	0.0931
3	0.9685	-	0.1099	0.9952	-	0.1050
4	0.9908	-	0.1161	1.0621	-	0.1131
5	1.0074	-	0.1188	1.1002	-	0.1171
6	1.0215	-	0.1206	1.1279	-	0.1200
7	1.0325	-	0.1224	1.1446	-	0.1217
8	1.0458	-	0.1239	1.1516	-	0.1227
9	1.0550	-	0.1250	1.1571	-	0.1233
10	1.0608	-	0.1260	1.1585	-	0.1233

Table Annex3-5: Purchase Price - Multi-step ahead prediction results with NAR

Concerning with the purchase price, the relative error is unavailable because zero is a possible value of the price.

The NSRMSE is the most interesting index to evaluate the performance of the prediction, because it takes into account the standard deviation of the measured values. When the value of the NSRMSE is more than unitary value, it means that the deviation of the prediction error is greater than the standard deviation of the target value itself, therefore the accuracy of the model would be better if the mean value was output. Moreover, in some cases, while the relative error could be considered acceptable, the NSRMSE is greater than one, to confirm that the predicted value tends towards the mean value.

Multi-step-ahead prediction performance results with NARX

To make predictions on prices, SSSA has applied the multi-ahead prediction algorithm also by using NARX, with only wind prevision time-series data as exogenous input. Since only wind prevision data for future hours are *priori* known, only those data have been taken into account as external inputs.

NARX performance results for prediction of the selling price for the next ten hours are shown in Table Annex3-6, for North and South macro zone.

	NORTH			*SOUTH*		
Hour	*NSRMSE*	*Relative Error*	*Absolute Error*	*NSRMSE*	*Relative Error*	*Absolute Error*
1	0.6432	0.1711	0.0316	0.6640	0.2089	0.0365
2	0.8028	0.2301	0.0422	0.8479	0.2943	0.0503
3	0.8710	0.2531	0.0465	0.9338	0.3348	0.0566
4	0.9110	0.2634	0.0485	0.9626	0.3481	0.0586
5	0.9452	0.2689	0.0499	0.9725	0.3569	0.0598
6	0.9701	0.2715	0.0506	0.9871	0.3706	0.0616
7	0.9846	0.2734	0.0511	1.0032	0.3905	0.0639
8	0.9930	0.2749	0.0515	1.0215	0.4112	0.0663
9	0.9972	0.2758	0.0516	1.0376	0.4289	0.0685
10	0.9996	0.2758	0.0517	1.0521	0.4422	0.0701

Table Annex3-6: Selling Price – Multi step ahead prediction results with NARX

NARX performance results for prediction of the purchase price for the ten next hours are shown in Table Annex3-7, for North and South macro zone.

	NORTH			*SOUTH*		
Hour	*NSRMSE*	*Relative Error*	*Absolute Error*	*NSRMSE*	*Relative Error*	*Absolute Error*
1	0.7622	-	0.0831	0.7085	-	0.0699
2	0.9406	-	0.1084	0.8484	-	0.0899
3	1.0251	-	0.1196	0.9313	-	0.1002
4	1.0894	-	0.1291	0.9753	-	0.1067
5	1.1307	-	0.1346	0.9911	-	0.1091
6	1.1599	-	0.1384	1.0018	-	0.1108
7	1.1738	-	0.1405	1.0074	-	0.1112
8	1.1763	-	0.1410	1.0071	-	0.1111
9	1.1732	-	0.1406	1.0104	-	0.1116
10	1.1657	-	0.1397	1.0127	-	0.1117

Table Annex3-7: Purchase Price – Multi step ahead prediction results with NARX

Comparing NARX multi step ahead prediction results with those reached with NAR, they turned out to be comparable, meaning that most of informative contents is already included inside the historical target.

<u>Annex 4</u>

Mathematical formulation of Production Re-scheduling model (Responsible SSSA)

There is a certain time $t_{m,m'}$ needed to transport products from machine m to machine m′. In order to avoid a too large decrease of the temperature of the molten steel, the waiting time spent by a heat p after stage st is restricted by a maximum allowed delay time $t_{p,st}^{max}$. Specific rules about the sequences of heats are applied in the continuous-casting stage. Heats are divided in groups and all the heats of the same group need to be assigned to the same continuous cast and are casted subsequently without waiting times. For all stages, except for CC, a machine specific setup t_m^{setup} has to be performed in advance in order to carry out the processing of the next heat. On the other hand, for the continuous casting, a setup is needed only for the first heat of the sequence or group of heats. The processing duration $\theta_{p,m}$ depends both on the product p and on the machine m where it is processed. Among input parameters there is the power consumption $h_{p,m}$, which is specific of products and machines.

To model the assignment of the heat p to the machine m, a binary variable $X_{m,p}$ is used. This variable must equal one if p is assigned to m and zero otherwise. Starting and finishing times of the processes are stored in the variables $t_{m,p}^s, t_{m,p}^f, t_{p,st}^s, t_{p,st}^f$. They represent starting and finishing times of product p, when processed on machine m and of product p at stage st respectively ($t_{m,p}^s = t_{m,p}^f = 0$ if p is not processed on m). A binary variable, necessary for this formulation, represents precedence relations between two heats p,p′ on a given stage. The variable $V_{st,p,p'}$ equals one if p is processed before p′ at stage st and equals zero otherwise. Heats might not be processed immediately from stage to stage, and thus there might be waiting times. These waiting times are contained in the variables $w_{st,p}$.

The following equality and inequalities serve to model the constraints of the problem and mathematically define the variables. To start, observe that exactly one machine must process a heat in a given stage st, thus

$$\sum_{m \in M(st)} X_{m,p} = 1 \qquad \forall p \in P,\ st \in ST \tag{1}$$

where M(st) is the set of machines at stage st. The finishing time of a process equals the starting time, plus the process duration $\theta_{p,m}$. The starting (finishing) time of heat p in a given stage is the starting (finishing) time of p on the machine where it is processed. Hence the following equations define starting and finishing times

$$t_{m,p}^f = t_{m,p}^s + X_{m,p} \cdot \theta_{p,m} \quad \forall m \in M, p \in P \tag{2}$$

$$t_{m,p}^s \leq B \cdot X_{m,p} \quad \forall m \in M, p \in P \tag{3}$$

$$t_{p,st}^s = \sum_{m \in M(st)} t_{m,p}^s \quad \forall st \in ST, p \in P \tag{4}$$

$$t_{p,st}^f = \sum_{m \in M(st)} t_{m,p}^f \quad \forall st \in ST, p \in P \tag{5}$$

Where the inequalities are made to force $t_{m,p}^s = t_{m,p}^f = 0$ if p is not processed on m (B is a large enough number).
The next equations define the waiting time between stages as the difference between the starting time of stage st + 1 and the finishing time of stage st.

$$w_{p,st} = t_{p,st+1}^s - t_{p,st}^f \qquad \forall p \in P, st \in ST, st < |ST| \tag{6}$$

Waiting times between stages have restrictions: an heat should wait at least the time needed to transfer it from the machine of one stage to the machine of the next stage; on the other hand, waiting times are upper bounded, since heats must not cool off below a certain level.

$$\begin{aligned} &t_{m,m'}^{min}(X_{m,p} + X_{m',p} - 1) \leq w_{p,st} \qquad \forall p \in P, st \in ST, m \in M(st), m' \in M(st+1) \\ &w_{p,st} \leq t_{p,st}^{max} \qquad \forall p \in P, st \in ST \end{aligned} \tag{7}$$

The precedence relations are defined by the following equations, stating that if p is processed before p′ on the same machine, then $t_{m,p'}^s > t_{m,p}^f$ plus the setup time of machine m

$$t^s_{m,p'} \geq t^f_{m,p} + t^{setup}_m - B \cdot (3 - V_{st,p,p'} - X_{m,p} - X_{m,p'})$$
$$\forall p \neq p' \in P, st < |ST| \in ST, m \in M(st) \quad (8)$$

At the CC stage there are groups of heats are processed continuously. Therefore the machine setup time is necessary only between the last heat of a group and the first heat of the next group.

$$t^s_{m,p'} \geq t^f_{m,p} - B \cdot (3 - V_{st,p,p'} - X_{m,p} - X_{m,p'})$$
$$\forall p \neq p' \in P, st = CC, m \in M(CC) \quad (9)$$

$$t^s_{m,p'} \geq t^f_{m,p} + t^{setup}_m - B \cdot (3 - V_{st,p,p'} - X_{m,p} - X_{m,p'})$$
$$\forall p \in Last(HG), p' \in First(HG), st = CC, m \in M(CC) \quad (10)$$

Constraints (11) force the heats of the same group to be assigned to the same caster

$$X_{m,p} + X_{m',p'} \leq 1 \qquad \forall m \neq m' \in M(CC), p \neq p' \in P, HG(p) = HG(p') \quad (11)$$

Heats are ordered in the groups according to their casting sequence. The following constraints ensure that heats in the same groups are continuously cast

$$t^s_{p+1,st} = t^f_{p,st} \qquad \forall p \in P - Last(HG), st = CC \qquad (12)$$

The following equations serve for the precedence relation between two heats to be well defined: either p is processed before p' or p' is processed before p

$$V_{st,p,p'} + V_{st,p,p'} = 1 \qquad \forall p < p' \in P, st \in ST \qquad (13)$$

The sequence of heats processed on the CC stage, must be the same at all stages, this is enforced by the following equations

$$V_{st+1,p,p'} = V_{st,p,p'} \qquad \forall p < p' \in P, st < |ST| \in ST \qquad (14)$$

Moreover, in the scheduling model task start times are represented by continuous variables.

Task start times variables are related to the energy part of the model, leading to the computation of the total electricity consumption within a given time interval.

These variables are used to find the contribution of a task to the electricity consumption within a given time interval by considering four possible cases:

- Case 1: a task is processed entirely within the time slot.
- Case 2: a task starts before and finishes within the time slot.
- Case 3: a task starts within and finishes after the time slot.
- Case 4: a task over-spans the full time slot.

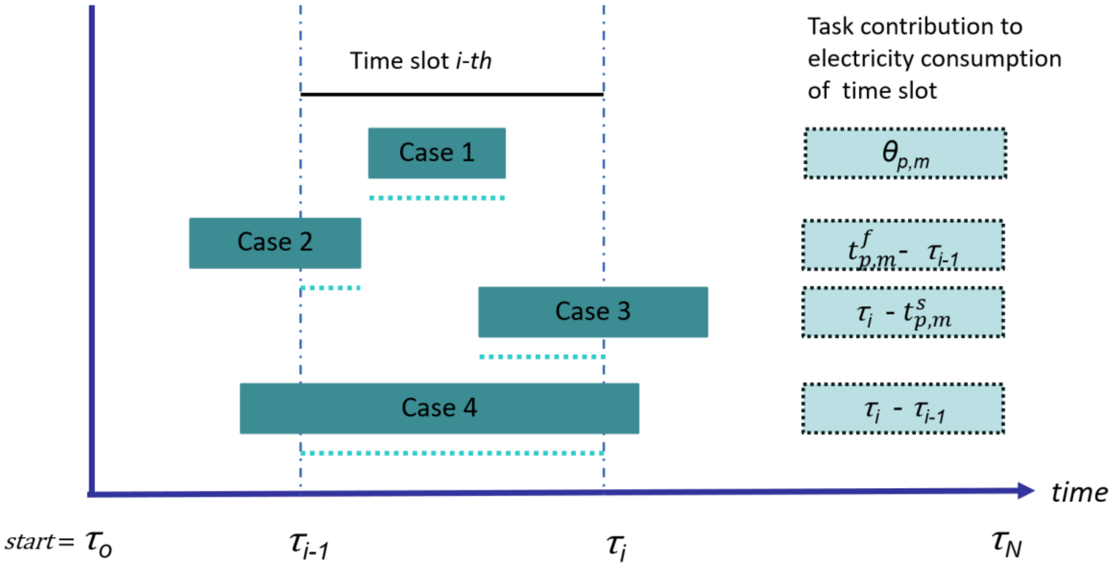

Figure Annex4

Figure Annex4 1: Task contribution to electricity consumption of a time slot

Figure Annex4 1 describes the four possible cases considered to compute a task consumption of energy in a time slot: in the light blue boxes the process duration within the time slot *s-th* is indicated, by putting into relation the starting or final time of a heat *p* on machine *m* with the lower, τ_{s-1}, and upper bound, τ_s, of the time slot. For example, when the task is entirely processed within the time slot, as in case 1, the complete process duration of the heat on the machine $\theta_{p,m}$ is accounted for.

The overall electricity consumption q_s within the *s-th* time interval can be computed by summing the contributions of all tasks in the interval. The total electricity consumption q_s is needed for the evaluation and optimization of KPI.

In order to be able to define the consumptions in the four cases a number of technical constraints are formulated.

First the variables $Y^s_{p,st,s}$, $Y^f_{p,st,s}$, modelling whether a heat p on stage st starts (or finishes) during time slot s, are defined. The variable $Y^s_{p,st,s} = 1$ if and only $\tau_{s-1} \leq t^s_{p,st} \leq \tau_s$ and, similarly, $Y^f_{p,st,s} = 1$ if and only $\tau_{s-1} \leq t^f_{p,st} \leq \tau_s$. To model these logical conjunctions, auxiliary binary variables are used: the auxiliary variables $A^s_{p,st,s}$ ($A^f_{p,st,s}$) are true if and only if $\tau_{s-1} \leq t^s_{p,st}$ ($\tau_{s-1} \leq t^f_{p,st}$); the auxiliary variables $\Omega^s_{p,st,s}$ ($\Omega^f_{p,st,s}$) are true if and only if $t^s_{p,st} \leq \tau_s$ ($t^f_{p,st} \leq \tau_s$). The variables $Y^s_{p,st,s}$, $Y^f_{p,st,s}$ must then be true if and only if both $A^s_{p,st,s}$ and $\Omega^s_{p,st,s}$ ($A^f_{p,st,s}$ and $\Omega^f_{p,st,s}$) are true. The variables $A^s_{p,st,s}$ and $A^f_{p,st,s}$ are defined by the following equations:

$$
\begin{aligned}
t^s_{p,st} &\leq \tau_{s-1} + B \cdot A^s_{p,st,s} && \forall p \in P, st \in ST, s \in S \\
t^s_{p,st} &\geq \tau_{s-1} \cdot A^s_{p,st,s} && \forall p \in P, st \in ST, s \in S \\
t^f_{p,st} &\leq \tau_{s-1} + B \cdot A^f_{p,st,s} && \forall p \in P, st \in ST, s \in S \\
t^f_{p,st} &\geq \tau_{s-1} \cdot A^f_{p,st,s} && \forall p \in P, st \in ST, s \in S \\
t^s_{p,st} &\geq \tau_s - B \cdot \Omega^s_{p,st,s} && \forall p \in P, st \in ST, s \in S
\end{aligned}
\qquad (15)
$$

Recall that B is a large constant. The variables $\Omega^s_{p,st,s}$ and $\Omega^f_{p,st,s}$ are defined by the following equations

$$
\begin{aligned}
t^s_{p,st} &\leq \tau_s + B\cdot(1-\Omega^s_{p,st,s}) && \forall p\in P, st\in ST, s\in S \\
t^f_{p,st} &\geq \tau_s - B\cdot\Omega^f_{p,st,s} && \forall p\in P, st\in ST, s\in S \\
t^f_{p,st} &\leq \tau_s + B\cdot(1-\Omega^f_{p,st,s}) && \forall p\in P, st\in ST, s\in S
\end{aligned} \tag{16}
$$

With the previous equations, the variables $Y^s_{p,st,s}$ can be defined.

$$
\begin{aligned}
Y^s_{p,st,s} &\geq A^s_{p,st,s} + \Omega^s_{p,st,s} - 1 && \forall p\in P, st\in ST, s\in S \\
Y^s_{p,st,s} &\leq A^s_{p,st,s} && \forall p\in P, st\in ST, s\in S \\
Y^s_{p,st,s} &\leq \Omega^s_{p,st,s} && \forall p\in P, st\in ST, s\in S
\end{aligned} \tag{17}
$$

The variables $Y^f_{p,st,s}$ are defined similarly

$$
\begin{aligned}
Y^f_{p,st,s} &\geq A^f_{p,st,s} + \Omega^f_{p,st,s} - 1 && \forall p\in P, st\in ST, s\in S \\
Y^f_{p,st,s} &\leq A^f_{p,st,s} && \forall p\in P, st\in ST, s\in S \\
Y^f_{p,st,s} &\leq \Omega^f_{p,st,s} && \forall p\in P, st\in ST, s\in S
\end{aligned} \tag{18}
$$

In order to model on which machine m the product p is processed at stage st during slot s, other variables are introduced: $y^{saux}_{p,m,st,s}(y^{faux}_{p,m,st,s})$: they are true if and only if both $X_{m,p}$ and $Y^s_{p,st,s}$,$(Y^f_{p,st,s}$)are true. The inequalities used to define them are the following:

$$
\begin{aligned}
y^{saux}_{p,m,st,s} &\geq X_{m,p} + Y^s_{p,st,s} - 1 && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
y^{saux}_{p,m,st,s} &\leq X_{m,p} && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
y^{saux}_{p,m,st,s} &\leq Y^s_{p,st,s} && \forall p\in P, st\in ST, s\in S, m\in M(st)
\end{aligned} \tag{19}
$$

Similarly

$$
\begin{aligned}
y^{faux}_{p,m,st,s} &\geq X_{m,p} + Y^f_{p,st,s} - 1 && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
y^{faux}_{p,m,st,s} &\leq X_{m,p} && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
y^{faux}_{p,m,st,s} &\leq Y^f_{p,st,s} && \forall p\in P, st\in ST, s\in S, m\in M(st)
\end{aligned} \tag{20}
$$

Four variables are used to capture the energy consumption in the four cases described in Figure 30. For the first case a binary variable $a_{p,m,st,s}$ is used. It is true if and only if p is processed on m at stage st starting and finishing within time slot s. This definition is enforced as follows

$$
\begin{aligned}
a_{p,m,st,s} &\geq y^{saux}_{p,m,st,s} + y^{faux}_{p,m,st,s} - 1 && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
a_{p,m,st,s} &\leq y^{saux}_{p,m,st,s} && \forall p\in P, st\in ST, s\in S, m\in M(st) \\
a_{p,m,st,s} &\leq y^{faux}_{p,m,st,s} && \forall p\in P, st\in ST, s\in S, m\in M(st)
\end{aligned} \tag{21}
$$

Real variables are used for the second case. The value $b_{p,m,st,s}$ is the amount of time taken in time slot s at stage st by processing p on the machine m. In other words $b_{p,m,st,s} = t^f_{m,p} - \tau_{s-1}$ if and only if it starts before time slot s and finishes within time slot s, $b_{p,m,st,s} = 0$ otherwise.

$$
\begin{aligned}
b_{p,m,st,s} \geq t^{f}_{m,p} - \tau_{s-1} - B \cdot (1 - y^{faux}_{p,m,st,s} + y^{saux}_{p,m,st,s}) \\
b_{p,m,st,s} \leq t^{f}_{m,p} - \tau_{s-1} \cdot y^{faux}_{p,m,st,s} \\
b_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot y^{faux}_{p,m,st,s} \\
b_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot (1 - y^{saux}_{p,m,st,s}) \\
\forall p \in P, st \in ST, s \in S, m \in M(st)
\end{aligned}
\tag{22}
$$

Symmetrically, real variables are used for the third case. The value $c_{p,m,st,s}$ is the amount of time taken in time slot s at stage st by processing p on the machine m. In other words $c = \tau_s - t^{s}_{m,p}$ if and only if it starts within time slot s and finishes after time slot s, $c_{p,m,st,s} = 0$ otherwise.

$$
\begin{aligned}
c_{p,m,st,s} \geq \tau_s - t^{s}_{m,p} - B \cdot (1 - y^{saux}_{p,m,st,s} + y^{faux}_{p,m,st,s}) \\
c_{p,m,st,s} \leq \tau_s - t^{s}_{m,p} \cdot y^{saux}_{p,m,st,s} \\
c_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot y^{saux}_{p,m,st,s} \\
c_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot (1 - y^{faux}_{p,m,st,s}) \\
\forall p \in P, st \in ST, s \in S, m \in M(st)
\end{aligned}
\tag{23}
$$

Finally in the fourth case the variable $d_{p,m,st,s}$ equals $\tau_s - \tau_{s-1}$ (namely the entire time slot), if the task of processing p on machine m is at stage st, starts before time slot s and finishes after time slot s, $d_{p,m,st,s} = 0$ otherwise. This is enforced by the following equations

$$
\begin{aligned}
d_{p,m,st,s} \geq (\tau_s - \tau_{s-1}) \cdot (\sum_{s'<s} y^{saux}_{p,m,st,s'} + \sum_{s'>s} y^{faux}_{p,m,st,s'} - 1) \\
d_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot \sum_{s'<s} y^{saux}_{p,m,st,s'} \\
d_{p,m,st,s} \leq (\tau_s - \tau_{s-1}) \cdot \sum_{s'>s} y^{faux}_{p,m,st,s'} \\
\forall p \in P, st \in ST, s \in S, m \in M(st)
\end{aligned}
\tag{24}
$$

The specific electricity consumption$h_{p,m}$ of process p on machine m is known for every process and for every machine. This consumption is assumed to be constant over time, introducing an approximation that creates an acceptable error.
Using the variables a, b, c, d is possible to calculate the electricity consumption q_s of each time slot s as follows

$$
q_s = \frac{\sum_{p,st,m \in M(st)} h_{p,m} \cdot (a_{p,m,st,s} \cdot \theta_{p,m} + b_{p,m,st,s} + c_{p,m,st,s} + d_{p,m,st,s})}{60} \tag{25}
$$

where the sum is divided by the number of minutes in a the time slots, which in our case is 60.

Having defined the electricity consumption q_s it is possible to compute the objective function, which is a combination of the function M_4 defined before and a function that penalizes the scheduling delay, namely the sum of all starting times. Therefore the objective function f is as follows

$$f = k \cdot \sum_{p,m} t^s_{p,m} + \frac{\sum_s MGP_s \cdot |\hat{q}_s - q_s|}{|SL|} + \max_s \gamma(q_s)$$

Where |SL| is the number of times slot and

$$\gamma(q_s) = \begin{cases} 0 & q_s < ML_s \\ \Phi \cdot q_s & x \geq ML_s \end{cases}$$

The parameter ϕ is the fee for exceeding the maximum peak as described in the previous section. Moreover k is a parameter that tunes the tradeoff between the total scheduling time and the quality of the solution in terms of the KPI.

This expression of the objective function f is nonlinear as it contains modules and a maximum calculation. In order to obtain a linear expression of the objective function, further equations are needed. To linearize modules $|\hat{q}_s - q_s|$, real variables μ_s are introduced, so that $\mu_s = |\hat{q}_s - q_s|$. Therefore

$$\begin{aligned} \mu_s &\geq \hat{q}_s - q_s & \forall s \in S \\ \mu_s &\geq q_s - \hat{q}_s & \forall s \in S \end{aligned} \tag{26}$$

The max over the cases function can be linearized by introducing the variable M representing the max of the electricity consumption over all the time slots.

$$M \geq q_s \qquad \forall s \in S \tag{27}$$

If this maximum is bigger than the maximum load ML, then the real variable $\Gamma = M * \phi$, otherwise, $\Gamma = 0$. This is enforced by the following equations

$$\begin{aligned} M - ML &\leq B \cdot \delta & \forall s \in S \\ \Phi \cdot M &\leq B \cdot (1 - \delta) + \Gamma & \forall s \in S \end{aligned} \tag{28}$$

where δ is an auxiliary binary variable (and the previous equation forces $\delta = 1$, if M > ML). The objective function becomes thus

$$f = k \cdot \sum_{p,m} t^s_{p,m} + \frac{\sum_s MGP_s \cdot \mu_s}{|SL|} + \Gamma \tag{29}$$

In order to account for the possibility of machines of the same type having different consumption $h_{p,m}$ another term is added to the objective function, namely the total consumption. Therefore the final objective function is

$$f = k \cdot \sum_{p,m} t^s_{p,m} + \frac{\sum_s MGP_s \cdot \mu_s}{|SL|} + h \cdot \sum_s q_s + \Gamma \tag{30}$$

The number of variables and constraints in the formulation is sensibly high, and therefore the problem cannot be solved in an acceptable running time if the input is too big. An iterative algorithm is designed to overcome this problem, when the set of products too large.

The set of products is divided into smaller subsets, which are iteratively processed: the reduced products set is given as input to the MILP described above. The solution is stored and the booked consumptions vector is updated to account for the consumptions q_s^1 of the first iterations. Hence $\hat{q}_s$ becomes $\hat{q}_s - q_s^1$. Moreover the maximum assigned start time L(m) of each machine m is used as a lower bound for the start times on m in the next iteration by adding the following constraints

$$t^s_{p,m} \geq X_m \cdot L \qquad \forall p \in P, m \in M \tag{31}$$

A new solution is found and the process is repeated until all orders are assigned (or until there is no more time available for the scheduling).

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